Patterns of Downstream Fining on the Lower Chippewa River

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Introduction

Research has shown that the bed material of gravel-bed rivers tends to become finer in the downstream direction (Rice and Church, 2010). Since the late 19th century, quantitative studies have established that the relationship of gravel size to downstream distance is generally best described by an exponential decay function (Gomez et al 2001). Two sets of processes responsible for change in sediment size include abrasion (changes in sediment size via mechanical processes like grinding, impact, and rubbing) and sorting (selective transport caused by flow, fluid, and sediment properties that affect bedload transport) (Knighton, 1980). However, downstream fining process operate over a range of scales which can create complex patterns of bed material size.

This study examines downstream fining of bed armor on the lower Chippewa River (LCR) in west-central Wisconsin at two different scales: at a river scale and at a local scale of individual armored bars. The upstream limit of our study area is located downstream of the city of Eau Claire where I-94 crosses the Chippewa River and ends approximately 5 km upstream of the city of Durand (60 km). 30 km downstream from the study area the LCR joins the Upper Mississippi River (UMR) (Figure 1). The LCR contains abrupt changes in channel planform morphology. Most notable is an anabranching reach in the middle of the study area. Both upstream and downstream from this reach the river exhibits a single meandering channel planform. Sedimentology changes within the channel are possibly related to the anabranching reach. Changes in channel pattern from reach to reach are moderated by variations in alluvial material and hydrology (Church, 1983).

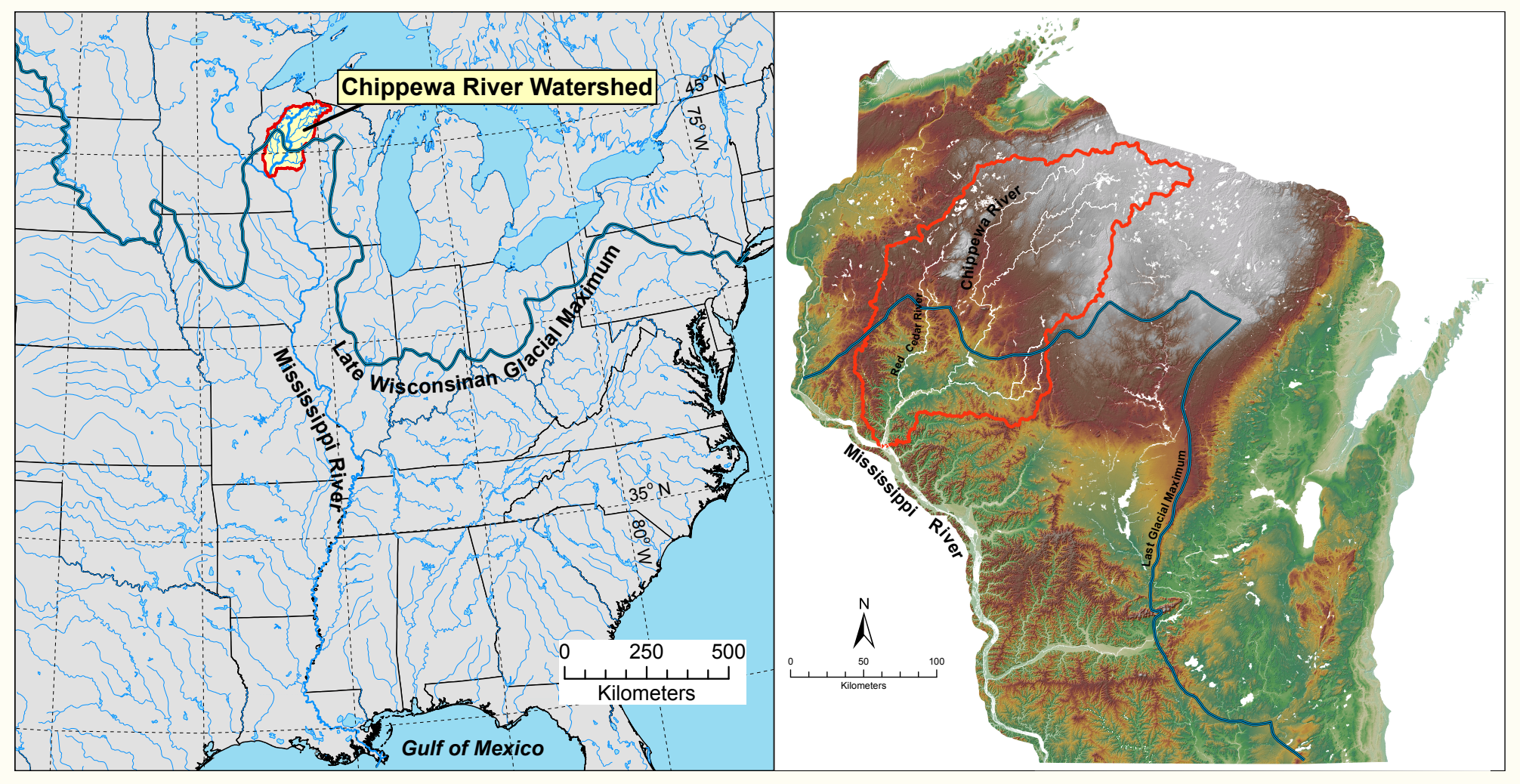


Figure 1: To the left is the location of the Chippewa River in west-central Wisconsin. The Chippewa River watershed is located at the northern edge of the Mississippi drainage basin in north-central United States (pictured left). The Chippewa River watershed drains approximately 25,000 km2 of land – about two- thirds of which was covered by ice at the LGM.

This research tested the findings of Rice and Church: Grain-size sorting within river bars in relation to downstream fining along a wandering channel on the lower Fraser River (a gravel bed river). Rice and Church found a clear downstream fining trend and a decreasing trend for the ratio of median grain sizes of upstream to downstream thirds of the bar on the Fraser River. Our research looked to observe comparable downstream fining and ratio trends on the lower Chippewa River using similar methods.

