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Ecological strategies for managing tamarisk on the C.M. Russell National Wildlife Refuge, Montana, USA

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Abstract

Tamarisk (*Tamarix ramosissima*) is an introduced shrub or small tree associated with the loss of biological diversity in riparian habitat throughout much of western North America. Control measures are often expensive and ineffective, so land managers need site-specific information to guide cost-effective integrated management strategies. We sampled 12 randomly selected tamarisk-infested inlets on Fort Peck Reservoir on the C.M. Russell National Wildlife Refuge stratified by stream basin size. At each site we sampled 2–5 stands of riparian vegetation, recording plot elevation, canopy cover of vascular plants, density of woody species and age estimates for representative woody plants. Tamarisk plants 1–3 years old were abundant in the drawdown zone along the shore of Fort Peck Reservoir. The lack of plants older than three years indicates that tamarisk in the drawdown zone were destroyed during a recent two summers of inundation and suggests that three months of inundation will kill tamarisk plants. The oldest (17–22 years) and largest tamarisk plants in the study area were found in the full-pool zone and were recruited in periods of significant drawdown following high-water years. Tamarisk was uncommon in cottonwood and silver sagebrush stands on stream terraces above full pool. Only the largest streams in our study area appeared capable of supporting tamarisk and significant native riparian vegetation. Tamarisk plants at or above full pool level should be removed in these drainages to prevent upstream invasion and loss of native species. The level of the reservoir should be raised to the level of full pool for three consecutive months during the growing season every 3–5 years to prevent development of extensive stands of tamarisk in the drawdown zone capable of producing large quantities of seed.

Keywords: *Tamarix*; Saltcedar; Regulated river; Integrated pest management; Invasive species; Dams; Riparian

1. Introduction

Invasive exotic plants threaten the biological values of natural areas such as national parks and wildlife refuges (Cole and Landres, 1996; Usher, 1988). Plants like tamarisk, purple loosestrife and melaleuca can radically alter species composition and ecosystem functions (de Waal et al., 1994; Drake et al., 1989; Luken and Thieret, 1997). Weed infestations are often extensive, occupying available habitat over thousands of hectares. The large size and inaccessibility of many nature reserves make control difficult and eradication impossible. Moreover, the ability of land managers to combat invasive plants is often limited by funding constraints.

Integrated pest management (IPM) is a conceptual strategy for choosing control actions based on predicted ecological consequences. IPM principles state that the presence of a pest species does not necessarily justify control actions. Controls are imposed only as required to protect economic and/or ecological values (Bottrell, 1979). The continued existence of potentially harmful species at tolerable levels is implicit in IPM strategies. IPM holds the promise of ecologically sound and economically feasible weed control. As such, IPM strategies are appropriate for large nature reserves.

Tamarisk or saltcedar (*Tamarix ramosissima, T. chinensis* and hybrids; Gaskin and Schaal, 2002) is a shrub or small tree native to Europe and Asia that has become a dominant plant along rivers and streams in the

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southwestern US (Robinson, 1965). It has been present in Montana since at least 1960 (Swenson et al., 1982) and has been found along most major rivers in the eastern half of the state (Grubb et al., 1997). Tamarisk is adapted to colonizing moist, barren soil along streams (Everitt, 1980). It is also reported to invade the shorelines of lakes and reservoirs (Brotherson and Winkel, 1986; Duncan, 1997; Hudson, 1999; Tallent-Halsell and Walker, 2002) and wet meadows, especially where soils are saline (Carman and Brotherson, 1982). Seeds are produced throughout the growing season and germinate in wet soil, quickly sending down deep roots (Everitt, 1980; Merkel and Hopkins, 1957). It is a drought-tolerant, facultative phreatophyte, capable of surviving reductions in ground water levels detrimental to native cottonwood and willow because it obtains moisture from unsaturated soil as well as groundwater (Busch and Smith, 1995; Cleverly et al., 1997). Tamarisk is an early successional species with dispersal strategies and habitat requirements similar to native cottonwood and willow (Bradley and Smith, 1986; Merkel and Hopkins, 1957; Stromberg, 1997). It can replace the native cottonwood and willow where natural flow regimes or water chemistry have been altered (Busch and Smith, 1995; Cleverly et al., 1997). Tamarisk invasion is associated with lower native plant and small mammal diversity (reviewed in Brock, 1994) and may alter the avian composition of riparian communities (Ellis, 1995; Hunter et al., 1988), with insectivores and frugivores being more common in native vegetation (Cohan et al., 1978). The many adverse effects of tamarisk infestation have caused it to be considered one of the ten worst weeds in the US (Grubb et al., 1997) and listed as a noxious weed in Montana.

