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EQUILIBRIUM RESPONSE OF RIPARIAN VEGETATION TO FLOW REGULATION IN THE PLATTE RIVER, NEBRASKA

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ABSTRACT

The Platte River in central Nebraska responded to water development by rapid channel narrowing and expansion of native riparian woodland. Woodland expanded most rapidly in the 1930s and 1950s; open channel and woodland area stabilized in the 1960s and have remained stable for most reaches into the mid-1990s, despite relatively low flows and infrequent peak flows in the past decade. Open channel area may have been maintained or increased under recent lower flows because of increased erodibility of the floodplain as it has aggraded, developed vertical banks and as its woodland vegetation has become older, sparser and less protective of banks.

One section of the Platte River, near Grand Island, has disequilibrated in the past decade by undergoing a 10% loss of channel area. The reach occurs below an area where vegetation has been removed to increase open channel area for migrating whooping and sandhill cranes and other water birds. Vegetation clearing may have liberated excess sediment, locally aggraded the channel and stimulated tree and shrub recruitment. This management practice needs to be examined before it is used more widely in the Platte River. © 1997 John Wiley & Sons, Ltd.

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INTRODUCTION

Human activity has greatly modified native riparian vegetation in the western United States. A pervasive effect of water development along meandering rivers has been a decline in the establishment of *Populus–Salix* woodlands, which typically support high biodiversity (Johnson and Jones, 1977; Ward and Stanford, 1979; Hughes, 1994). *Populus* and *Salix* recruitment depends on point bar formation during channel meandering (Everitt, 1968; Johnson *et al.*, 1976). To illustrate, lower peak flows have reduced recruitment of *Populus fremontii* in the Southwest (Fenner *et al.*, 1985). Bradley and Smith (1986) attributed a decline in *Populus deltoides* reproduction along the Milk River in Montana and Alberta to reduced frequency of flow events greater than the two-year-return annual flood. Similarly, several species of *Populus* along the Marias River in Montana have declined owing to flow regulation and sediment trapping in upstream reservoirs (Rood and Mahoney, 1995). Flood control and reduced channel meandering have also caused a decline in the establishment of *Populus–Salix* forests along the Missouri River in North Dakota (Johnson *et al.*, 1976; Reily and Johnson, 1982; Johnson, 1992) and in Montana (Scott *et al.*, 1997).

In meandering river systems, the effects of reduced *Populus–Salix* recruitment rates are slow to appear in the general floodplain vegetation, unless accompanied by increases in vegetation of contrasting form such as *Tamarix* and *Elaeagnus* (Knopf *et al.*, 1988; Johnson *et al.*, 1995). Detectability of vegetation change is further reduced by the high natural variation in stream flow and tree recruitment (Scott *et al.*, 1996), longevity of *Populus* and *Salix* trees established prior to regulation and slow replacement by later successional species. Johnson (1992) estimated that almost two centuries would be required for riparian vegetation to reach a new post-dam steady state along the Missouri River.

Water development has produced the opposite effect on forest regeneration along braided, sand-bed rivers in semi-arid regions (Schumm and Lichty, 1963; Williams, 1978; Nadler and Schumm, 1981; Johnson, 1994). For

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example, in the Platte River of the central Great Plains, reduced flows caused major expansion of *Populus–Salix* woodlands by favoring tree recruitment and improving seedling survival in the river bed (Johnson, 1994). The river has been transformed from one with wide channels and scattered woodlands in pre-development times to one with much narrower tree-lined channels and extensive riparian forest on its floodplain.

The response of the Platte River to stream flow regulation was both rapid and extensive. For example, between the 1930s and 1950s approximately half of the active channel (but as much as 90% in some reaches) became wooded (Johnson, 1994). Woodland expansion, however, was short-lived. Johnson (1994) found that the area of active channel and woodland came into rough balance for most reaches in the 1960s; the only statistically significant changes between the 1960s and 1980s were increases in channel area for some reaches. Adjustments by other biotic components to river regulation have been described by Petts (1987).

The stabilization of active channel area led Johnson (1994) to propose that the river had adjusted to the water development effects and had reached a state of dynamic equilibrium or steady state. The relative stability of active channel and perennial vegetation in the Platte River after the 1960s fits the classic, narrowly oscillating pattern expected for rivers in dynamic equilibrium (Schumm and Lichty, 1965; Morisawa, 1968; Richards, 1982). The term 'dynamic' implies that the balance may change between drought periods, when vegetation would increase, and flood periods, when channel area would increase, but that the long-term (i.e. decadal) average for active channel area should remain relatively constant unless there is a change in water use or climate. This concept is analogous to the shifting mosaic steady state of Bormann and Likens (1979), in allowing for turnover of vegetated patches under equilibrium conditions; i.e. young patches may regenerate in some places as older patches are eroded in others, but that the total area of open channel or floodplain vegetation changes little. An apparent equilibrium in the Platte River has developed because active channel area has come into balance with stream flow, thereby reducing tree recruitment and increasing tree mortality (Johnson, 1994).

While the equilibrium issue is of conceptual importance in characterizing the response of rivers to regulation, the channel–woodland balance has special significance for certain rare or uncommon migratory birds that utilize wide, open channels of the Platte River [e.g. whooping crane (*Grus americana*), piping plover (*Charadrius melodus*), least tern (*Sterna antillarum*); FWS 1981].

The purpose of this research was to evaluate Johnson's (1994) conclusion that channels of the Platte River had largely completed the transient phase of adjustment to stream regulation (Petts, 1987) and were in dynamic equilibrium. This was done by remeasuring channel and woodland area in the Platte River on 1995 aerial photographs, nine years after Johnson's (1994) last measurements. Interpretation of the causes of the changes measured from aerial photographs was augmented by field measurements of tree recruitment and mortality and by a GIS (geographic information system) analysis of patch-scale vegetation dynamics based on computer map overlays.