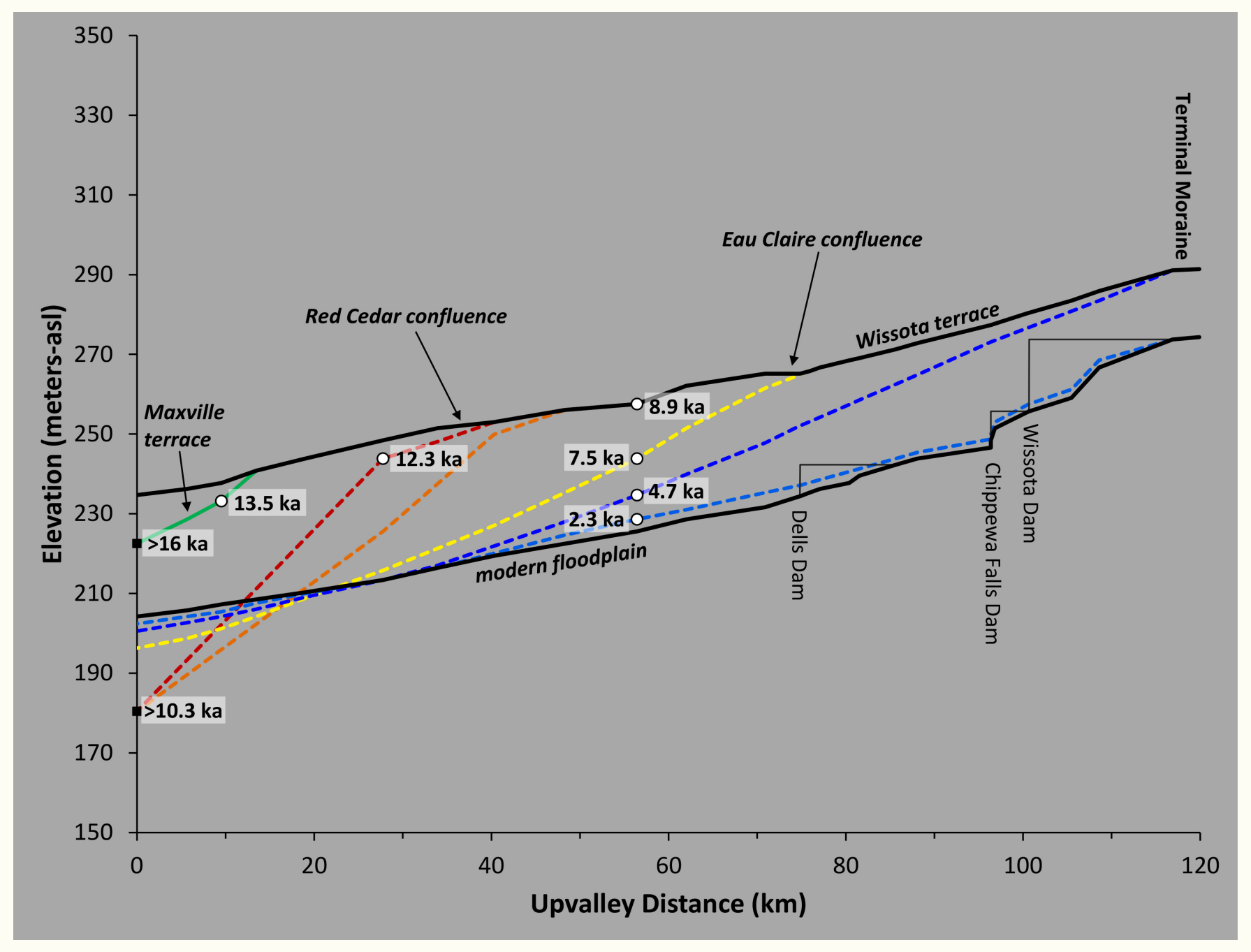


Figure 2: Proposed model of longitudinal profile evolution of the Lower Chippewa River. These profiles were constructed by connecting the scattered terrace remnants. With OSL and radio carbon dates, periods of incision can be seen as the Mississippi River incised as well as aggradation as sediment flushed out of the Chippewa Valley due to changes in the base level.

Methods

Bar sediments were studied over the summer months of July and August to characterize the spatial variability of gravel sizes along a 60-kilometer reach on the lower Chippewa River. The late summer months were chosen to assure lower river levels for preferred bar exposure.

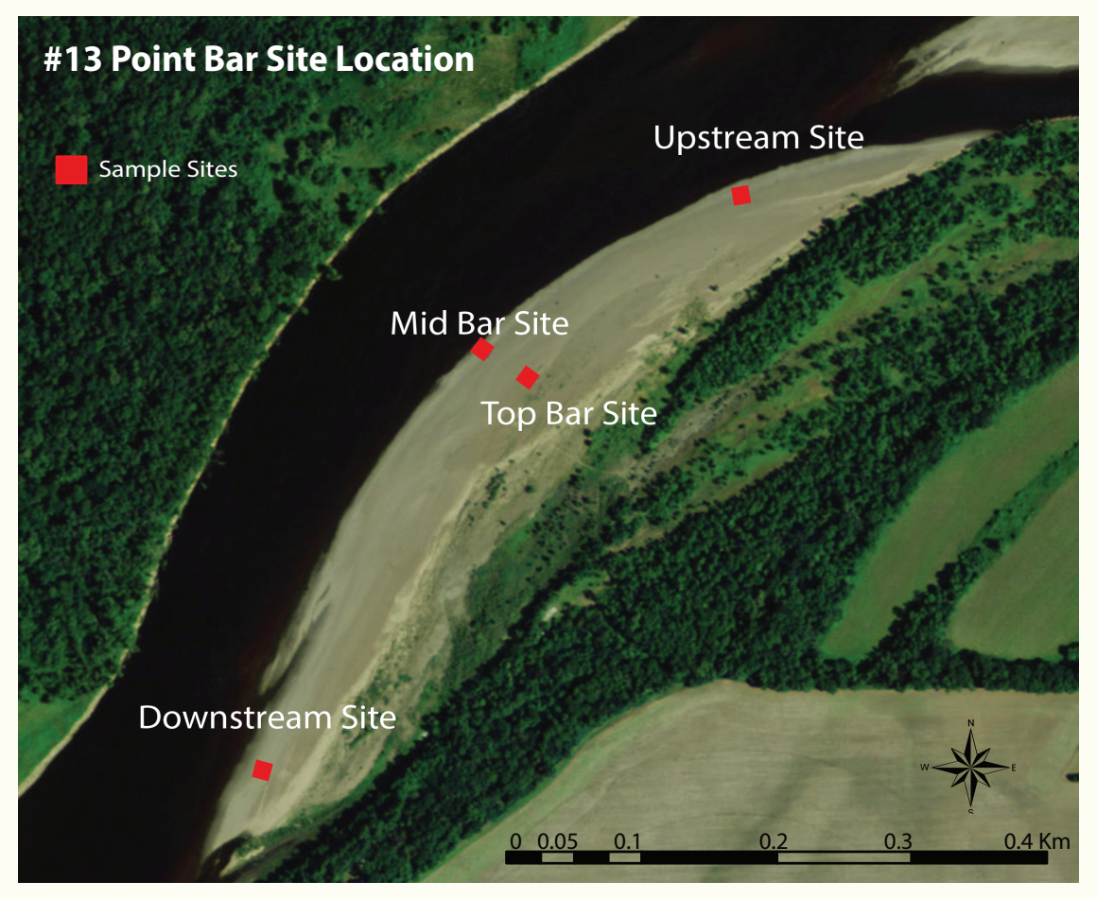


Figure 3: An illustration of one of the bars sampled. Three of the sample sites (upstream, mid bar, and downstream sites) were placed as low as possible on each bar, with the edge of one side parallel to the river. The fourth site (top mid bar site) was placed on the highest point in the middle each bar.