Large infestations of tamarisk occur along the 2600 km-long shoreline of Fort Peck Reservoir on the Charles M. Russell National Wildlife Refuge. Most infestations occur along the south shore in bays and inlets where drainages enter the reservoir (Pearce and Smith, 2003). Tamarisk can be controlled by herbicide treatment under some conditions (Duncan, 1997; Stevens and Walker, 1998). Inundation for periods of three months or more is also reported to kill tamarisk (Warren and Turner, 1975). However, control measures are often expensive and ineffective (Grubb et al., 1997; Stevens and Walker, 1998). Land managers need site-specific information on tamarisk ecology that will guide cost-effective integrated management strategies and prioritize habitats for control.

Traditional chemical or mechanical treatments will be possible for only a small fraction of the infestations along Fort Peck Reservoir because of funding constraints, so an IPM approach is warranted. Control by manipulating reservoir levels may be possible for some shoreline stands. Costly control measures should be aimed at areas where tamarisk poses the greatest threats to native species and communities. The purpose of our study was to provide descriptions of habitats and geomorphologic settings threatened by tamarisk invasion. Knowing which stands can be killed by inundation and which stands most threaten native biological diversity will aid managers in planning integrated tamarisk management. Specifically we (1) determine the types of vegetation in which tamarisk occurs or is likely to occur, (2) provide information on the age of tamarisk stands and how they are likely to alter native plant communities, (3) develop criteria for managers on how to identify stands that are most likely to adversely affect native plant communities and the biological diversity they support, and (4) determine which hydrologic regimes destroy tamarisk at which elevations.

2. Methods

2.1. Study area

Fort Peck Reservoir is a 215 km-long impoundment of the Missouri River in northeast Montana. Fort Peck Dam was completed in 1940. The reservoir covers an area of 97,100 ha and has a shoreline of approximately 2575 km. Elevation of full pool is 685 m. Our study area was the south shore of Fort Peck Reservoir east of the mouth of the Musselshell River where most significant populations of tamarisk were found in 2000 (Pearce and Smith, unpublished data).

Fort Peck Reservoir is bounded on the south by steep bluffs and badland topography eroded from beds of Cretaceous-age sandstones and calcareous marine shales of the Hell Creek formation. Soils are sandy to clayey and calcareous (Veseth and Montagne, 1980). Streams entering the reservoir in the study area have drainage basins of more than 750,000 ha to less than 100 ha. Most streams are intermittent or ephemeral. All drainage basins occur at low elevations where winter snow pack is minimal, and most flood events occur during the growing season.

Climate of the region is semi-arid and continental. Jordan, at 795 m elevation, is the closest weather station, 37 km south of our study area. Mean annual precipitation between 1950 and 1980 was 318 mm with more than half (165 mm) falling in June through September. Snow cover was generally light with only 52 mm of precipitation falling between November and March. Mean January minimum and July maximum temperatures were −17.3 and 31.8 °C, respectively (NOAA, 1982).

Upland vegetation in the study area is shrub-steppe dominated by sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and perennial grasses including needle-and-thread (*Stipa comata*), western wheatgrass (*Agropyron smithii*) and blue grama (*Bouteloua gracilis*). Vegetation of uppermost river terraces is dominated by silver sagebrush (*Artemisia cana*) and western wheatgrass. Groves of Great Plains cottonwood (*Populus deltoides*) occur along some of the larger tributaries. Moist, mineral soil is exposed along the margins of the reservoir when water level is below full pool. This drawdown zone is extensive in "inlets" where relatively flat-bottomed stream valleys have been inundated. The short-lived vegetation of these drawdown zones is composed of numerous early-seral species including cottonwood, willow (*Salix* spp.) and tamarisk.

2.2. Field methods

We sampled 12 of the 37 inlet sites in our study area reported to have at least 50 tamarisk plants (Pearce and Smith, unpublished data). We randomly selected four inlet sites from each of three stream-basin size classes: (1) 100–1000 ha, (2) 1001–10,000 ha, and (3) >10,000 ha (Fig. 1). At each study site, we sampled a representative 500 m^2 circular plot subjectively located in each distinct wetland and riparian vegetation type present (Hansen et al., 1995). Each site had 2–5 sample plots for a total of 39 plots. We sampled stands with tamarisk when it was present.