METHODS

Aerial photograph analysis

Nine Platte River reaches, named for their nearest town/city, were sampled and analysed (Figure 1). Six of these had been analysed by Johnson (1994) with measurements made at approximate 10-year intervals between 1938 and 1986 (i.e. long-term reaches). Several of these reaches are within the critical habitat area (Figure 1) designated by the US Fish and Wildlife Service as migratory habitat for whooping cranes (FWS, 1981). Three new reaches extended the present analysis further downstream (below the critical habitat area) for the most recent decade (1986–1995 and 1989–1995, i.e. short-term reaches). These reaches were added to evaluate the potential effects of habitat alterations between reaches 7 and 8 (Figure 1) on the open channel and the woodland balance of unaltered areas immediately downstream. Woody vegetation on islands and outer banks has been cleared and many islands removed by plowing and disking in this managed reach to increase open channel area for crane roosting (Currier, 1984; Currier and Stubbendieck, 1985). Vegetation management in this reach was initiated in the early 1980s and has continued at varying intensity and extent to the present.

The largely unmanaged Wood River-East reach is just upstream of the area of concentrated vegetation management (Figure 1), hence it is referred to as the upstream 'reference'. The Grand Island reach (comprising

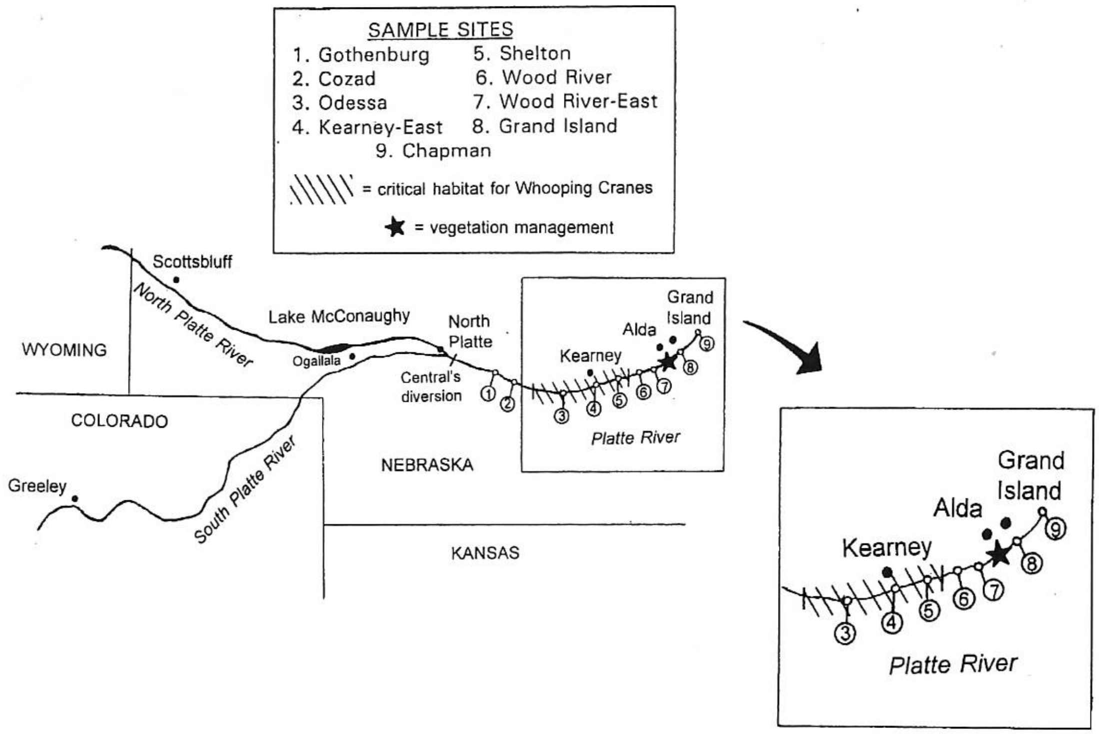

Figure 1. The study area along the Platte River, Nebraska. The hatched area was designated by the US Fish and Wildlife Service as critical habitat for migrating whooping cranes. The star identifies the reach in which large areas of riparian vegetation have been cleared and islands removed to increase unobstructed channel width for roosting cranes

three channels measured separately) occurs just downstream of the managed area, but was not cleared or disked. Thus, it served as a 'treatment' reach in the analysis. Chapman (downstream 'reference') is further downstream of the managed area than the Grand Island reach, with any effects of the management probably attenuated.

The photogrammetric methods of Johnson (1994) were followed in this analysis, including the use of growing season and black-and-white aerial photographs at a scale of 1:12000. Briefly, reaches were sampled by positioning the 1986 sample grid on the 1995 photographs using common control points in AUTOCAD (Autodesk, 1985). At each grid intersection one of five possible cover types was recorded: *open channel* (mostly sand and/or water, without well-established, perennial vegetation), *low-growing vegetation without trees* (mostly short, perennial vegetation or willow thickets), *sparse forest* (widest spaced trees), *dense forest* (densely spaced trees with overlapping crowns) and *open land* (tended, treeless land beyond the high banks of the river or on large islands between river channels—mostly land under agriculture).

A change matrix (Johnson, 1994) was calculated for each pair of photographs for each reach (1986 and 1995; 1989 and 1995 for Chapman). This matrix summarized all shifts in cover categories that occurred during the period and enabled calculation of gross and net changes in channel or woodland area and overall erosion rates (i.e. average annual percentage of vegetated points that converted to open channel during the period).

