INTEGRATING SPECIES- AND GEOMORPHIC-CENTRIC VIEWS OF HABITAT: A CASE STUDY OF THE RELATIONSHIP BETWEEN INTERIOR LEAST TERN AND PIPING PLOVER NESTING INCIDENCE AND CHANNEL WIDTH

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ABSTRACT

The endangered interior least tern (*Sterna antillarum athalassos*) and piping plover (*Charadrius melodus*) nest on emergent sandbars in several braided river segments in Nebraska, USA. Previous habitat selection and geomorphic investigations identified a relationship between channel width and nest incidence. Species-centric analyses indicated selection for the widest available channels. Geomorphic-centric analyses indicated the species occurred in narrow channels that better supported suitable sandbar habitat. We examined species use in relation to channel width metrics across segments of the Platte River, Niobrara River, and Loup River from both perspectives. We found the probability of nesting incidence increases with increasing maximum unvegetated channel width in all river segments. However, maximum unvegetated width decreases with increasing total channel width once total width exceeds 500 m as does the probability that a channel will be free of permanently-vegetated islands. Channels with total widths of 500 – 800 are both wide enough to have a high probability of nest incidence and narrow enough to be free of vegetated islands. Actions that affect channels <500 m and >800 m would likely have a small influence on species use. Actions that change the width characteristics of 500 – 800 m channels could have a strong negative or positive influence on species use. Integration of species- and geomorphic-centric analyses provided a fuller picture of species-width relationships.

SHORT TITLE: Least tern and piping plover nesting incidence and channel width

KEY WORDS: channel width, interior least tern, piping plover, Platte River, Niobrara River, Loup River, nesting colony incidence, cross-disciplinary.

INTRODUCTION

The endangered interior least tern (*Sterna antillarum athalassos*; hereafter, least tern) and threatened piping plover (*Charadrius melodus*) nest on emergent sandbar habitat present in several braided river systems in Nebraska, USA including segments of the Platte, Niobrara, and

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Loup Rivers (National Research Council 2005). Resource managers and conservationists have long been concerned about the impacts of basin water development on the habitats used by the species with much of the focus centered on the central and lower Platte River.

The Platte River Recovery Implementation Program (Program) invested substantial resources in observational studies of sandbar dynamics and evaluating sandbar height in relation to peak flow stage and the probability of sandbar inundation during the species' nesting seasons. This led to stakeholder concerns that too much emphasis was being placed on sandbar height when previous analyses identified channel width as an important variable for determining least tern and piping plover nest initiation in the Platte River system (Ziewitz *et al.* 1992, Elliott 2011 and Jorgensen *et al.* 2012). Program stakeholders hypothesized channel width was the primary driver for selection of on-channel habitat with the species initiating nests on the available sandbar habitat that occurred within suitably-wide channel segments.

Ziewitz *et al.* (1992) performed a habitat selection analysis for 40 nest sites that defined average channel width as the area of a 402 m long channel segment, free of permanent vegetation, divided by the length of the segment (Figure 1). Ziewitz *et al.* (1992) found average channel width, as defined, at central Platte River (CPR; n=6) and lower Platte River (LPR; n=34) nest sites was significantly greater than mean width at systematic samples of available sites (CPR: 295 m vs. 201 m; LPR: 519 m vs. 430 m).

Elliott (2011) performed a geomorphic classification of the lower segment of the Platte River below the Loup River confluence and evaluated species nest occurrence in relation to geomorphic groupings. They defined total channel width as the distance between left and right channel banks including permanently vegetated islands (Figure 1). Elliott (2011) found least tern and piping plover nest sites (n=265) occurred disproportionally in narrower reaches of the LPR without permanently vegetated islands in 2006–2008. Their results lead to the conclusion narrow channels, under 2006 flow regimes, provide ample sediment transport capacity for sandbar maintenance and likely furnished the most opportunity for providing least tern and piping plover habitat in the LPR (Elliott 2011).

Jorgensen *et al.* (2012) also investigated the relationship between channel width and nest site incidence in the LPR using a transect-based logistic regression approach. They defined channel width as the distance between left and right channel banks, but treated channel segments split by vegetated islands as separate channels (Figure 1). For example, a 365 m channel split in the middle by a 65 m wide vegetated mid-channel island would be treated as two 150 m channels. They found a strong relationship between nesting incidence (n=64) and channel width. The modeled probability of presence of nesting sites was low (<0.03) when channel widths were ≤327 m and increased sharply as channel width increased with 610 m wide channels having the highest probability of nesting (>0.80).

Each of these investigations had unique objectives and employed different definitions of channel width, which in turn influenced the authors' interpretations of the relationships between species' use and channel width. The two bird-centric or bird-focused habitat selection analyses (Ziewitz et al. 1992, Jorgensen et al. 2012) concluded the species use the widest channels, indicating actions that reduce width would reduce habitat suitability. The geomorphology-focused analysis (Elliot 2011) concluded narrower channels with less potential for occurrence of permanently vegetated islands supported the conditions needed for species nesting. Taken independently, these analyses could lead to very different interpretations of the channel width characteristics that support least tern and piping plover nesting.