To evaluate gravel-size variability, sample sites were placed on the upstream, mid bar, top mid bar, and downstream areas of each bar. The locations of sample sites were determined by walking the perimeter of each bar with a GPS to develop a polygon of the area. From the GPS-surveyed polygons, specific points were then chosen as sample sites, as long as they were located in gravel dominated areas with little to no vegetation or human disturbance. It should be noted that the downstream ends of bars were often dominated by sand; these sand-dominated areas were avoided. Bars were selected based on spatial location to achieve an accurate representation of the study area. Distances between the selected bars are relatively the same to avoid clustering of bar sites.

The sample sites on each bar were 5x5 meter grids (Figure 6). Three of the sample sites (upstream, mid bar, and downstream sites) were placed as low as possible on each bar, with the edge of one side parallel to the river. The fourth site (top mid bar site) was placed on the highest point in the middle each bar. Gravel clasts were selected for measurement at quarter meter intervals. Approximately 400 clasts were measured at each site. We made sure to take samples that fell right on the quarter meter interval, consciously trying to avoid the tendency to pick up larger clasts. Our method is essentially a modification of the Wolman pebble-count method, which determines grain–size distributions based upon an evaluation of the relative area covered by clasts in pre-determined size classes rather than their relative weights (Wolman, 1954). Clast size is, by convention, based on its intermediate axis. We used gravelometers to measure the intermediate axes of selected clasts and to sort them into half-psi size classes. Data was imported to Excel and percent finer than was calculated and was used to create graphs. Using the data from Excel, we used a computer program called GRADISTAT to analyze grain size statistics such as D50 and D90. Grain size is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition (Blott and Pye 2001).

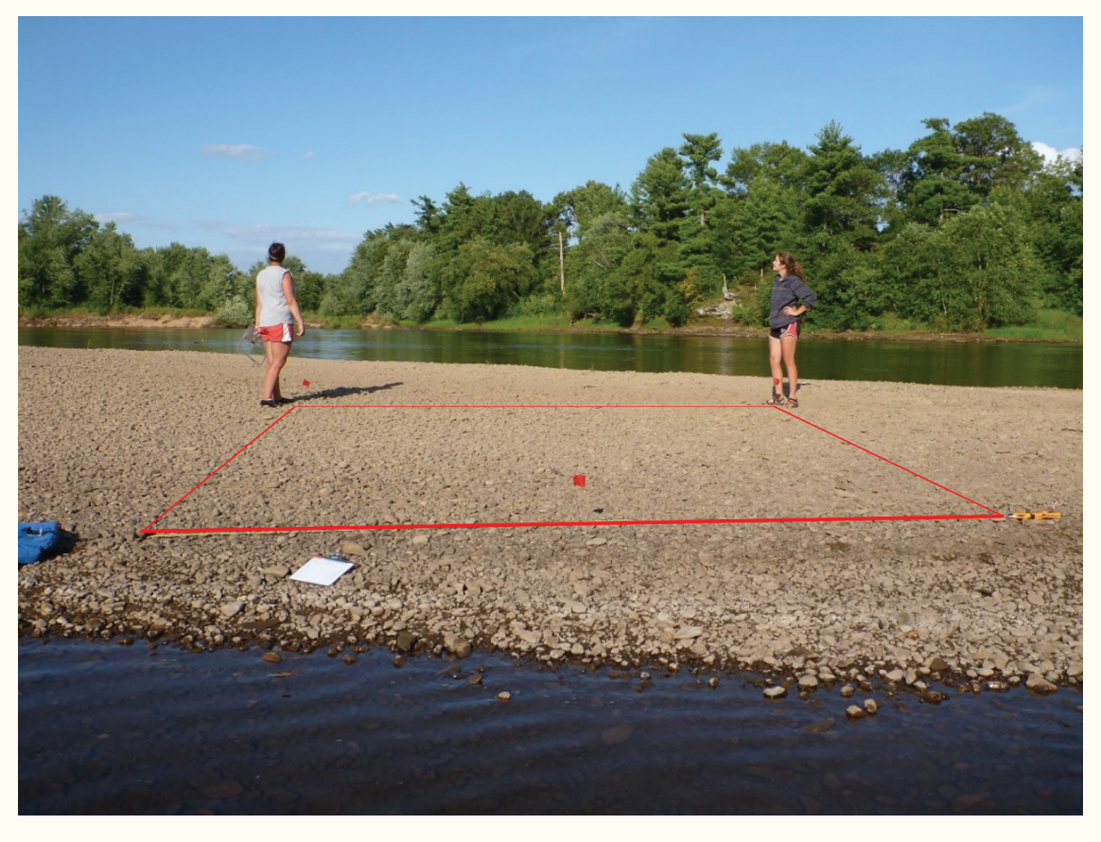


Figure 4: Above left is a 5 by 5 meter gird outlined in red. Measurements were taken at every quarter-meter mark – approximately 400 clasts were measured at each site.