A second method was used to measure and display changes in open channel and woodland conditions in the Platte River over the past decade. Specifically, a GIS (PC ARC/INFO; Environmental Systems Research Institute, 1991) was used to map changes in a 2 km long subsection (192 ha) of the 6.2 km long Shelton reach, using the same aerial photographs used in the AUTOCAD analysis. The GIS analysis enabled comparison of the 1986 and 1995 maps in order to measure total area changes by cover type, locate areas of change and determine patch turnover.

Tree demographic analysis

Recruitment and mortality of *Populus* and *Salix* have been monitored in the Odessa and Shelton reaches of the Platte River since 1985 (Johnson, 1994). The demographic analysis was conducted to relate seedling mortality to environmental conditions statistically, and particularly to seasonal patterns of stream flow and weather. In this paper, results from the monitoring network assist in interpreting the effects of a significant flood in 1995 on the balance between open channel and woodland area.

Briefly, sample plots were selected using a stratified random design to include the widest range of site conditions in which *Populus* and *Salix* seedlings became established in the river channels. New sample plots were added to the network each year in mid-July after the seed germination period. All established sample plots were revisited and seedlings recounted each season (May, July, September). Plots were revisited in January and ice measurements made but seedlings were not recounted. Seedling mortality was calculated seasonally. See Johnson (1994) for details regarding the seedling monitoring protocol and past statistical relationships between seedling mortality and environmental factors.

RESULTS

Channel area dynamics in long-term reaches

Open channel area in the past decade for the six long-term reaches generally continued the patterns established earlier (Johnson, 1994). Channel area did not decline in any reach (Figure 2). Rather, channel area either changed little, or increased, between 1986 and 1995. Thus, the reversal of the initial trend of open channel area loss, which began for most reaches in the 1960s, has continued now for three decades.

The reversal has been greatest for the upper Platte River reaches—Cozad and Gothenburg (Figure 2). The open channel area in these reaches in 1995 was 3–4 times greater than at its lowest point in the late 1950s and 1960s. In fact, channel area in 1995 was comparable to 1951 levels (Figure 2).

The central Platte River reaches exhibited only small increases in open channel area between 1986 and 1995, continuing the trend started in the 1960s. Channel area in 1995 for most of these reaches occupied from several to 10% more of the floodplain area than at its lowest point in the 1960s.

Historical patterns in the rate of channel area change are more clearly shown by plotting the average annual change (gains and losses) since the 1930s (Figure 3). The general pattern was a shift over time in the location of the curves from the lower left portion in each graph (zone of decreasing channel area) early in the period, to the upper right (zone of increasing channel area) later in the period. The curves generally moved above the 0 change line (a reversal from losses to gains in channel area) in the 1960s. While all curves (except Cozad) were above the 0 change line for 1986–1995, the rates of channel area increase generally were less than for the previous time period (Figure 3).

Reaches within the two zones differed substantially in total channel width (sum of all channels). The upper Platte River reaches (Cozad and Gothenburg) ranged from 88–115 m wide in 1986, while the central Platte River reaches (Odessa, Kearney-West, Shelton, Wood River) were wider, ranging from 243–293 m (Johnson, 1994). In general, the narrowest reaches in 1986, which were closest to major upstream water diversions, increased the most between 1986 and 1995; the correlation between initial channel width and percentage increase in channel area was negative, as expected ($r = -0.20$), but not statistically significant ($p = 0.15$).

Channel area changes—last decade

GIS analysis. The summarized results from the GIS analysis of the Shelton reach essentially matched those of the AUTOCAD analysis. Open channel area increased by 7.6% (from 32.8 to 35.3% of total area) and perennial vegetation decreased by 3.7% (from 67.2% to 64.7% of total area) over the period in the GIS analysis, while open channel area in the larger reach increased by 5.6% in the AUTOCAD analysis.

Visually, the patterns of channel structure and vegetation distribution were very similar between the 1986 and 1995 GIS maps (Figure 4). This was especially true on the left half of the maps associated with the widest single

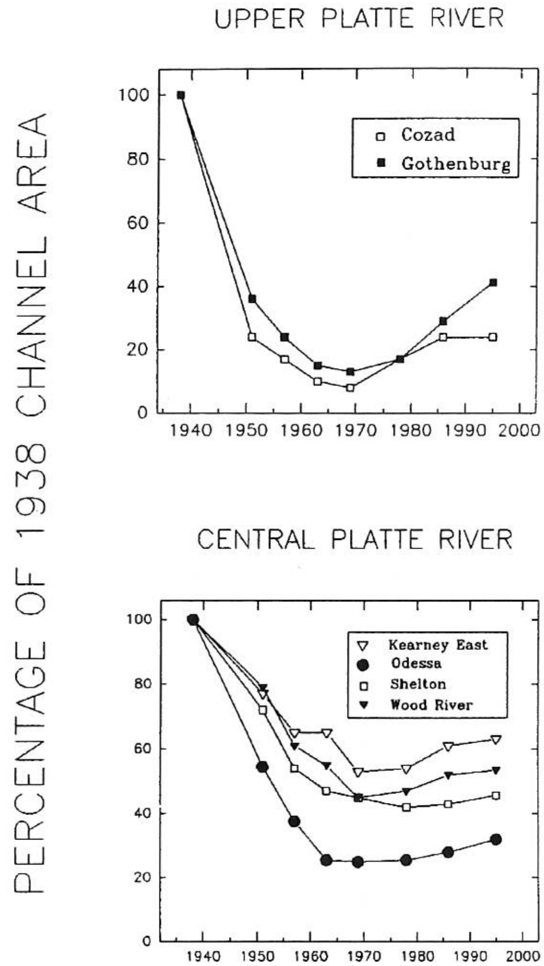

Figure 2. Open channel area changes (%) for upper and central Platte River reaches between 1938 and 1995 based on aerial photographs. Channel area in 1938 set at 100%

channel. Closer examination of the right side of the maps, however, which included many islands and small channels, revealed areas of significant change.