In this investigation, we endeavored to reconcile the bird- and geomorphic-centric views of species-width relationships to help inform management decisions that may affect channel widths in the braided river segments used by the species. Our primary objectives were: 1) evaluate least tern and piping plover nest site selection in relation to total channel width and maximum unvegetated channel width; and 2) evaluate the relationship between total channel width and maximum unvegetated channel width across segments of the Platte, Niobrara, and Loup Rivers that are used by the species. The analyses were conducted with the clear understanding the species also select nest sites based on non-width related metrics including the presence of emergent sandbar habitat. As such, our results are contingent on the understanding that suitable width may be a necessary but insufficient condition for least tern and piping plover nest initiation.

METHODS

Study Areas

The four study areas included river segments from three regional river systems in Nebraska that have been utilized by least tern and piping plover for nesting (Figure 2). The 166 km lower Platte River (LPR) study area extended from the confluence of the Loup River downstream to the Missouri River confluence. The 64 km Niobrara River study area extended from State Highway 137 downstream to the Spencer Hydropower plant. The 116 km Loup River study area extended from the confluence of the Middle and North Loup Rivers downstream to the confluence with the Platte River at Columbus. The AHR of the central Platte River (CPR) study area included a 145 km reach extending from Lexington, NE downstream to Chapman, NE, USA. The CPR study area was excluded from the analysis of the relationship between channel width and nest incidence because species use sites were confined to mechanically-created habitats in three short river segments. However, all four study areas were included in our efforts to establish a relationship between total channel width and maximum unvegetated channel width.

Nest Data

Least tern and piping plover nest data was obtained from several sources. Nest and colony locations (hereafter, “use sites”) were generally reported to the nearest 161 m in the LPR, Niobrara and Loup study areas. As such, our analyses were performed at a colony scale such that all nests on each island were treated as a colony and the colony location was assumed to be a single point on the island. Use sites within the LPR study area for the period of 2008–2013 were obtained from joint annual reports produced by the Tern and Plover Conservation Partnership and Nongame Bird Program of the Nebraska Game and Parks Commission (Brown and Jorgensen 2008, 2009, 2010;

Brown *et al.* 2011, 2012, 2013). Use sites from the Niobrara study area were provided for the period of 2005–2013 by Jim Jenniges, biologist with Nebraska Public Power District (personal communication, 2014). Use sites for the Loup River study area for the period of 2010–2012 were obtained from USFWS reports (Lackey and Runge 2010; Lackey 2011, 2012).

Aerial Imagery

Channel width measures for the LPR, Niobrara and Loup River study areas were estimated from aerial imagery collected by the Farm Service Agency (FSA) National Aerial Imagery Program (NAIP). Imagery was gathered during the months of June and July and provided data coverage for all study areas. NAIP imagery was not collected annually, however, which resulted in the occasional need to use one imagery dataset for two analysis years. We deemed this acceptable given there is little change in the area or distribution of permanently vegetated islands between years (Jorgensen *et al.* 2012). Channel width metrics within the CPR study area were measured using aerial imagery collected under the Program's remote sensing data collection protocol (Program 2011).

Channel Width Measurements

Channel widths were measured using ESRI ArcMAP geographic information system (GIS) software. Measurements at systematic locations were made perpendicular to the direction of flow at approximately 305 m intervals for each year (hereafter referred to as "available sites"). Channel width measurements were also developed at each species use site in the LPR, Niobrara and Loup study areas. Two width measurements were recorded at each use and available site including 1) total channel width and 2) maximum unvegetated channel width (Figure 3). Total channel width was defined as the total distance from apparent left bank to apparent right bank and included permanently vegetated islands which was consistent with the total channel width definition used by Elliott (2011). Maximum unvegetated channel width at available sites was calculated as the longest contiguous unvegetated channel width from apparent left bank to apparent right bank. This was similar to the Jorgensen *et al.* (2012) definition of active channel width, except that the shorter unvegetated channel width segments along individual transects were not included as additional independent transects in our analyses. Maximum unvegetated channel width at use sites was calculated as the contiguous unvegetated channel width at the nesting colony location.

Approximately 40% of the central Platte River study area has river channels that are split by up to 2 km wide and 10 km long permanent islands resulting in a main and one or more side channels. Similar conditions do not occurr in our other three study areas. As such, in reaches where the channel was split by these large permanent islands channel width measurements at available sites within the CPR study area were limited to the main channel.

Data assimilation and processing

A single data set was created by combining channel width measurements at use and available sites. A value of zero (0) was assigned to each available site measurement, and a value of one (1) was assigned to each use site measurement. The river study area associated with each use and available site was also included in order to identify the river system where the measurements were taken. A covariate called "channel break" was created and was assigned a value of one (1) if the maximum unvegetated channel width was <95% of the total channel width and zero (0) if the maximum unvegetated channel width was ≥95% of the total channel width. This covariate was used as an indicator of whether or not the channel was free of permanently vegetated mid-channel islands. Finally, the assimilated data was split into training and test datasets where approximately 50% of the data was randomly assigned to the training dataset and 50% to the test dataset.