For each sample plot, we estimated tall-cottonwood ($\geqslant$5 m high) canopy cover with a spherical densiometer at plot center. Canopy cover of vascular plant species that occurred more than twice in a plot was estimated to the nearest 5%. Vascular plant nomenclature follows Great Plains Flora Association (1986). We recorded the number of cottonwood trees in each of four size classes: (1) seedling – <135 cm high or <2.5 cm diameter at breast height (dbh); (2) sapling – $\geqslant$ 135 cm high and 2.5–13 cm dbh; (3) pole – 13–23 cm dbh; and (4) mature – >23 cm dbh. We recorded the number of tamarisk and willow plants in each of three size classes: (1) small – <0.5 m high; (2) medium – 0.5–1.0 m high; (3) large – >1.0 m high. When plant density was high, we obtained estimates of woody species from eight, 0.8–7.1 m^2 circular microplots placed along four, evenly spaced plot radii. Microplot size was adjusted to obtain an easily countable number of stems per plot. Otherwise, we counted all plants of these riparian woody species in the macroplot. We estimated the height of tamarisk to the nearest 0.5 m with a range pole.

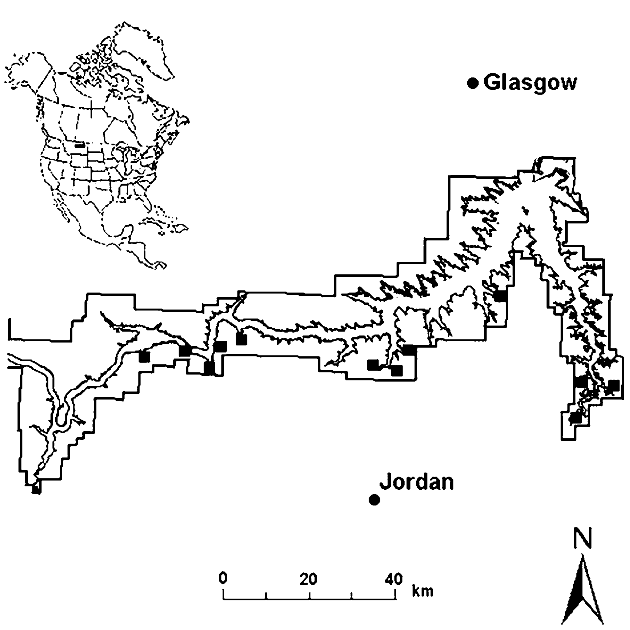

Fig. 1. Location of 12 study sites (black squares) along the south shore of Fort Peck Reservoir on the C.M. Russell National Wildlife Refuge (outlined).

We obtained age estimates of tamarisk and cottonwood from two representative plants in the dominant size class and at least one plant in subordinate classes in each plot. Pole and mature cottonwood ages were derived from increment cores taken just above ground level. Age of seedling and sapling cottonwoods were taken from cross sections taken just above root branching. Estimates of larger cottonwoods were likely to be less than the actual age because ground level is often not the level of the establishment surface (Bradley and Smith, 1986; Scott et al., 1997). Tamarisk and willow branch at the establishment surface of the substrate during the first or second year of growth. Age estimates for these plants were obtained from cross-sections of excavated plants taken at the point just below the union of the lowest stems.

We recorded the location of each plot with a Garmin GPS76, a hand-held, 12-channel global positioning system receiver using the WGS-84 datum. Plot elevations above full pool were estimated from digital USGS topographic maps using the recorded GPS location. We recorded plot elevations at or below full-pool level using a rotating-beam laser level by determining height above reservoir level and adding to reservoir level recorded at Fort Peck Dam at noon of that day (US Army Corp of Engineers, personal communication). We were unable to record elevations for Big Dry Creek plots at or below full pool because the reservoir was many kilometers away across the low-gradient drawdown zone.

2.3. Data analysis

We employed indirect gradient analysis to reveal underlying environmental gradients. Plots and common (present in $\geqslant$ 3 plots) native species were ordinated using detrended correspondence analysis (DCA; Ejrnaae, 2000; Gauch, 1982) using canopy cover as the measure of species abundance. Computations were performed with PC-ORD (McCune and Mefford, 1995). We used Spearman's non-parametric correlation coefficient (ρ) to assess the significance of associations between stand vegetation (as determined by DCA) and stand elevation and age. Stand age was taken as the age of the oldest woody plant measured in the sample plot.

3. Results

3.1. Vegetation ordination

We identified five riparian plant community types classified by Hansen et al. (1995): (1) Great Plains Cottonwood/Recent Alluvial Bar community type, (2) Western Wheatgrass habitat type, (3) Silver Sagebrush/Western Wheatgrass habitat type, (4) Sharp Bulrush habitat type and (5) Great Plains Cottonwood/Herbaceous community type. Hansen et al. (1995) mention but do not describe a tamarisk (saltcedar) community type.