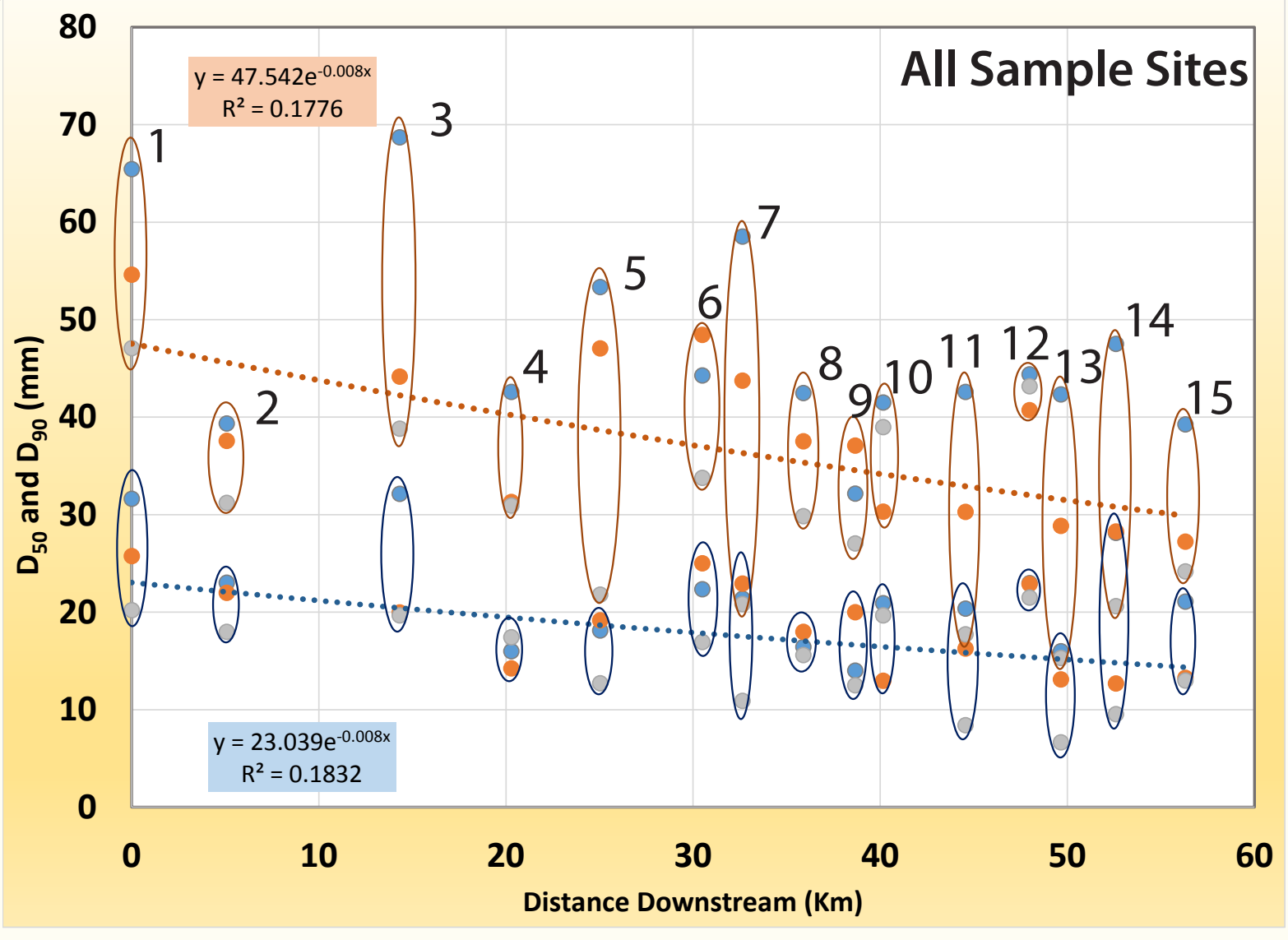


Figure 5: The trend line shows a downstream fining of clast sizes on the reach. When looking at all the data there is significant scatter, which is due to downstream fining on individual bars (circled in blue for D50 values and orange for D90 values). 14 bars show progressive fining from the upstream to downstream sample sites for the D90 values and eight bars for D50 values.