Relationship between nest incidence and channel width

Logistic regression was used to analyze the relationship between nest incidence and channel width metrics. Twelve models including most subsets of main and interaction effects of study area (LPR, Niobrara River and Loup River), total channel width, maximum unvegetated channel width, and channel break were evaluated to determine their usefulness for predicting probability of nesting incidence across study areas (Table 1). The logistic regression models were fit to the training data set with the probability of nesting incidence for each observation in the test data set predicted using the models. The predicted probability of nesting and the test data set were used to calculate predictive deviance (i.e., –2 times the predictive log-likelihood) and the model with the lowest predictive deviance was selected as the best model.

Relationship between channel width metrics

The relationship between total and maximum unvegetated channel width was evaluated using generalized additive models (GAM) assuming a Gaussian (normal) response and a smoothing spline (Hastie and Tibshirani 1990). GAMs are a type of regression model which allow for nonlinear relationships between the response variable (maximum unvegetated channel width) and a covariate (total channel width). GAMs use a series of polynomials to approximate unknown functional relationships, which made them particularly useful in this case given the theoretical relationship between the variables was unknown. Although GAMs can be used to model nonlinear relationships when the functional form of the relationship is unknown, particular care needs to be taken so the model does not over fit the data. To ensure over fitting did not occur, the target equivalent degrees of freedom for the smoothing spline were varied in integer values from 1 to 5. An additive and interaction effect of river segment (LPR, Niobrara, Loup and CPR) were included to test for different relationships between river systems. This resulted in 16 models to fit using training data. To select the best model, the mean square error was calculated for test data and the model that minimized this value was chosen (Hastie *et al.* 2009).

Logistic regression was also used to evaluate the relationship between total channel width and channel consolidation, where consolidation refers to channels free of permanently vegetated islands. A single model that included total channel width and river system as an additive and interaction effect was tested. All analyses were conducted in Program R 3.2.4 (R Core Team, Vienna, Austria). Plots of predicted relationships obtained with testing data were developed and presented for the best nest incidence and channel width relationship models as well as for the single logistic model.

RESULTS

Relationship between nest incidence and channel width

A total of 73, 78, and 16 use sites were reported in the LPR, Niobrara, and Loup River study areas, respectively. Median total channel width at use sites across all river segments was 485 m and median maximum unvegetated channel width was 434 m (Table 2). Ninety percent of use sites occurred in channels with total widths exceeding 352 m and maximum unvegetated channel widths exceeding 265 m. Channel width measures were generally greater at use sites than available sites.

The logistic regression model with the highest predictive ability (i.e., lowest predictive deviance) contained the effects maximum unvegetated channel width, channel break, river system, and an interaction between maximum unvegetated channel width and channel break (Table 1). We found probability of nesting increased rapidly once maximum unvegetated channel width reached approximately 500 m for consolidated channels, regardless of river system (Figure 4). In unconsolidated channels, the probability of nesting also increased with increasing maximum unvegetated channel width, but not as rapidly. The Niobrara River had the highest likelihood of use of any study area with probability of use maximized when total channel width and maximum unvegetated channel width were approximately 780 m. Utilizing the predictive model built using data collected on the lower Platte, Niobrara, and Loup River systems, we found the CPR study area was predicted to have a very low probability of nesting which was similar to the Loup River.

Relationship between channel width metrics

The modeled relationship between total channel width and maximum unvegetated channel width was similar for all study areas. Our model predicted maximum unvegetated channel width would increase until total channel width exceeded approximately 500 m (Table 3; Figure 5). In channels wider than 500 m, maximum unvegetated channel width decreased in spite of increasing total channel width due to the increasing occurrence of vegetated islands in wider channels. However, the underlying data was highly variable as segments of the LPR channels as narrow as 335 m contained vegetated islands and channels as wide as 700 meters were found to be fully consolidated (Figure 5). The width relationship and underlying data in the Niobrara study area was very similar to the lower Platte River. The general relationships for the Loup and CPR study areas were also similar, but overall widths were narrower with few consolidated channels occurring when total channel width exceeded 350 m.

The relationship between total channel width and probability of channel consolidation (i.e., free of vegetated islands) indicates a decreasing probability of consolidation with increasing total channel width (Figure 6). We estimate there is a 50% probability of consolidation when total channel width exceeded 560 m in the LPR study area, 480 m in the Niobrara River study area, 360 m in the Loup River study area, and only 100 m in the CPR study area.

DISCUSSION

Jorgensen *et al.* (2012) found probability of least tern and piping plover nesting incidence on the LPR increased sharply with unvegetated channel width and that both species appeared to avoid anabranch (side) channels. Similarly, we found probability of nesting incidence increased with increasing maximum unvegetated channel width and the widest channels free of vegetated islands had the highest probability of use in all study areas (Figure 4).