We ordinated sample plots in a three-dimensional solution based on the structure of the correlations among plots and species using DCA. The first axis of this solution accounted for 49% of the variation in stand composition. DCA axis 1 appeared to be a successional gradient (Fig. 2(a)). Squirreltail barley (*Hordeum juba-*

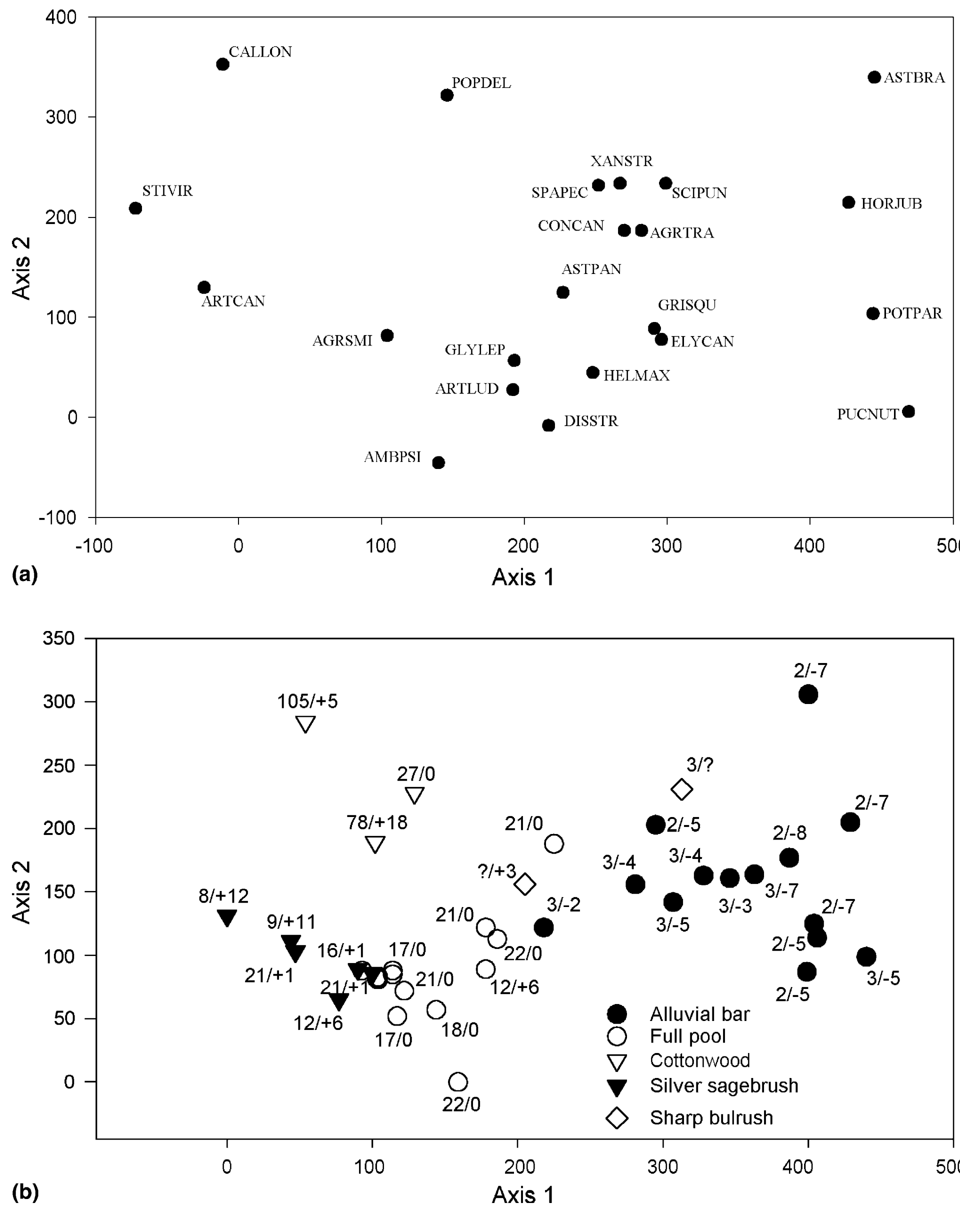

Fig. 2. Results of detrended correspondence analysis. (a) Species: *Agropyron smithii* (AGRSMI), *A. trachycaulum* (AGRTRA), *Ambrosia psilostachya* (AMBPSI), *Artemisia cana* (ARTCAN), *A. ludoviciana* (ARTLUD), *Aster brachyactis* (ASTBRA), *A. pansus* (ASTPAN), *Calamovilfa longifolia* (CALMON), *Conyza canadensis* (CONCAN), *Distichlis stricta* (DISSTR), *Elymus canadensis* (ELYCAN), *Glycerrhiza lepidota* (GLYLEP), *Grindellia squarrosa* (GRISQU), *Helianthus maxmillianii* (HELMAX), *Hordeum jubatum* (HORJUB), *Populus deltoides* (POPDEL), *Potentilla paradoxa* (POTPAR), *Puccinellia nuttalliana* (PUCNUT), *Scirpus pungens* (SCIPUN), *Spartina pectinata* (SPAPEC), *Stipa viridula* (STIVIR), *Xanthium strumarium* (XANSTR). (b) Sample plots giving plot age/plot elevation relative to full pool level.

tum), cinquefoil (*Potentilla paradoxa*), gumweed (*Grindelia squarrosa*) and aster (*Aster brachyactis)* had high scores on DCA axis 1 and are early-seral species characteristic of bare mineral soil. Silver sagebrush, western wheatgrass, green needlegrass (*Stipa viridula*) and sandreed (*Calamovilfa longifolia*) had high scores and are typical of shrub-steppe vegetation. There was a strong correlation between DCA axis 1 scores and age of the oldest woody plant sampled (Spearman's $\rho = 0.67$, $p < 0.001$; Fig. 2(b)). There was also a strong correlation between the elevation and vegetation of the stands (Spearman's $\rho = 0.86$, $p < 0.001$; Fig. 2(b)). Age and elevation together accounted for 79% of the variation in DCA axis 1 scores. The second DCA axis accounted for 30% of the variation in species composition and separated late-seral cottonwood stands from those dominated by silver sagebrush (Fig. 2(b)).

3.2. Occurrence of tamarisk

Tamarisk plants 1–3 years old and 0.5–1.5 m high were abundant in the drawdown zone ($\leqslant 685$ m) along the shore of Fort Peck Reservoir in association with Great Plains Cottonwood/Recent Alluvial Bar vegetation (Fig. 2(b)). We observed colonies of dead tamarisk apparently killed by inundation. The Sharp Bulrush community type below full pool along Big Dry Creek had 3 year-old tamarisk plants at 0.2 plants/m^2, while the stand along Nelson Creek was above full pool and did not support tamarisk. We observed little seed production in these stands, although we did not quantify the relationship between age and fecundity.

Most stands of tamarisk in the Western Wheatgrass habitat type occurred on stream terraces at or just above full-pool level of the reservoir (684.5–686.5 m). Tamarisk plants were 2–22 years old; those in the largest size class were 17–22 years old and averaged 3.1 m high (Fig. 2(b)). The oldest and largest tamarisk in the study area were found in this habitat. We also sampled the Western Wheatgrass habitat type on stream terraces above full pool at two sites. The largest tamarisk plants in these stand were 5–12 years old and 2 m high.