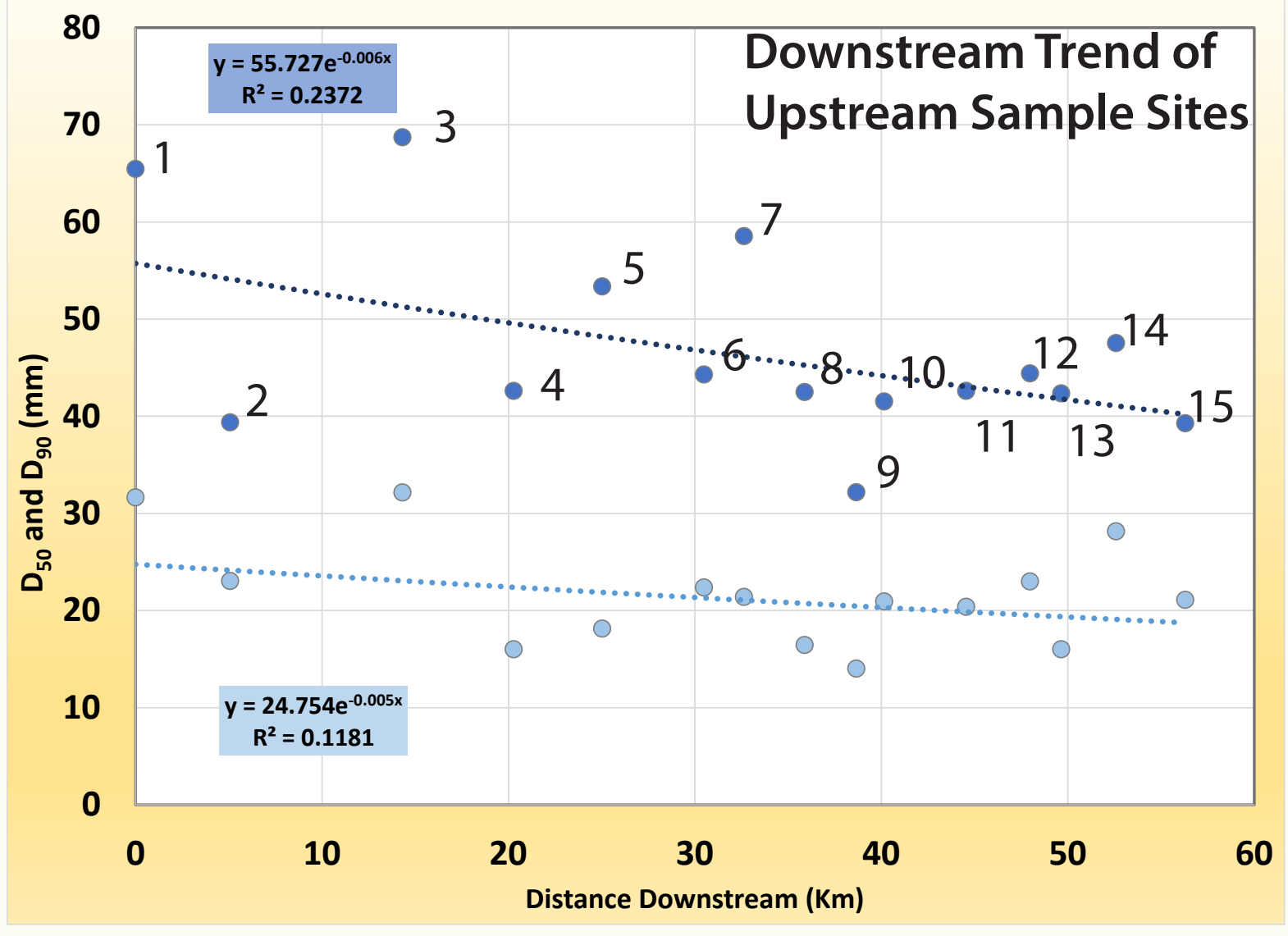


Figure 6: Because of downstream fining apparent on individual bars, D50 and D90 values for sample sites located at the same bar position were separated from other bar position values. This graph for upstream sample sites shows a downstream fining trend. Data points seem to be scattered randomly around the respective trend lines.

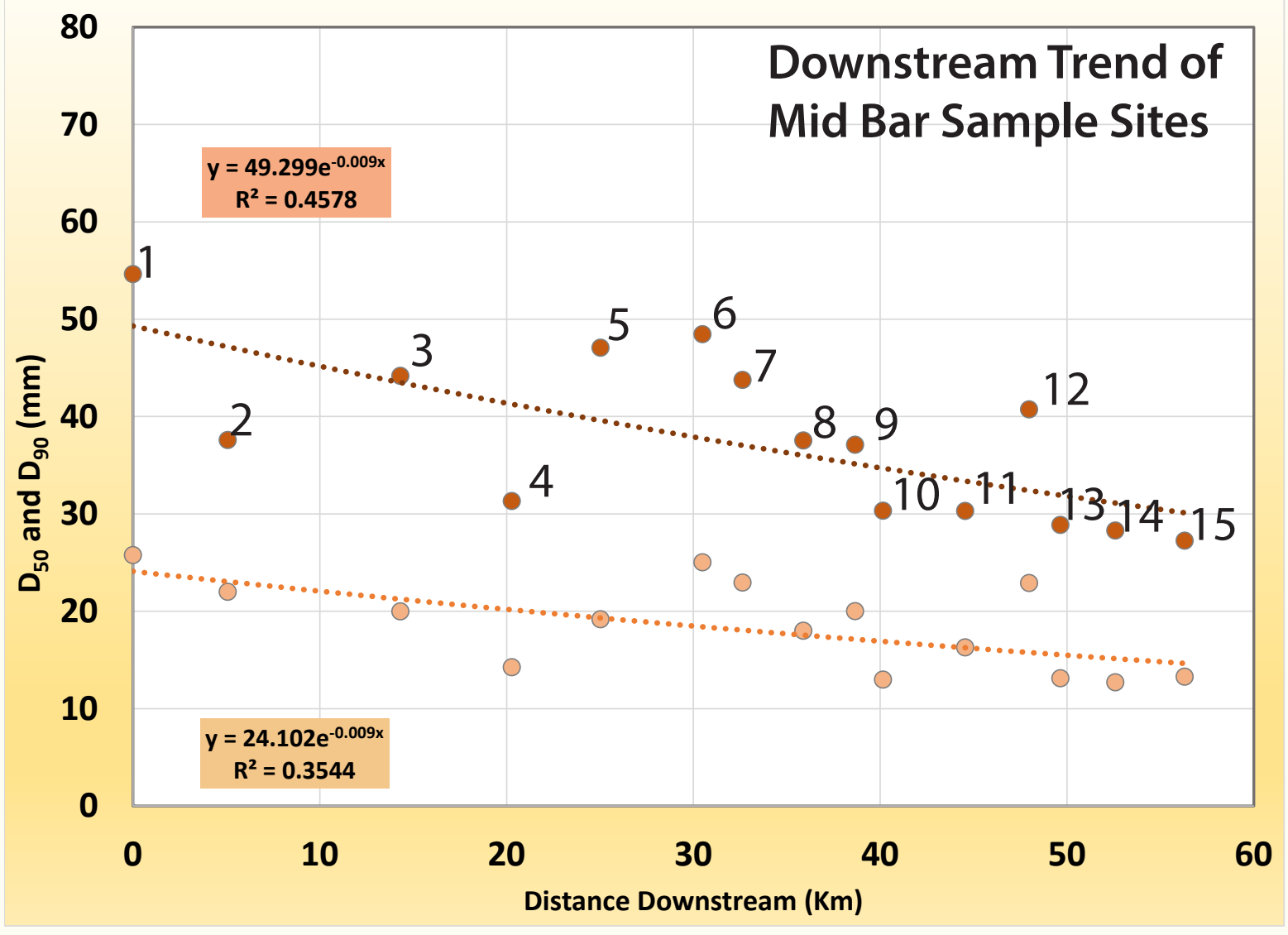


Figure 7: This graph shows the nonrandom distribution of data points around the D50 and D90 trend lines. There is an overall downstream fining trend prevalent in this graph. The data points exhibit a downstream fining for the first four sites and then a coarsening of clast sizes. Downstream of bar 6 there is again a downstream fining trend. Bar 12 appears to be an outlier of coarse sediment.