All shifts that occurred between channel and vegetation cells during the period 1986–1995 are shown in Plate 1. Shifts from vegetation to open channel as a result of erosion are shown in orange, while those from open channel to vegetation due to succession are in yellow. Only the larger areas that shifted categories are shown; a threshold distance tolerance of 7.5 m was used in overlaying the two coverages in order to reduce overlay error and show only areas of significant change.

The amount of turnover of open channel and vegetation during the period was approximately 6% of the map area. The map reveals considerable exchange between these categories despite relatively stable proportions over time (Plate 1). Thus, new vegetation patches were becoming established in some places (in low-flow years), while vegetation was being eroded in others (in moderate- and high-flow years). Most change occurred in multi-channelled areas with a high density of islands; the widest channel on the Shelton map (*c.* 325 m) widened slightly during the period (Plate 1). Increases in open channel area mostly occurred as the result of erosion along high banks bordering wide reaches, between small islands and of small islands.

AUTOCAD analysis. During the latest measurement period [1986 (or 1989) to 1995], open channel area in all reaches upstream of and including the Wood River reaches increased slightly or was stable (range 0–55%,

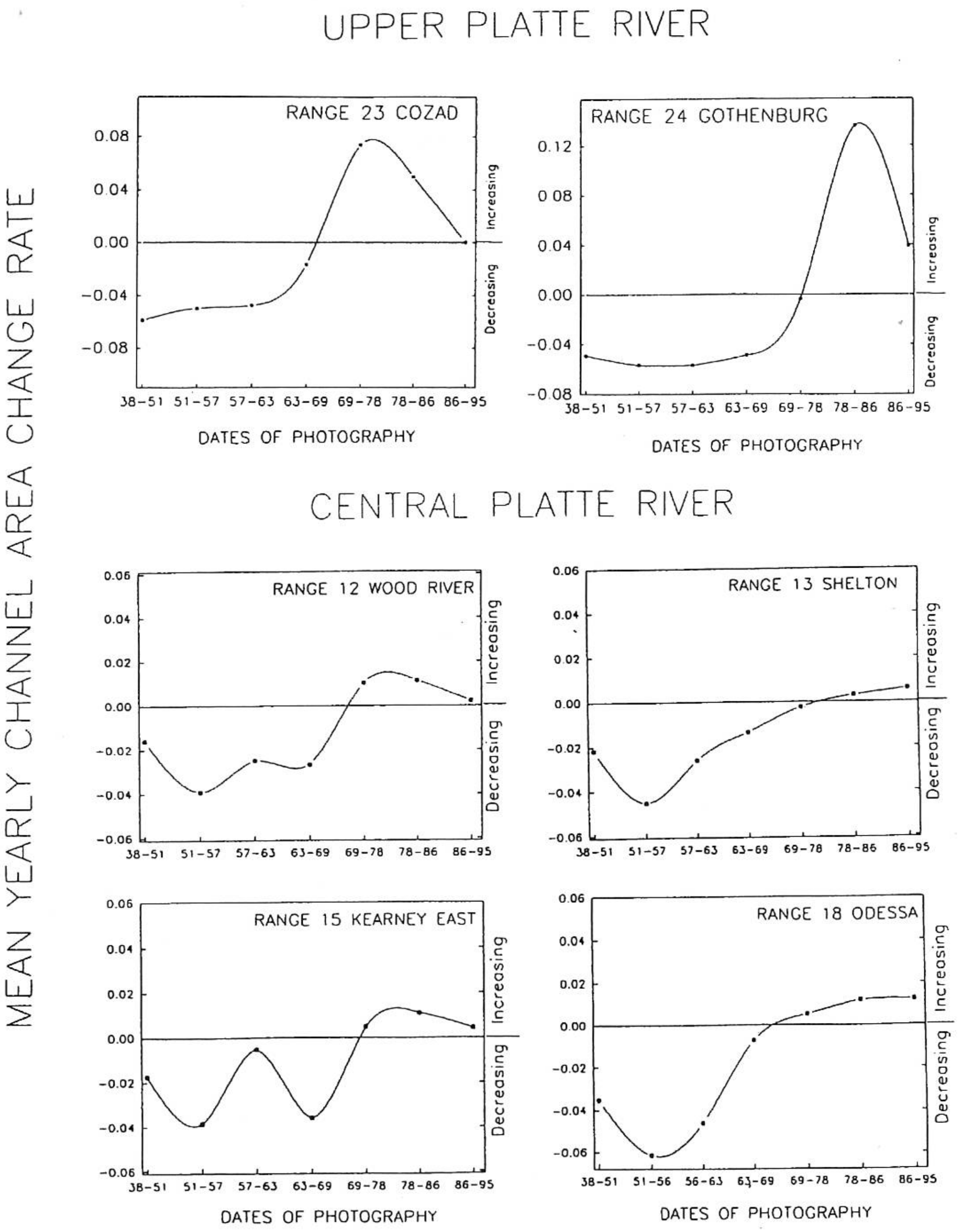

Figure 3. Mean yearly channel area change rate for upper and central Platte River reaches. Negative values indicate decreasing area, while positive values indicate increasing area

median = + 1.9%; Table I). This set of sample reaches represents approximately 200 km of the Platte River, from near its origin at North Platte downstream to just below Wood River and including all of the 75 km long critical habitat area (Figure 1).