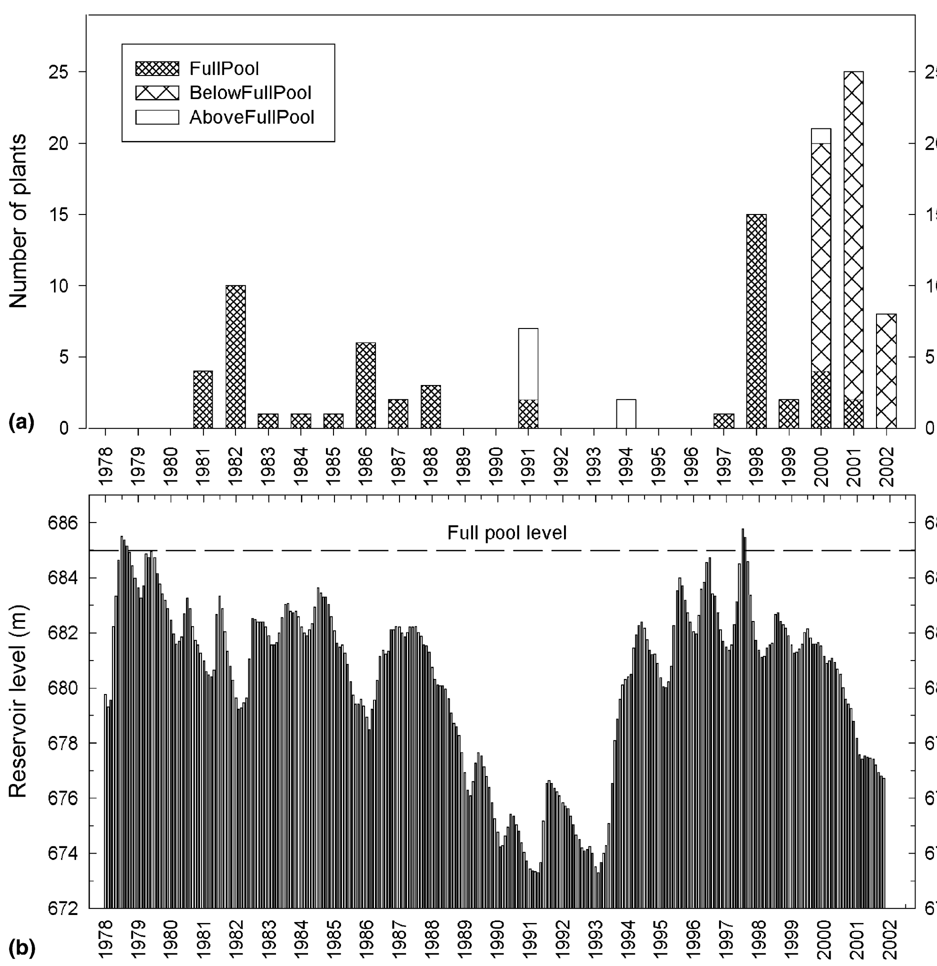

Fig. 3. (a) number of sampled tamarisk plants recruited in 1978 through 2002 (tick marks are placed at January of each year) and (b) monthly level of Fort Peck Reservoir January, 1978 through December 2000.

Cottonwood and silver sagebrush stands occurred on stream terraces at or above the full-pool level of Fort Peck Reservoir. Tamarisk occurred in five of the nine stands sampled. Plants were 9–22 years old and 2–4 m high. Tamarisk occurred only near stream channels. Stands with tamarisk were below 692 m in elevation, while all but one without were higher than 695 m.

3.3. Tamarisk age distribution

Sampled tamarisk plants ranged in age from 1 to 22 years old. Our sampling was not adequate to accurately determine age-class distributions at any site or across the study area. Nonetheless, the frequency distribution of sampled tamarisk ages suggests that recruitment and survival among years was varied (Fig. 3(a)). All plants sampled in the drawdown zone were 1–5 years old, having recruited since the high-water years of 1996 and 1997 (Fig. 3). Ages of tamarisk plants in the full-pool zone were more widely distributed. Recruitment occurred commonly in 1981–1982, 1986 and 1998, all were periods of significant drawdown following high-water years (Fig. 3).

Stands of tamarisk were even-aged (± 1 yr) in the drawdown zone. Sixty-four percent of stands in the full-pool zone supported at least two tamarisk cohorts separated by at least five years. Tamarisk plants were the same age as willow and cottonwood in the drawdown zone. Tamarisk were 0–7 years older than silver sagebrush plants in the four Silver Sagebrush/Western Wheatgrass stands where both occurred and 3–6 years younger than cottonwoods in the one stand where both occurred together.

4. Discussion

US national wildlife refuges were established to conserve and protect animal diversity and associated habitats (Zaslowsky, 1986). Results of our study provide a basis for IPM of tamarisk on the C.M. Russell National Wildlife Refuge aimed at protecting native biological diversity. We first provide a description of habitat relationships for native riparian vegetation followed by a discussion of where tamarisk has or is likely to invade, We use this information to suggest low-cost control measures and a system to prioritize labor-intensive site-specific eradication.

4.1. Riparian vegetation dynamics

Riparian vegetation in the study area was not diverse. We observed only five vegetation types, and only three of these, Great Plains Cottonwood/Recent Alluvial Bar community type, Western Wheatgrass habitat type and Silver Sagebrush/Western Wheatgrass habitat type, were common. The Sharp Bulrush habitat type and Great Plains Cottonwood community type occurred only along streams with drainage basins greater than 10,000 ha. Although sandbar (*Salix exigua*) and yellow (*S. lutea*) willows were common in the drawdown zone, we did not observe a willow community in the study area. Many streams entering Fort Peck Reservoir west of the Musselshell River (outside our study area) have more diverse and extensive riparian vegetation (S. Miles, observations), probably because they have montane headwaters with stronger spring runoff and more perennial flows. Livestock grazing may have eliminated native woody riparian vegetation along perennial or strongly intermittent streams (reviewed in Belsky et al., 1999; Kauffman and Krueger, 1984). However, the lack of any wetland indicator species (Reed, 1988) along ephemeral drainages in our study area suggests that the paucity of willows and cottonwoods is due to hydrologic regimes that are not wet enough long enough.