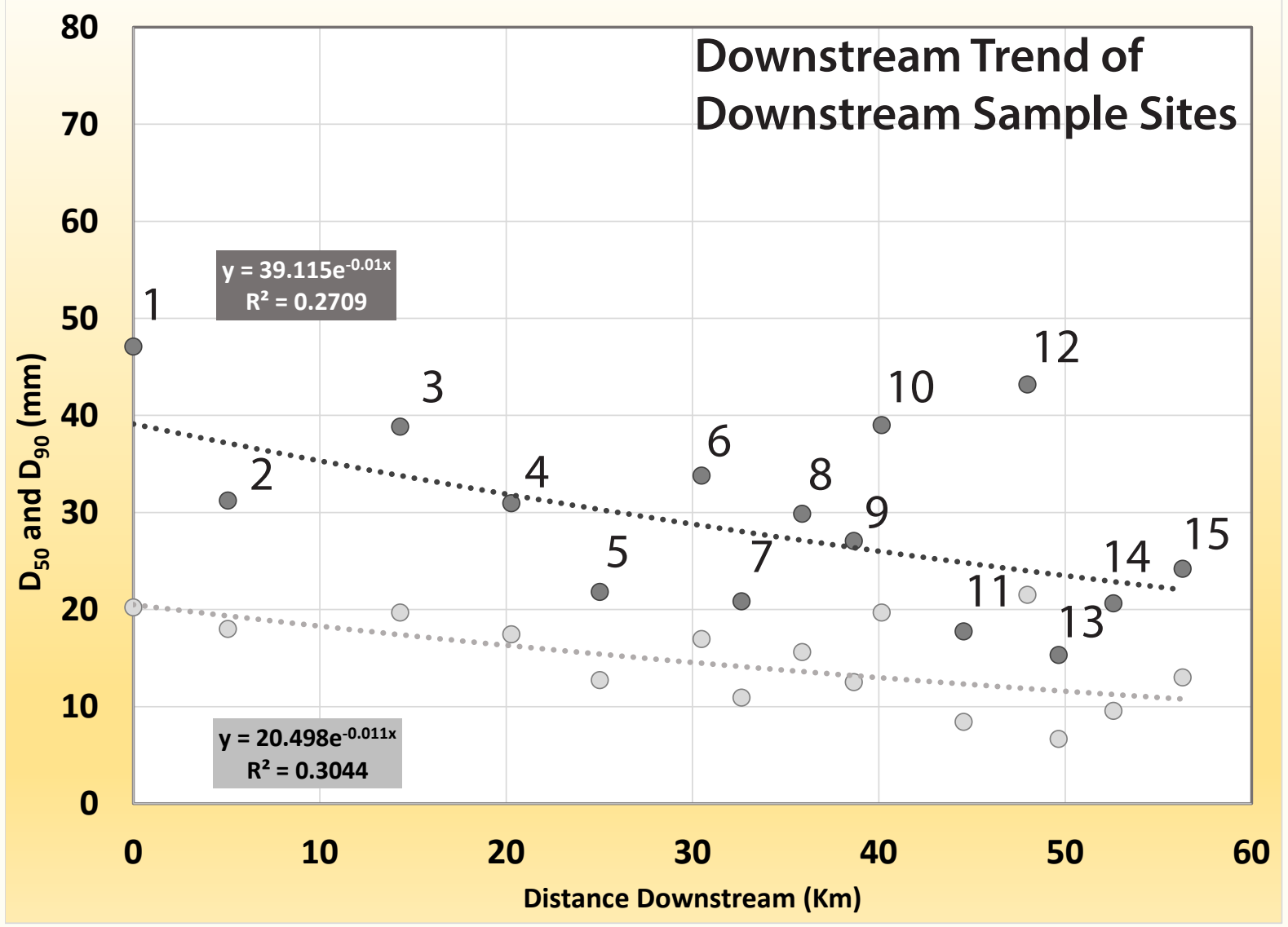
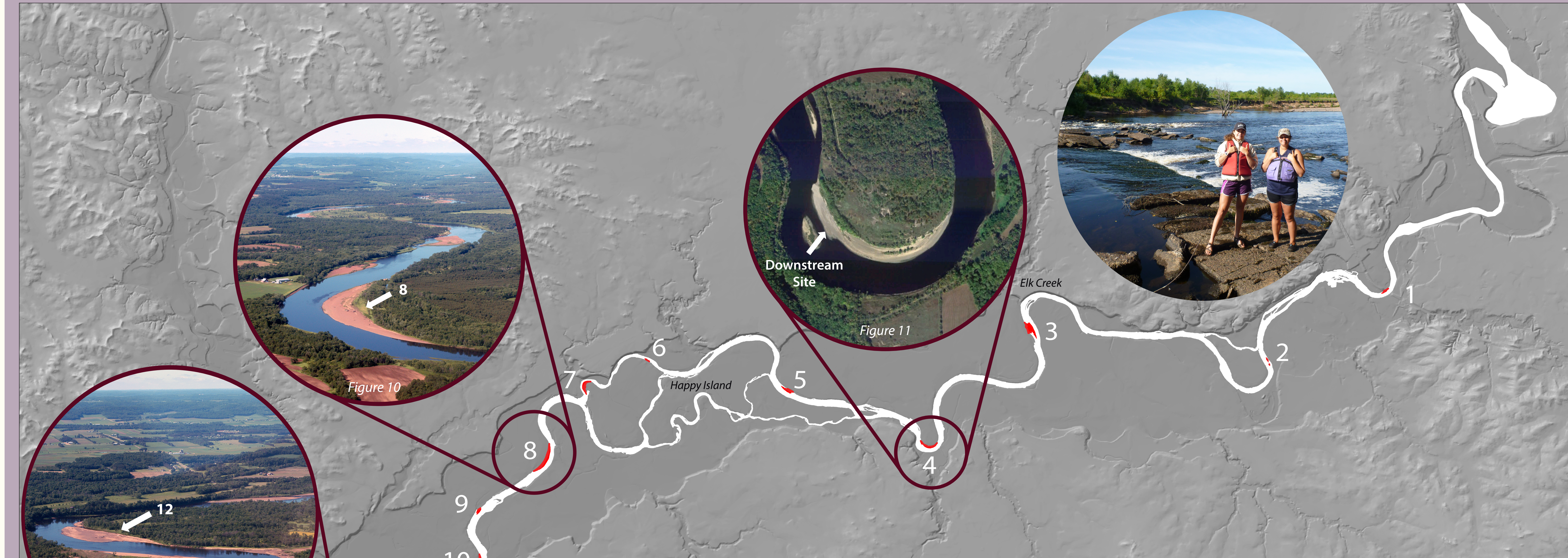


Figure 8: Again you can see that there is an overall downstream fining trend. While the data points are more randomly distributed around their respective trend lines compared to the mid bar sites, a fining, coarsening, and then fining trend is echoed in the downstream sites although it is less distinctive. Bar 12 still appears as an outlier in this graph.