Elliott (2011) on the other hand included vegetated islands in channel width calculations and concluded narrower channels, with less potential for occurrence of vegetated islands, were more suitable for nesting. This conclusion is supported by the relationship between total and maximum unvegetated channel widths indicating declining maximum unvegetated channel widths (and associated probability of nest incidence) when total width exceeds approximately 500 m (Figure 5). It is also supported by the logistic regression analysis which indicated a decreasing probability of the channel being free of vegetated islands with increasing total channel width (Figure 6).

When interpreted together, the bird- and geomorphology-centric relationships indicate the widest channels free of permanently vegetated islands are critical from a species use perspective. Comparatively narrow segments like the central Platte River and Loup River may be width-limited regardless of the presence of sandbar habitat. In the wider lower Platte and Niobrara River segments, there is a tradeoff between increasing probability of use and decreasing probability of consolidation with increasing total channel width. Consolidated channels with total widths of 500 – 800 m are relatively rare, but have the highest probability of use. Actions reducing width in these locations would have the greatest negative impact on least tern and piping plover use. Conversely, actions in the widest channels would likely have little impact on use as such channels cannot be maintained free of vegetated islands through natural processes. If management actions are contemplated to increase species use, removal of permanently vegetated islands in 500 – 800 m channels could greatly improve probability of use. However, there would be a tradeoff between increasing probability of use and a decreasing probability the channel will remain free of vegetated islands. Further exploration of differences in physical characteristics of consolidated and unconsolidated channels of similar widths would be beneficial.

Natural resource professionals tend to gravitate toward either a species- or geomorphic-centric viewpoint depending on their background and training. Both viewpoints are necessary, but taken independently (as in this case) can lead to a limited view of the implications of actions that affect the physical environments used by at-risk species. We encourage natural resource professionals to embrace cross-disciplinary research and training in order to build a more comprehensive understanding of at-risk species use of important habitats and to make this understanding more useful for management and decision making purposes.

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Table 1. A priori set of models used to evaluate in-channel nesting incidence in the lower Platte, Niobrara, and Loup River study areas as ranked by a predicted deviance statistic.

Model	Deviance	AIC
Channel Break * Max Unvegetated Channel Width + River System	738.22	630.69
Channel Break + Max Unvegetated Channel Width + River System	739.05	634.02
Channel Break * Max Unvegetated Channel Width	742.89	628.01
Max Unvegetated Channel Width	743.87	630.42
Channel Break + Max Unvegetated Channel Width	743.95	631.58
Channel Break * Total Width	745.57	629.61
Channel Break * Total Width + River System	745.76	633.60
Channel Break + Total Width	766.66	671.37
Channel Break + Total Width + River System	767.26	673.78
Total Width	774.15	678.70
Channel Break	775.87	685.74
Null	777.25	684.71

Table 2. Total channel width (m) and maximum unvegetated channel width (m) at systematic available sites and use sites.

TOTAL CHANNEL WIDTH						
	10th Percentile		Median		90th Percentile	
Study Area	*Available*	*Use*	*Available*	*Use*	*Available*	*Use*
Lower Platte	347	415	513	536	789	664
Niobrara	247	390	415	481	602	702
Loup	136	159	227	264	389	428
All Study Areas	200	352	416	485	671	668
MAXIMUM UNVEGETATED CHANNEL WIDTH						
	10th Percentile		Median		90th Percentile	
Study Area	*Available*	*Use*	*Available*	*Use*	*Available*	*Use*
Lower Platte	269	337	403	496	548	608
Niobrara	158	318	323	431	473	549
Loup	120	136	201	181	318	329
All Study Areas	156	265	325	434	495	588

Table 3. Top models for analysis of the relationship between total channel width and maximum unvegetated channel width in the lower Platte, Niobrara, Loup and central Platte study areas, ranked by mean square error (MSE) of predicted relationships.

Covariates	MSE	AIC
Total Width(df=5) * River System	7396.21	59358.83
Total Width(df=4) * River System	7424.42	59379.96
Total Width(df=3) * River System	7482.41	59432.75
Total Width(df=2) * River System	7812.20	59691.94
Total Width(df=1) * River System	9011.80	60444.38
Total Width(df=5) + River System	7937.66	59801.57
Total Width(df=4) + River System	7968.67	59821.93
Total Width(df=3) + River System	8021.78	59856.94
Total Width(df=2) + River System	8231.21	59996.69
Total Width(df=1) + River System	9339.30	60632.52
Total Width(df=5)	14899.60	62721.98
Total Width(df=4)	14970.44	62744.86
Total Width(df=3)	15127.98	62795.31
Total Width(df=2)	15658.53	62969.09
Total Width(df=1)	18490.09	63795.39