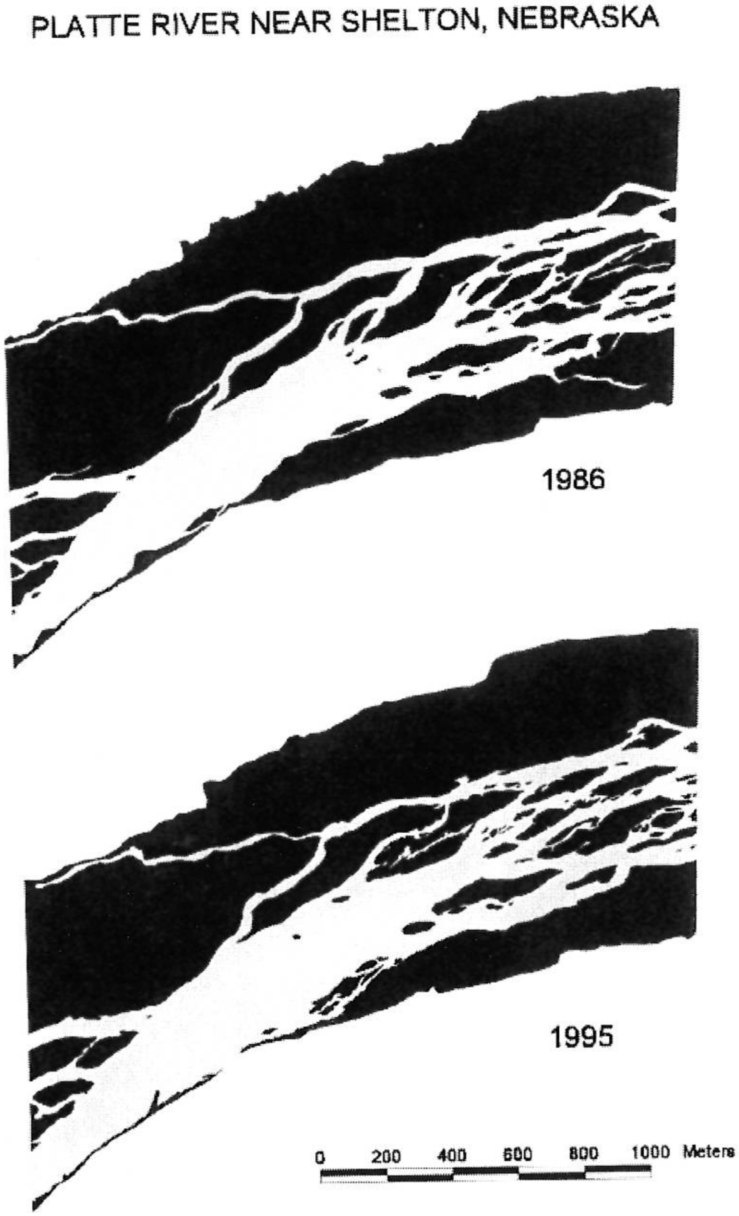

Figure 4. GIS map of open channel (light) and vegetation (dark) in 1986 and 1995 for a 2 km subsection of the Shelton reach of the Platte River, Nebraska

Channel area changes downstream of the Wood River reaches, and the approximately 15 km long managed section of the Platte River (Alda to Grand Island; Figure 1), differed substantially from the reaches upstream. The upstream 'reference' site (Wood River-East) showed a slight channel area increase between 1986 and 1995 (1.2% change; Table I); however, both reaches downstream showed declines in channel area. Channel area in the 'treatment' reach at Grand Island declined by 9.3%, while the Chapman reach, further downstream (downstream 'reference'), declined by 4.5% (Table I).

The channel area decline of 9.3% at Grand Island was the sum of changes in three channels (south, middle, north). When summarizing the changes by channel, it was apparent that all of the channel loss occurred in the

Table I. Change in channel area at sites on the Platte River, as measured in AUTOCAD, from 1986 (or 1989) to 1995

Site name	% of 1938 channel area		1986/1989 % channel	1995 % channel	Change in channel area 1986/1989 to 1995 (%)
	1986	1995			
Chapman	–	–	35.0	33.4	− 4.5
Grand Island	–	–	21.0	19.1	− 9.3
Wood River-East	–	–	25.7	26.0	+ 1.2
Wood River	52.0	53.5			+ 1.9
Shelton	43.0	45.6			+ 5.6
Kearney-East	61.0	63.0			+ 4.2
Odessa	28.0	32.0			+ 12.5
Cozad	24.0	24.0			0.0
Gothenburg	29.0	41.3			+ 54.8

south and widest channel, which underwent a 20.6% decline. Channel area in the middle channel increased by 25%, while it was stable in the north channel during the period. These channels coalesced immediately downstream of this reach forming a single, major channel at Chapman.

Stream flow and seedling mortality patterns, 1986–1995

The effects of water development on stream flow in the South Platte, North Platte and Platte rivers have been well documented and reported elsewhere (USGS, 1983; Hadley *et al.*, 1987; Johnson, 1994). Generally, the effect of water development projects on stream flow stabilized following the end of the major dam-building period on the North Platte River in the early 1940s (Figure 5).

Only one significant flood occurred during the 1986–1995 photograph period. The flood in 1995 was of moderate post-development magnitude (Figure 5). The dominant characteristic of flow during the period 1986–1995 was the long, continuous string of low-flow years, almost as low as, but of longer duration than the drought years of 1953–1956, when woodland expanded at record rates in the Platte River (Johnson, 1994).

Historically, the rate of woodland expansion has been negatively correlated with stream flow in June (Johnson, 1994). Woodland expansion rate has been low (or negative, indicating expanding channel area) during periods of high mean June flow, while it has been high during periods with low June flow. Open channel and woodland in the central Platte River were in approximate balance during periods when mean June flow approximated 75–85 cms. Thus, Johnson (1994) concluded that long-term average flows of this magnitude would be needed to maintain channel/woodland equilibrium in the future. Because of the numerous low-flow years in the 1986–1995 series (Figure 6), June flow averaged only 62 cms at Kearney, considerably below the flow estimated to maintain open channel area.