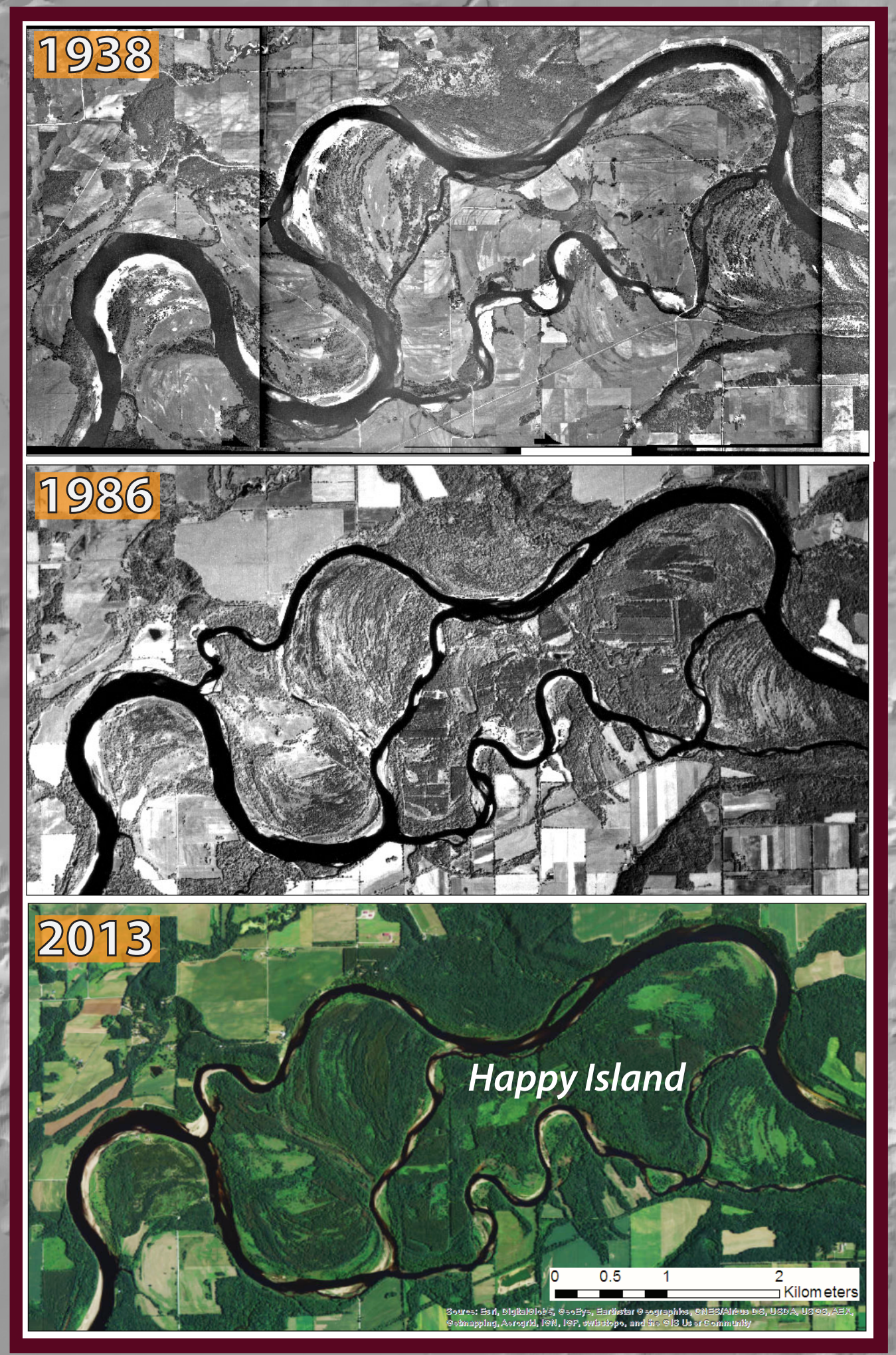


Figure 12: This compilation of aerial photos shows the evolution of an active anabranching reach. This reach is also categorized as a sedimentation zone (Church, 1983) where coarse sediment accumulated in this laterally unstable reach, supplying coarse sediment downstream. Since 1938, Happy Island as undergone drastic change. Within this anabranching reach channels have been abandoned and new ones have formed that suggests that this reach is unstable.