Lead Author: J. M. Farnsworth

Figure 1

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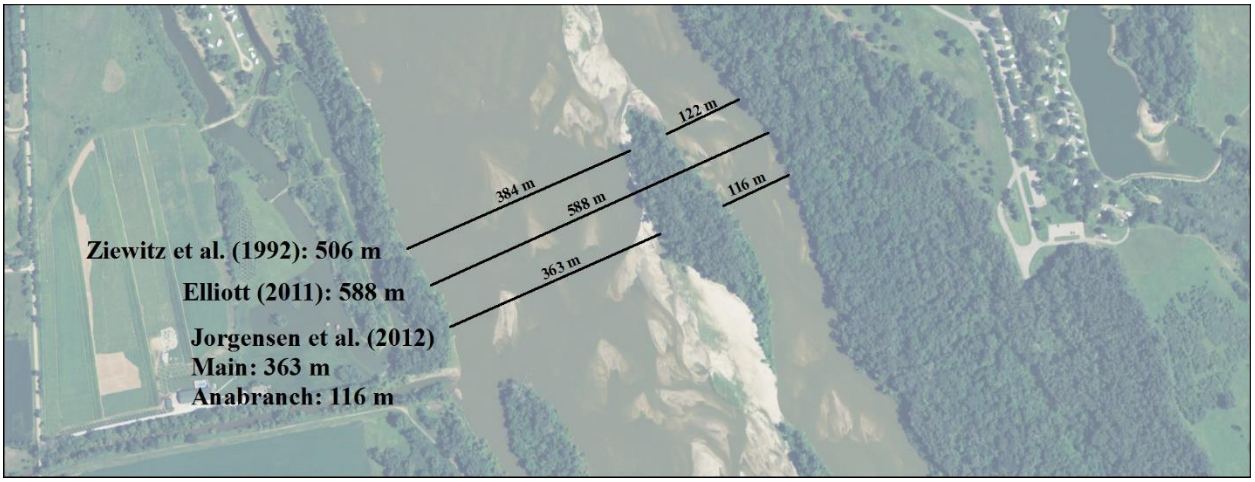

Figure 1. Examples of different in-channel width measurements. The channel width in the example ranged from 116 m (Jorgensen *et al.* 2012 definition) to 588 m (Elliot 2011 definition).

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Figure 2

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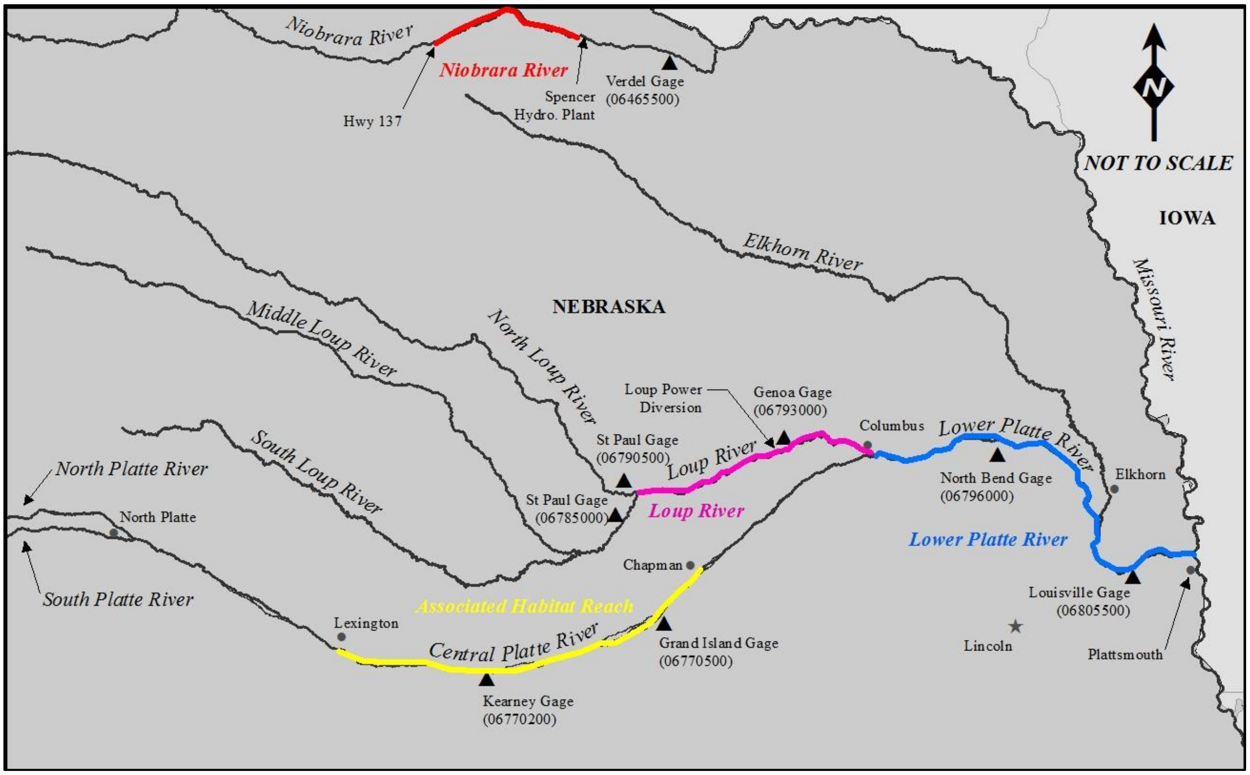

Figure 2. Niobrara River, Loup River, lower Platte River, and central Platte River study areas.