Seedling mortality measured in the Platte River at Shelton during the photograph interval varied markedly between seasons and years. Mortality ranged from a low of near 0 in spring 1994 to a high of 98% for winter 1985–1986 (Figure 7). Generally, mortality was highest in winter because ice cover and moving ice during break-up increased the hydrogeomorphological action of the river (greater erosion and sedimentation) (Johnson, 1994). The seedling data indicate consistently high seedling mortality across years. There were no periods longer than a year with consistently low mortality; low mortality in a given season was usually followed by high mortality the next season or two. These mortality patterns indicate generally poor conditions for seedling survival in the Platte River during this period, with extremely low probability that a seedling would survive the 3–4 growing seasons necessary to become highly resistant to erosion and sedimentation.

The 1995 flood produced the second highest seedling mortality measured in any growing season since 1985 (Figure 7). For example, seedling mortality was 91% at the Shelton demographic site, almost as high as the rate in the winter of 1985–1986 (98%), the record high for the 10-year-long data set (Figure 7). Prior to the 1995 flood, the highest seasonal mortality rates had almost always occurred in winter. The extremely high mortality caused by the 1995 flood was even more significant because of the age and size of the seedling population present in the

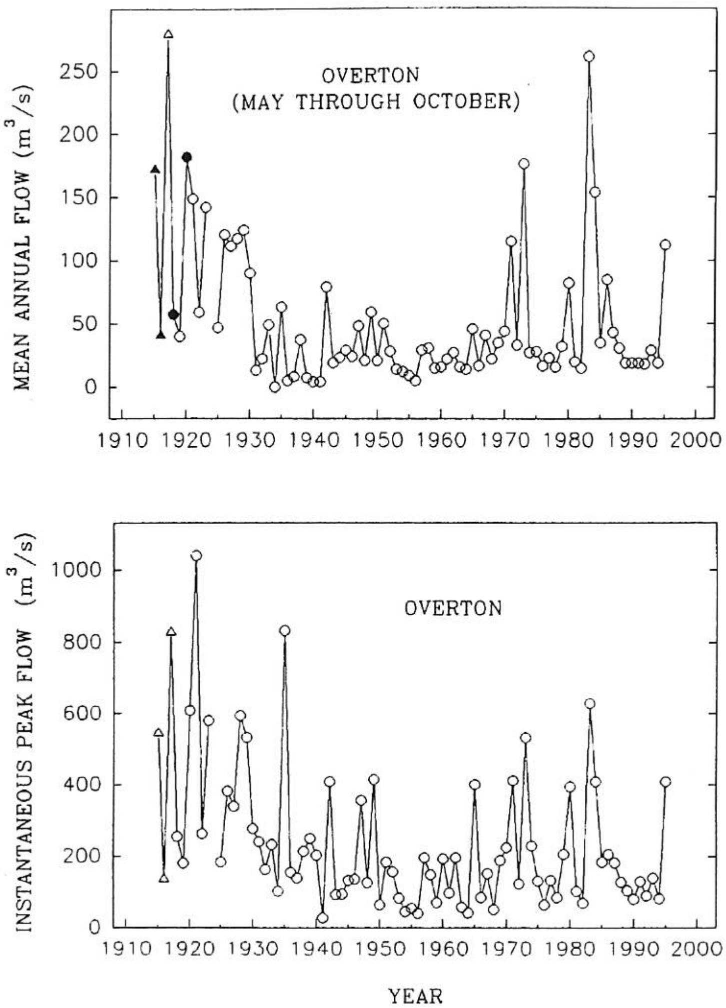

Figure 5. Mean annual flow and instantaneous peak flow at the Overton, Nebraska USGS gauge for the period of record. Triangles indicate data from the Elm Creek gauge (near Overton) and circles indicate the Overton gauge data. Darkened symbols denote years with incomplete data from May to October. No data were available for 1924. Data after September 1994 are provisional

river at the time. The 1985 population was mostly one year-old seedlings, while the 1995 population included seedlings from 1–4 years-old. Johnson (1994) found that seedling mortality was inversely related to seedling age.

DISCUSSION

Channel–vegetation balance

The channels of the Platte River appear to have adjusted to water development effects from large dams and diversions constructed mostly on the North Platte River during the first half of this century. The river responded to flow reductions by rapid expansion of cottonwood and willow woodland and corresponding channel narrowing, particularly in the 1950s. By the late 1960s, however, open channel area had ceased to decline. Since that time, open channel area in most Platte River reaches has either increased or remained relatively stable. This general equilibrium was reached because water coverage and depth increased in the remaining active channel as portions were deactivated by new woodland (Johnson, 1994). Greater coverage of sand-bars in the remaining active channel both reduced recruitment and increased mortality of tree seedlings, thus slowing woodland