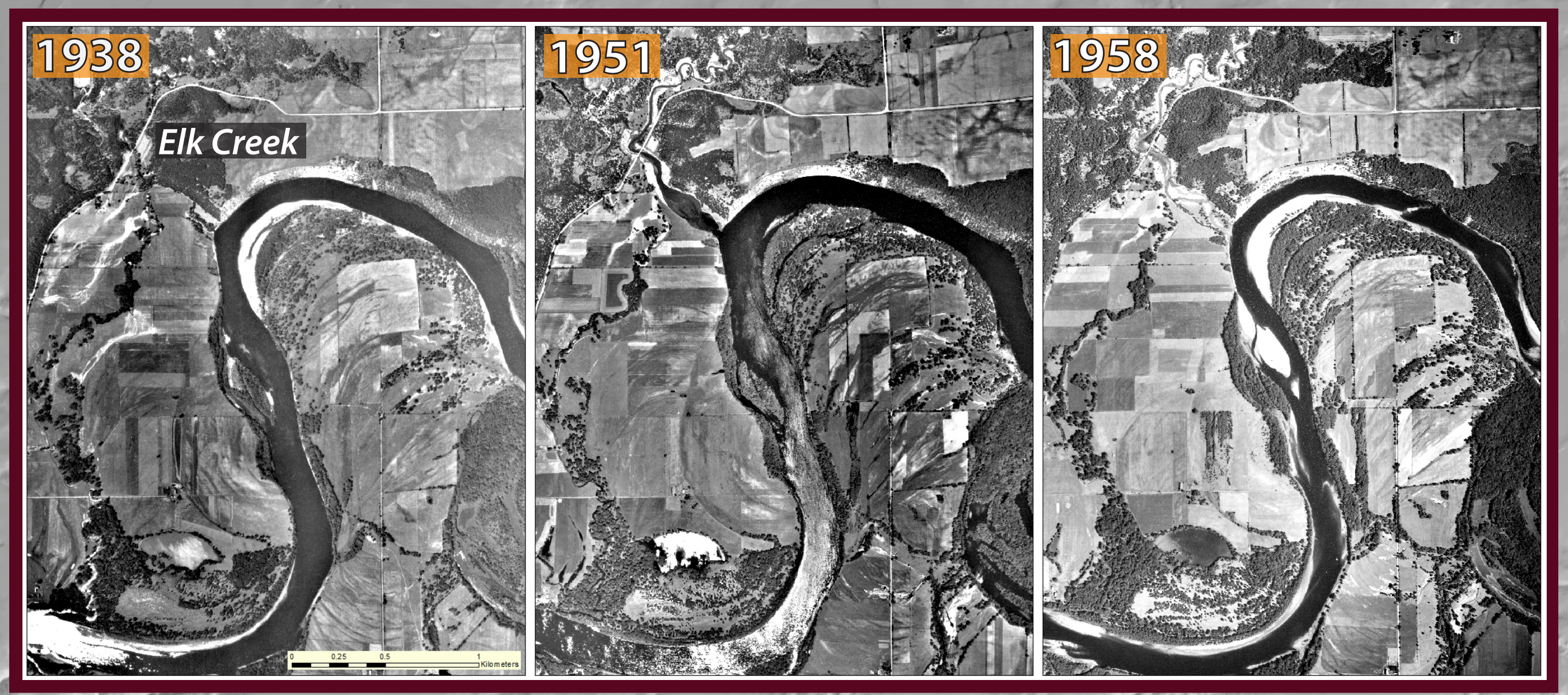


Figure 13: In the aerial photos taken in 1938, the Elk Creek and Chippewa River confluence is located in the bottom-left corner. There is evidence of an alluvial fan depositing sediment on the left side of the image as indicated by the highly reflective sediment material. Elk Creek drastically changed its direction and joined the Chippewa River further upstream (as indicated in the 1951 photo) probably during a flood event. The creek has since incised into the alluvium fan deposits which in turn supplied coarse sediment downstream. This is a possible explanation for why Bar 3 has such coarse material.

Discussion and Conclusion

Visual analysis of the bar sites in the anabranching reach (#5-7) and immediately downstream (#8-15) illustrates the role of sediment supply controlling downstream fining rates. The mid bar, top mid bar, and downstream sites suggest that the anabranching reach is a source of coarser bedload sediment. A clear exception to this trend is bar #12. The source of the coarse material on this bar is unclear, however, it should be noted that bar #12 is located within an old anabranching reach that could be exhibiting remobilization of deposits of coarse sediment (Figure 12). There is evidence that this area is still actively changing as bar #12 recently became a mid-channel bar (Figure 13). The current anabranching reach is possibly an indication of upstream incision that resulted in deposition downstream. Changes in bed elevation possibly resulted in upstream incision leading to the removal of bed material that was then deposited in downstream similar to an alluvial fan. This anabranching reach shows geomorphic similarities to the sedimentation zones described by Church (1983) and Desloges and Church (1987). These zones are zones with high sediment storage and are laterally unstable, which influences the channel pattern. Bar #3 is another bar that exhibits coarse material suggesting influence from lateral sources like the Wissota terrace scarp as well as from Elk Creek (Figure 13). These anomalies suggest that sediment supply is variable throughout our studied reach. Sediment can enter the stream via tributaries or other lateral sources (terrace scarps)

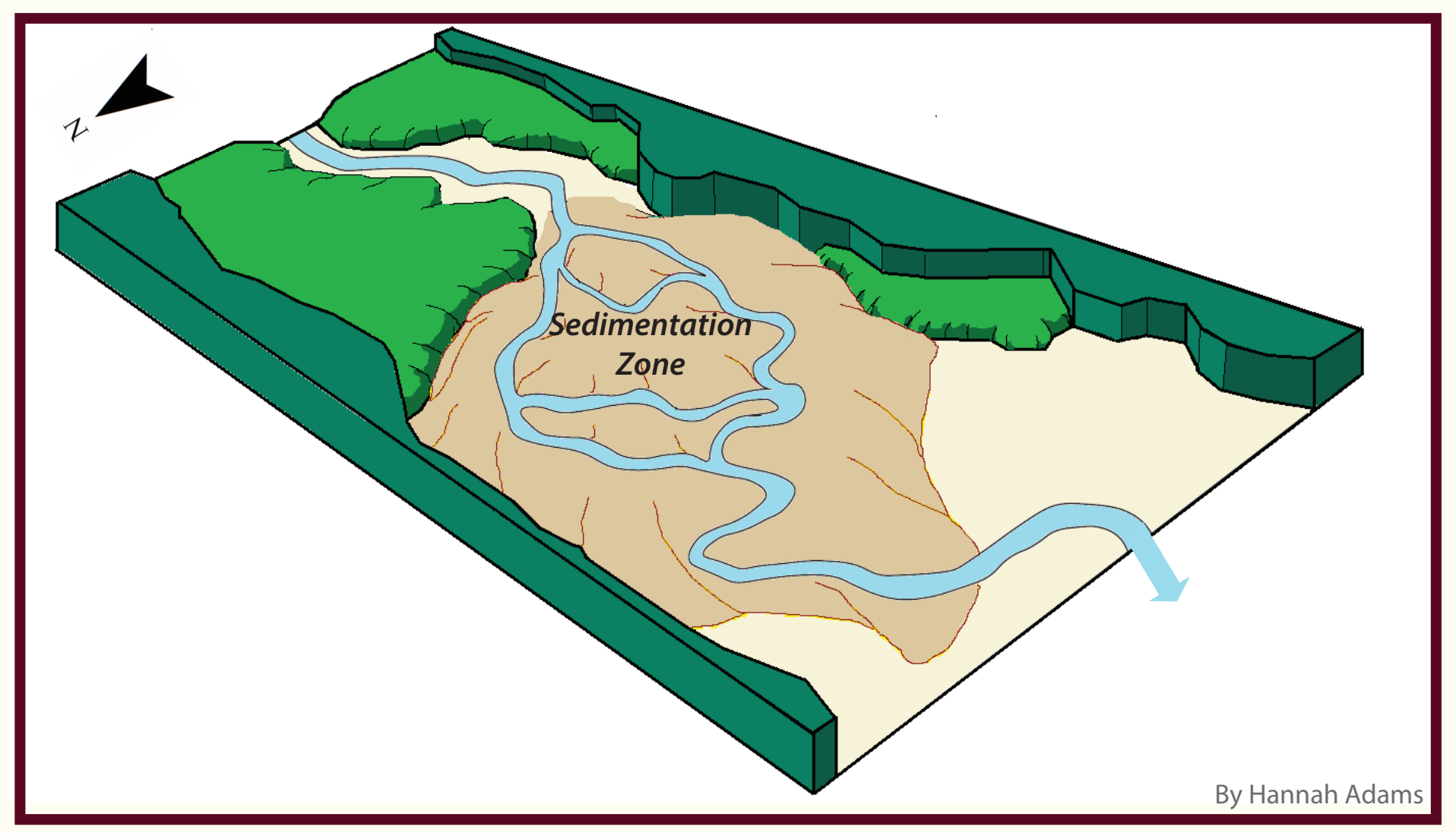


Figure 14: An illustration of the anabranching reach showing the possible changes in elevation that resulted from an upstream incision event leading to the removal of bed material that was deposited downstream similar to an alluvial fan.

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