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Figure 3

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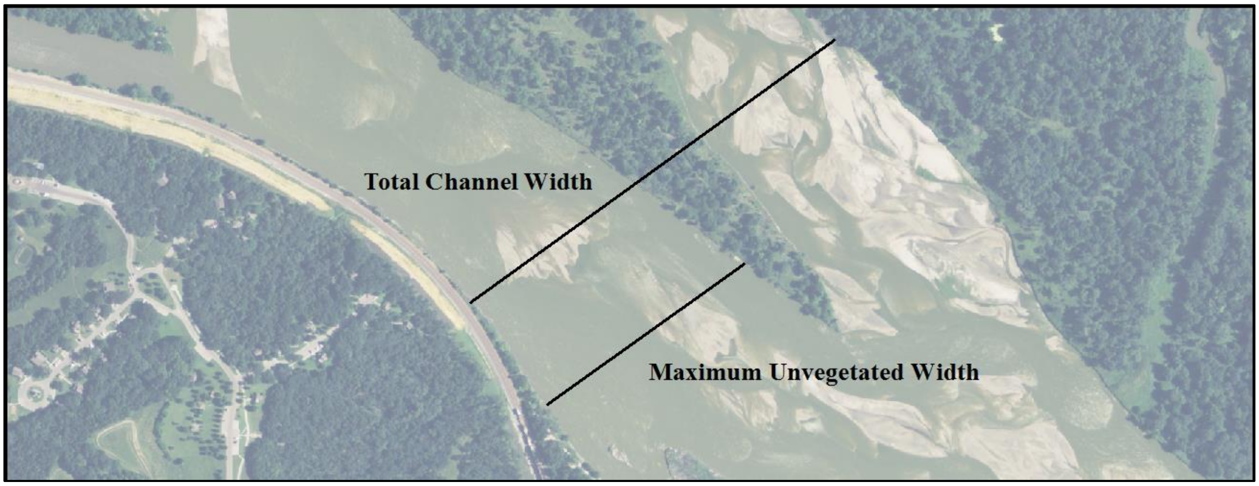

Figure 3. Total channel width and maximum unvegetated channel width metric measurement example.

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Figure 4

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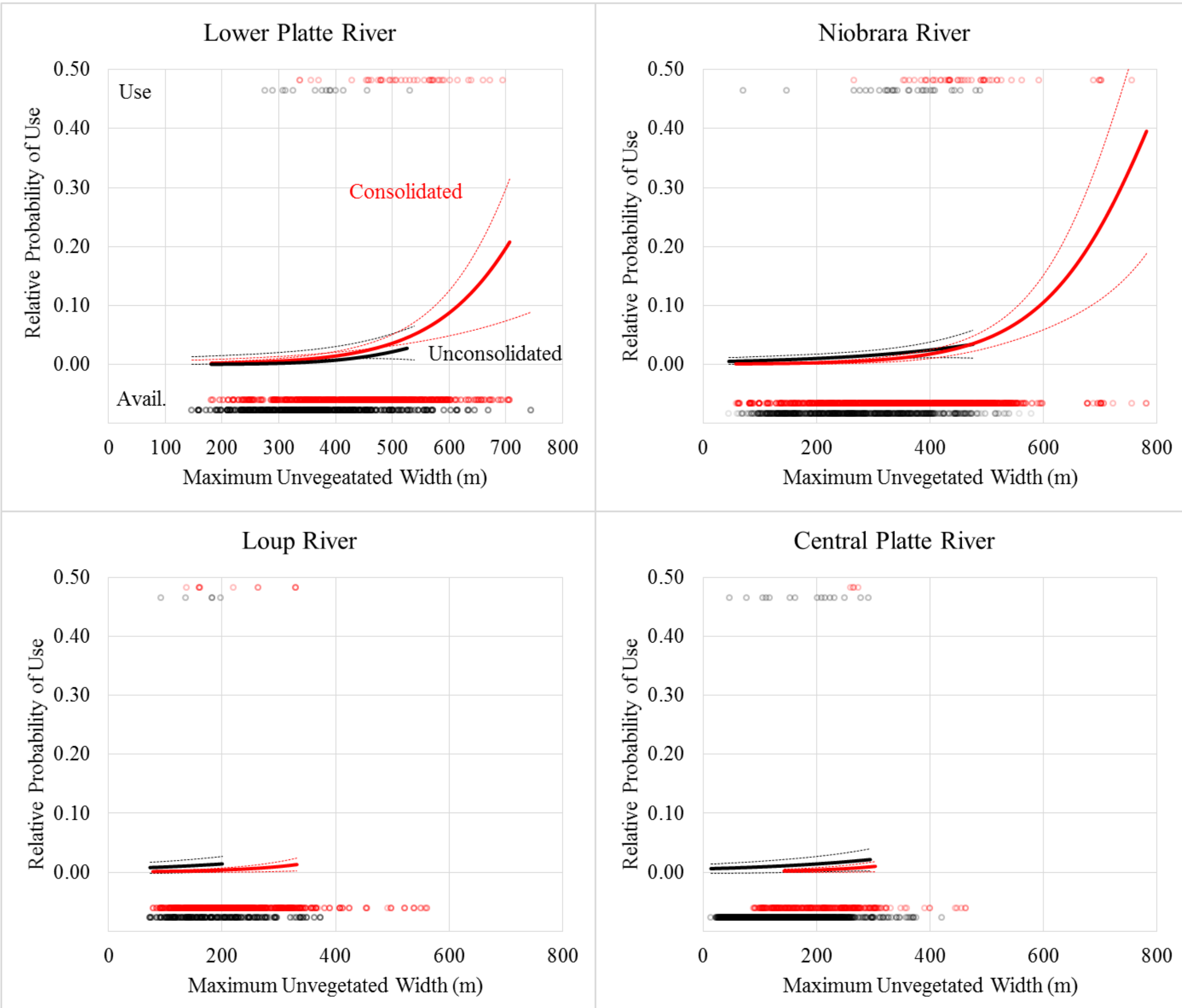