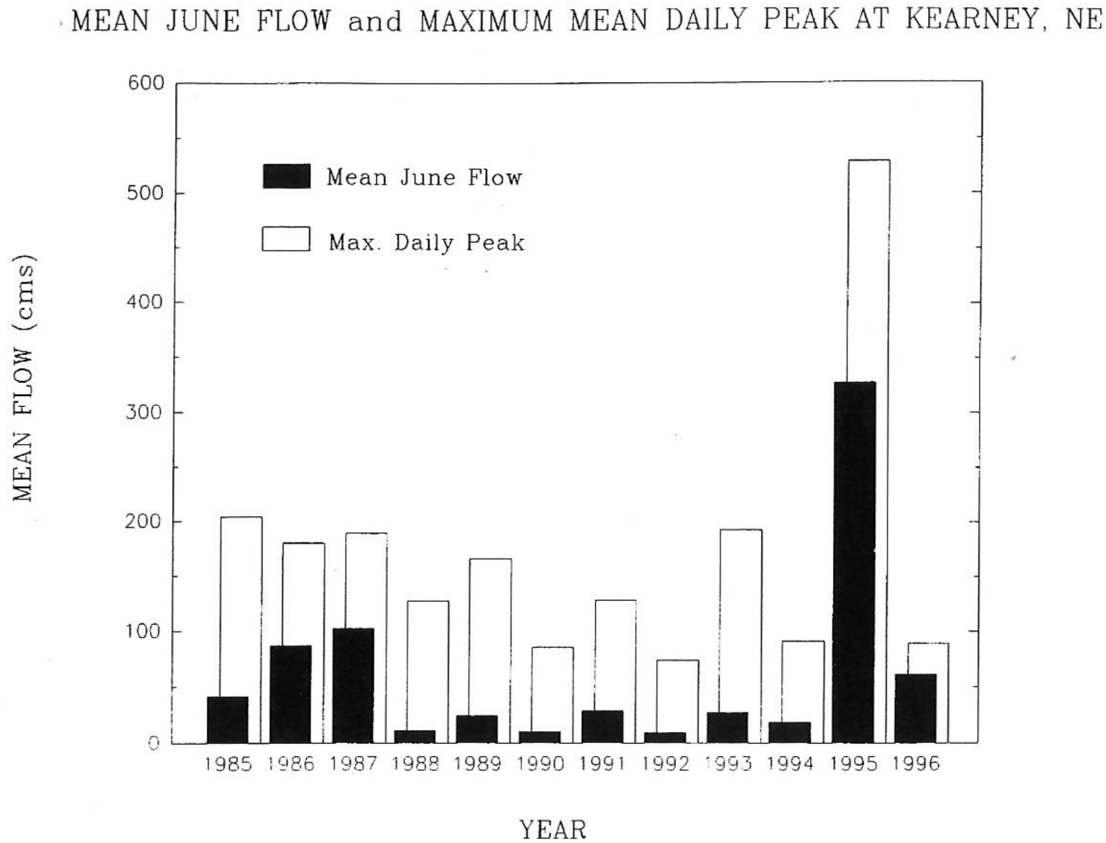

Figure 6. Mean June flow and maximum mean daily peak flow at the Kearney USGS gauge between 1985 and 1996. Data for 1996 are provisional

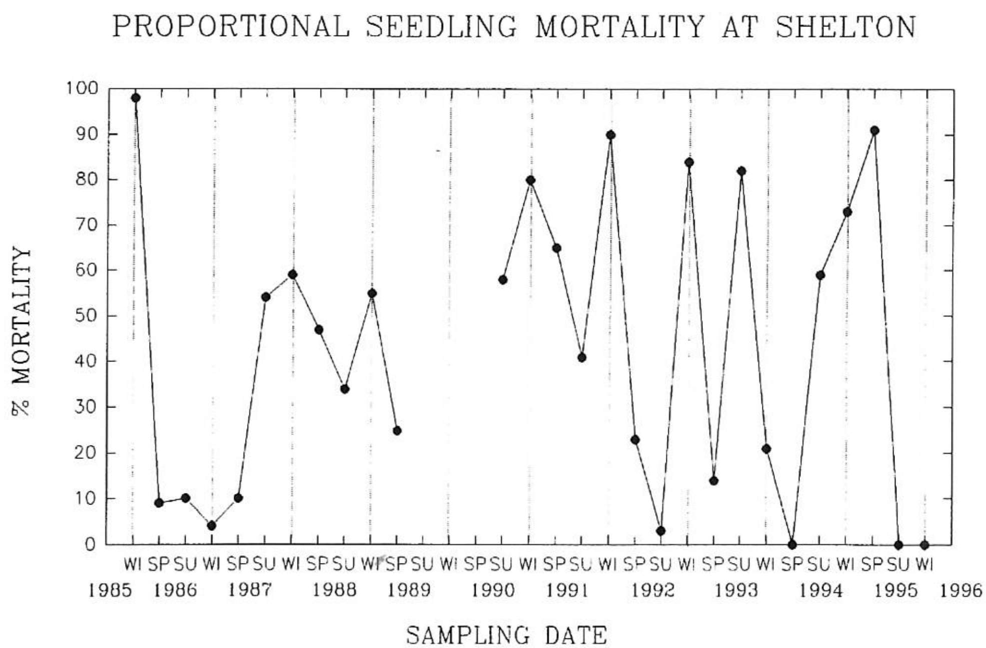

Figure 7. Seasonal seedling mortality rates in the Platte River at Shelton between 1985 and 1995

expansion. The reversal in channel area dynamics, from sharp declines before the 1960s to small increases since, does not appear to have been caused by correspondingly large changes in stream flow (Figure 5).

Channel area maintenance or expansion has continued in the past decade despite a low flood frequency (one overbank flow in 1995) and the occurrence of consecutive low annual flows (1987–1992, Figure 6). Moreover, mean June flow in the past decade has averaged approximately 62 cms, lower than that previously thought to be required to prohibit further woodland expansion (75–85 cms; Johnson, 1994).

This greater resiliency of open channel habitat may be related to the maturation of the floodplain vegetation. Floodplain surfaces initially vegetated in the 1930s and 1950s now may be more prone to erosion. Erosion rates calculated from the AUTOCAD matrices support this relationship. The rates at which vegetated sample points (low vegetation, sparse and dense forest) collectively converted to open channel have generally increased in the past three decades, from 2% of the starting vegetated sample points between 1969 and 1978, to 3.5% between 1978 and 1986, to 4.7% between 1986 and 1995.