The strong association between riparian vegetation, stand age and elevation reflects the successional relationship among vegetation types (Boggs and Weaver, 1994; Hansen et al., 1995, p. 211). Moist, bare alluvium deposited by flooding streams is colonized by annuals, biennials, short-lived perennials as well as small-seeded woody species such as cottonwood, willow and tamarisk. Continued deposition along streams or channel migration causes the site to become drier and higher. The ground layer is invaded by long-lived, more competitive species, such as western wheatgrass. Cottonwood and willows become older and larger if they are present. Eventually the site becomes dry enough to be colonized by silver sagebrush. Willows die out after 20–30 years, but cottonwood remains on the site for about 100 years, assuming it is not destroyed by fire or harvested by beavers or humans. Sites immediately adjacent to permanently inundated stream channels may remain wet enough to support swards of sharp bulrush.

Fort Peck Reservoir with its fluctuating water levels creates habitats different from those associated with natural riparian systems. The drawdown zone experiences repeated cycles of inundation (Fig. 3(b)) that prevent vegetation from proceeding beyond the earliest stages of succession (i.e., Alluvial Bar community type). Cottonwood and willow never become old enough to attain significant height or reproductive maturity in this zone. Immediately above the drawdown zone floodplain soils commonly remain moist without experiencing inundation. This full-pool zone (684.5–686.5 m) is stable and moist enough to support Western Wheatgrass habitat type vegetation but too wet to be colonized by silver sagebrush. The full-pool zone, created by the impoundment, provides the habitat where the vast majority of mature (i.e., reproductive) tamarisk plants occurred. Cottonwood and willow sometimes occurred in the full-pool zone but were usually harvested by beavers, while we never observed beaver damage to tamarisk (Lesica and Miles, 2004).

4.2. Tamarisk dynamics

Tamarisk is well adapted to invade moist, disturbed habitats adjacent to water bodies (DiTomaso, 1998; Everitt, 1980). It produces large numbers of small, wind-borne seeds that disperse widely and germinate upon contact with bare, moist soil. It is a facultative phreatophyte that grows quickly and is capable of surviving alluvial deposition as well as short periods of inundation. Tamarisk will colonize point bars and other depositional features along streams where there is sufficient moisture (Lesica and Miles, 2000; Sexton, 2000; Shafroth et al., 1998; Warren and Turner, 1975). In our study area such sites occurred only along the largest streams (basins >10,000 ha). These are the same sites capable of supporting cottonwood forests and willow thickets. Native biological diversity is most at risk in these largest stream basins.

Tamarisk may be better adapted to colonizing many prairie streams in the study area and other parts of the Northern Great Plains than native woody species. Cottonwood and willow are adapted to establish on snowmelt streams, by producing short-lived seed that germinates as flood waters decline in late spring (Mahoney and Rood, 1998; Segelquist et al., 1993). However, most tributaries of the Missouri River east of the Musselshell River have low-elevation watersheds with little winter snow accumulation. Flooding of these streams is more likely to occur following summer convectional storms. Cottonwood and willow seed are not usually available at these times. However, tamarisk produces seed throughout most of the growing season and is able to take advantage of summer floods (Merkel and Hopkins, 1957; Warren and Turner, 1975).

Tamarisk was abundant in the drawdown zone along the shoreline of Fort Peck Reservoir. Recruitment in the drawdown zone occurred in a period of relatively low reservoir levels following one or two years of high water. Reservoir levels were near or above full pool in June through August in 1996 and again in June through September in 1997 (Fig. 3(b)). Tamarisk plants greater than five years old were never observed at an elevation lower than 685 m. The lack of plants older than five years indicates that tamarisk in the drawdown zone were killed during the two summers of inundation. The zone was quickly recolonized by tamarisk in 1998 when the water retreated (Fig. 3). Our results and observations of others suggest that three months of inundation will kill tamarisk plants (Warren and Turner, 1975).

Tamarisk was also common in the Western Wheatgrass habitat type in the full-pool zone of the reservoir. In addition, 12 year-old tamarisk occurred in this habitat type on a low terrace along Seven Blackfoot Creek 6 m above full pool. It appears that tamarisk established most abundantly in the full-pool zone during periods of drawdown immediately after a period of maximum water level (1981–1982, 1986, 1998; Fig. 3). This slowly declining hydrologic regime is similar to that for an alluvial bar of a large river during and after a flood event (Mahoney and Rood, 1998; Segelquist et al., 1993). Early survival of tamarisk in this habitat may depend on subirrigation provided by the reservoir.