Figure 4. Predicted probability of use for consolidated (red) and unconsolidated channels (black) for the lower Platte (upper left), Niobrara (upper right), and Loup (lower left) segments from our best model. Predicted probability of nesting incidence is only plotted over the range of total channel widths observed within each river system. Open circle points show total channel widths for use sites (Red) and available (Black) sites. Predicted probability of use was plotted for the central Platte segment area (lower right) but data from the central Platte were not used to estimate model parameters.

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Figure 5

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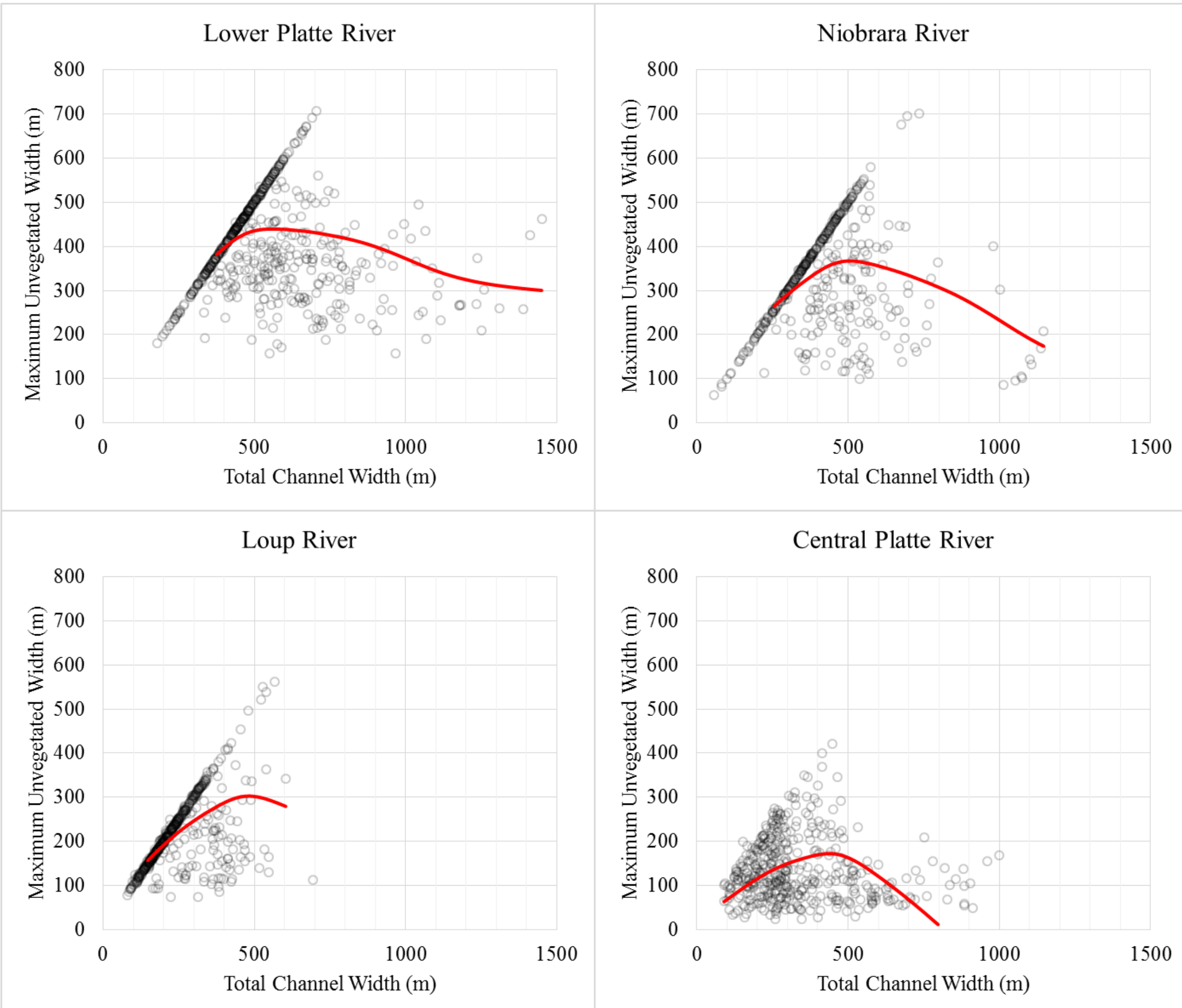