The greater erodibility of these, mostly wooded, surfaces as they reach maturity may be the result of higher floodplain surfaces caused by aggradation during floods, leading to steeper bank angles and to a decline in protective vegetation in the forest understorey and along banks. Young woody vegetation on low sand-bars is much more resistant to erosion than is older woodland on higher surfaces built up over time by overbank flow and sedimentation. Young vegetation is characterized by high stem density (often willows that reproduce vegetatively) and a network of dense roots and rhizomes. Newly formed sand-bar edges or banks are low angled, which makes them highly resistant to erosion by bank collapse. As vegetation develops, these surfaces become higher and banks more steeply angled and less protected by older, senescing plants. Given the naturally friable soils in the Platte River (high sand content, no clay, little silt), once vegetation becomes less effective in protecting banks, erodibility increases dramatically. Changes in floodplain erodibility may also explain the progressive increases in channel area in the South Platte River over the period of photographic record (Johnson, 1994) in the absence of any significant changes in streamflow.

This phenomenon has been observed by geomorphologists working on other river systems (Hickin, 1984; McKenney *et al.*, 1995). In particular, McKenney *et al.* (1995) reported that young, dense vegetation can contribute substantially to flow resistance and sedimentation. However, as vegetation ages and stem density decreases, vegetation becomes less effective at providing flow resistance; therefore, potential for scour within a vegetation patch increases with age. Their observations support a progressive decrease in the geomorphological threshold for sand-bar erosion 5–20 years after vegetation establishment.

The flood of 1995 influenced channel–woodland area dynamics during the past decade by removing some vegetation, but did not dominate them. Were this flood the only event removing young woody vegetation from the channel, many or all reaches may have shown channel area declines during the period 1986–1995. This is because of the very long gap between floods, which would have, in the absence of other mortality factors, enabled tree seedlings to reach ages of 5 + years before experiencing a significant flood. Trees of this age and size would not have been removed by a flood of moderate magnitude like the 1995 event. Clearly, the combination of small, naturally occurring peak flows in important seasons (June to reduce recruitment, July–August to kill fragile, young-of-the-year recruits, and winter to kill older and larger seedlings by ice action) acted during the last decade, with the 1995 flood, to limit new woodland establishment and to erode mature woodland.

Channel disequilibrium near Grand Island

Channel area loss near Grand Island appears to have a local cause, since channel area in all upstream reaches (Wood River-East to Gothenburg) was stable or increased during the period and the magnitude of the loss several km downstream of the Grand Island reach, near Chapman, was much attenuated. A probable cause of the increased vegetation near Grand Island was localized channel aggradation or a change in the flow split among channels caused by sediment liberated from upstream vegetation removal and mechanical treatment. If this is a non-equilibrium response (i.e. sediment is accumulating and not passing through this reach), the narrowing may be only temporary because the channel would be too small to carry the water and sediment load.

Although upstream vegetation management is a strong candidate for causing localized vegetation expansion and open channel area decline near Grand Island, other causes cannot be ruled out without further investigation.

For example, channel degradation caused by a sediment reduction could have caused a similar response by vegetation. In such a case, down-cutting of the channel could have exposed more of the unvegetated channel, improving the potential for tree recruitment and vegetation expansion. The long distance to upstream sediment trapping structures (almost 250 km to Central Nebraska Public Power and Irrigation District's diversion dam, and 325 km to the closest in-channel reservoir, Lake McConaughy on the North Platte River) and relative stability of open channel area both above and below the managed reaches near Grand Island argue against sediment undersupply and channel degradation. Channel cross-sections should have been established to monitor changes in channel geometry upstream and downstream of managed reaches. Identifying the cause of the disequilibrium at Grand Island is important because channel area losses in unmanaged reaches may be counterbalancing gains in managed reaches, reducing the overall effectiveness of vegetation management activities in providing wider unobstructed channels for migratory cranes. Moreover, if management turns out to be a causal factor, management methods need to be re-evaluated before they are prescribed more widely in the Platte River. Otherwise, vegetation management could initiate channel area declines downstream in unmanaged reaches that have been stable or modestly increasing for three decades or more.

CONCLUSIONS

Our knowledge of the effects of flow regulation on riparian vegetation in alluvial rivers is mostly limited to the initial stages of impact. The effects are either extremely slow to develop, as in the case of many meandering-type rivers, or measurements have been made only over a short period of time. The Platte is one of a few rivers that may have reached a new equilibrium after adjusting to past effects of channel narrowing and woodland expansion. This has occurred because of the large magnitude of water development early in the settlement history of the Great Plains, the relatively stable post-development reservoir and diversion operations and the high sensitivity of braided rivers to changes in hydrology and sediment supply. The youngest, large diversion dam was constructed on the Platte River over 50 years ago and much longer ago for the North and South Platte rivers. Thus, these rivers have had from 50–100 years to adjust to flow alterations.

After undergoing large reductions in channel area and increases in riparian woodland in the 1930s and 1950s, both had remained fairly stable between the 1960s and 1980s. Results from the past decade indicate continued stability in channel and woodland area, with increases in channel area in some reaches. The general equilibrium in the past decade was maintained despite lower flows than previously thought necessary to keep the 1986 balance in open channel and woodland area. This may have been possible because of increased erodibility of vegetated surfaces as they have aged. The 'middle-aged' forests that now dominate the Platte River floodplain are on higher surfaces, have high-angled banks and have less protective vegetation than did younger stages, all resulting in greater potential for erosion and movement in the direction of channel area equilibrium.

Of concern is the possibility that vegetation clearing on channel islands and banks may have upset the recent equilibrium in channel and woodland area by locally oversupplying the river with sediment and thus initiating recent channel narrowing and woodland expansion. While cleared areas have more open channel area, reaches immediately downstream have less, suggesting that clearing may not be an ecosystem-based solution (Stanford *et al.*, 1996) to the past channel-narrowing problem in the Platte River.

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