The Western Wheatgrass habitat type is widespread in eastern Montana and the Northern Great Plains in swales and depressions and on terraces where overland flow and fine-textured soils provide a greater than normal moisture regime (Hansen et al., 1995). Our sample stands in the full-pool zone may have a higher water table than most of those occurring outside the influence of the reservoir. Nonetheless, our results suggest that tamarisk may be able to invade the Western Wheatgrass habitat type, especially with disturbance or where it is found associated with depressional wetlands or stock ponds. The long-term effects of tamarisk on this community are not known; however, perennial grass cover will undoubtedly decline under shade of the invading shrub.

Tamarisk was uncommon above the influence of the reservoir in this arid region. We sampled only nine stands of riparian vegetation in the 12 study drainages that were above the full-pool zone ($\geqslant 2$ m above full pool), and tamarisk occurred in only three of these. At Hell Creek and Johnson Coulee, tamarisk occurred in the Silver Sagebrush/Western Wheatgrass habitat type, while along Seven Blackfoot Creek it was found in the Western Wheatgrass habitat type. In all three cases tamarisk occurred only in close proximity to the channel. Tamarisk was usually older than silver sagebrush in stands where both occurred, suggesting that tamarisk invaded these sites while they were dominated by western wheatgrass, before they became dry enough to support sagebrush.

4.3. Management recommendations

Many of the following recommendations are specific to our study area along the south shore of Fort Peck Reservoir. Impoundments in more humid or more arid climates or landscapes with headwaters with snow-melt recharge are likely to have different vegetation dynamics. Nonetheless, the conceptual framework for developing IPM strategies demonstrated in this study will be appropriate in many other settings.

Repeated cycles of inundation and drawdown will continue to provide moist, bare soil for colonization by tamarisk in the drawdown zone along the shore of Fort Peck Reservoir. Mature stands of tamarisk will eventually be present in the full-pool zone of most bays and inlets of Fort Peck Reservoir because the high water table and moderate levels of disturbance without prolonged inundation provide long-term habitat. The largest tamarisk stands will be present in bays of larger streams where low topographic relief of the valleys produces an extensive full-pool zone.

Chemical and mechanical eradication of tamarisk along the 2600 km-long shoreline of Fort Peck Reservoir will not be possible. We propose an IPM-type strategy in which active control efforts are directed toward infestations that pose the greatest threat to the biological values of the C.M. Russell National Wildlife Refuge. In addition, more passive control methods can be employed to manage less critical but more widespread infestations. This strategy engenders five recommendations.

(1) Control measures will not be necessary for silver sagebrush or old cottonwood stands. Mature cottonwood stands (>30 years) did not support tamarisk invasion, probably because the water table has been too far below the surface since tamarisk was introduced to the region. Stands of silver sagebrush vegetation are abundant in our study area. However, these stands will be little threatened because tamarisk appears to be confined to the immediate vicinity of stream channels above the full pool zone.

(2) Tamarisk established abundantly in the band of alluvial bar vegetation along the entire shoreline of Fort Peck Reservoir. However, this vegetation zone is below full pool, and our observations suggest that mature tamarisk stands capable of producing large quantities of seed will be killed by flooding if the reservoir level is raised to full pool for three consecutive months between June and September approximately every five years.

(3) Tamarisk is also abundant in western wheatgrass vegetation associated with the full-pool zone of inlets where drainages enter the reservoir. These stands cannot be controlled by flooding, so targets for intensive control efforts must be prioritized. Sharp bulrush and young cottonwood stands are important components of biological diversity in this semi-arid environment and are vulnerable to tamarisk invasion. However, these vegetation types have limited distribution in the study area, occurring only along streams with drainage basins greater than 10,000 ha. Tamarisk infestations along these larger drainages, especially in the full-pool zone should be treated on a continual basis to help prevent upstream invasion and loss of critical wildlife habitat. Smaller, ephemeral streams rarely support significant riparian vegetation in our study area, so controlling tamarisk at associated inlets is less important.

(4) The abundance of tamarisk in the full-pool zone of the reservoir also suggests that tamarisk may invade swales and pond margins dominated by western wheatgrass. Disturbance associated with livestock grazing may provide tamarisk's bare-soil regeneration niche. Stock ponds in the vicinity of the reservoir should be monitored for infestations.

(5) Tamarisk invasion of riparian areas can be curtailed by managing for the more competitive, native cottonwood (Lesica and Miles, 2001; Sher et al., 2000, 2002). Cattle prefer to browse cottonwood and willow compared to tamarisk (Lesica and Miles, 2000). Livestock grazing should be carefully managed in the larger drainages to allow cottonwood and willow regeneration and growth to maturity. Beavers may have to be controlled in some areas to allow cottonwood stands to develop (Lesica and Miles, 2004).

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