Figure 5. Relationship between total channel width and maximum unvegetated channel width for all study segments.

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Figure 6

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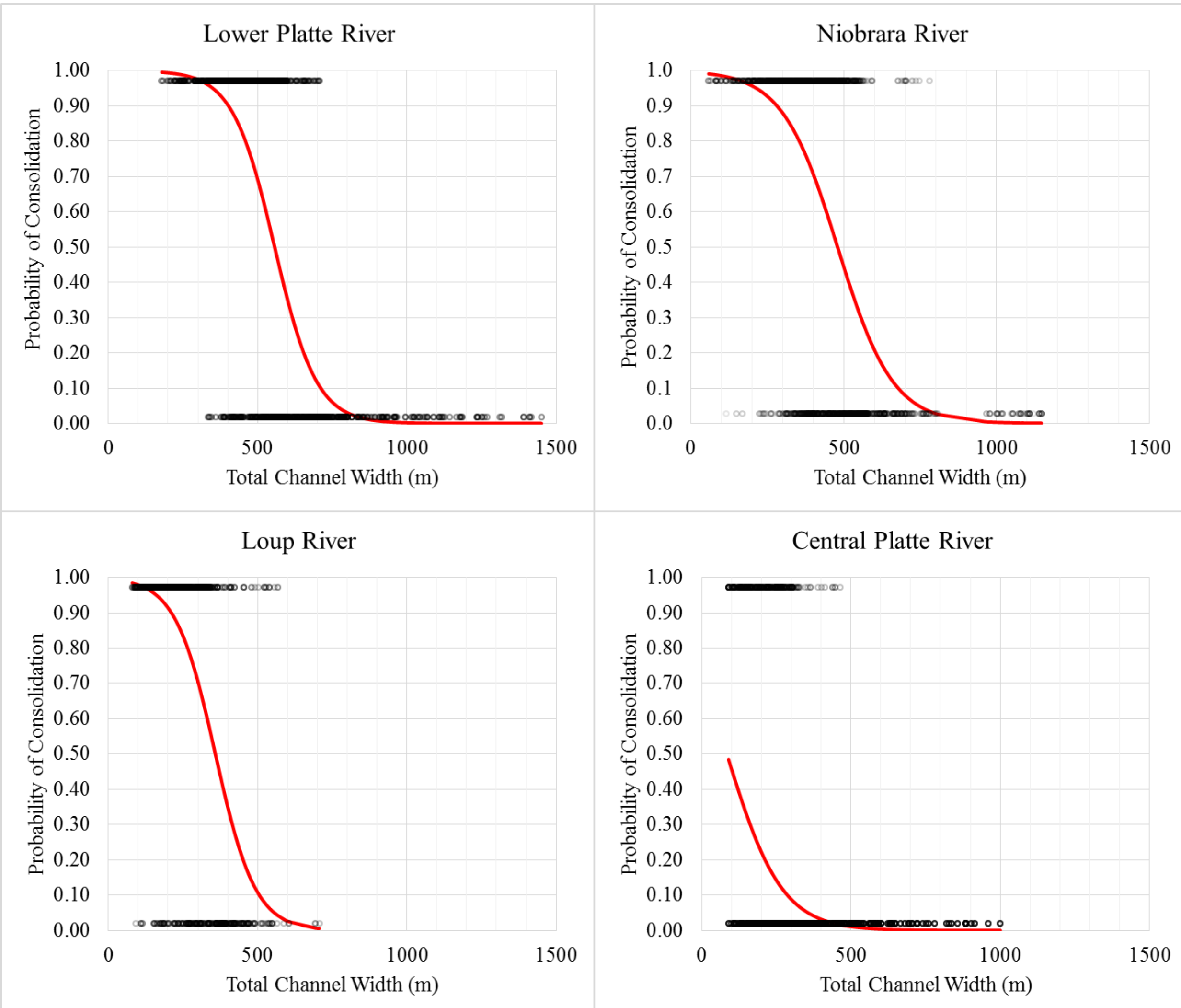

Figure 6. Relationship between total channel width and probability that channel will be free of vegetated islands (consolidated) for all study segments.