

**TAMARISK CONTROL PROGRAM
1987-1990
PETRIFIED FOREST NATIONAL PARK
ARIZONA**

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ABSTRACT

Various efforts to control tamarisk (Tamarix spp.) at Petrified Forest National Park have been made over the last 25 years. This paper summarizes earlier efforts and reports on the most recent tamarisk control program which ran from 1987-1990. This recent program removed all tamarisk growing in the Dry Wash drainage within the Park, an area of about 34 square miles (about 8,800 ha.). Data was also collected to model tamarisk population growth and the long-term effectiveness of various measures in controlling population growth. Results of this program indicate the importance of cutting tamarisk plants off at ground level and prompt application of herbicide for effective control. Based on control effectiveness and population data collected, recommendations are made for an ongoing tamarisk control program for Petrified Forest National Park.

INTRODUCTION

Tamarisk (or salt cedar, Tamarix spp.) is an exotic plant of Eurasian origin that has become established throughout the southwestern United States. Originally introduced for ornamental planting and erosion control, the tamarisk escaped cultivation and colonized riparian vegetation zones throughout the region. In the Little Colorado River drainage, tamarisk was cultivated close to the river in Winslow as early as 1909. By 1937, tamarisk was growing wild along the Little Colorado (Hereford, 1984).

The earliest record of tamarisk in Petrified Forest is from 1937, when it was growing along the Puerco River (Walker, 1937). A few clumps were growing along Jim Camp Wash behind the old Rainbow Forest Lodge by 1950 (Whitcraft, 1950). Establishment of the heavy stand of tamarisk at the confluence of Ninemile Wash and the Puerco River was first noted in 1951. The plants began growing "like magic" on a mudbank deposited by the flooding Puerco River, just as efforts began to stabilize the channel of the Puerco at that point (Superintendent's Monthly Report, 9/13/51).

Since its introduction, tamarisk has spread up washes throughout the park, and the spread appears to be continuing or perhaps accelerating. The age of tamarisk

scattered through the Dry Creek drainage were checked through tree ring dating after control work in 1987-88. It was found that 61% of the tamarisk had sprouted since 1970, the oldest sprouting in 1940 (Knight, 1989, see also Simpson, 1987). Numerous young sprouts along the main fork of Dry Creek indicate that the wash could be a tamarisk dominated community in another ten years (Smith, 1988). The accompanying graph (Figure 1) shows population growth in the Dry Wash drainage derived from tree ring data, and its projected growth through the next century modeled on the known population growth rate.

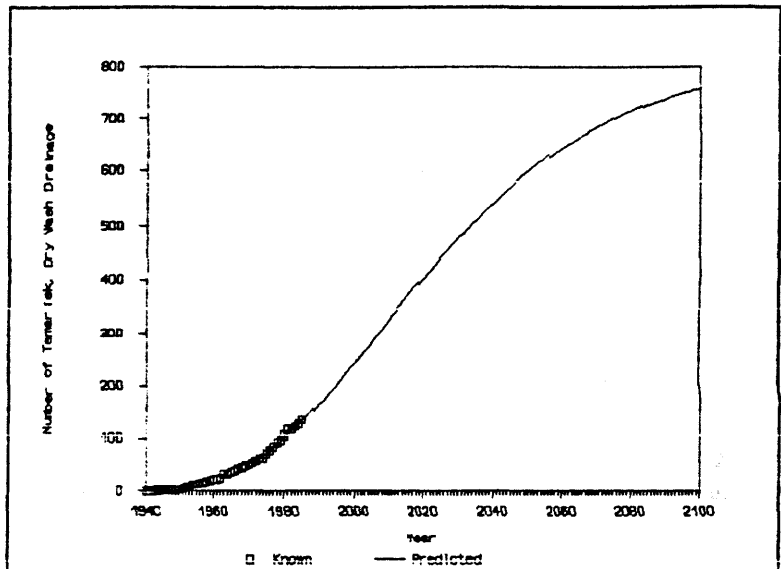


Figure 1: Tamarisk Populations in the Dry Wash Drainage, Petrified Forest National Park

In Petrified Forest National Park today, tamarisk forms dense thickets along the Puerco River and Ninemile Wash in the central part of the Park, and extensive stands along the Lithodendron, Jim Camp and Cottonwood washes, as well as around stock tanks remaining from former grazing in the Park. Isolated clumps of tamarisk are found along nearly all Park drainages, but, with the exception of the Puerco River floodplain, there are no tamarisk dominated plant communities presently in the Park. The tamarisk species found in the park has been identified as Tamarix pentandra (Kierstead, 1981), but it seems likely the species present is T. ramosissima.

EARLIER CONTROL EFFORTS, 1968-1980

BACKGROUND

Control of tamarisk has been attempted by many groups, in several areas, for a variety of reasons. The mere fact that tamarisk is an exotic makes it eligible for control in any National Park System area. The National Park Service management policy in effect at the start of the present program stated:

Manipulation of population numbers of exotic plant and animal species, up to and including total eradication, will be undertaken whenever such species threaten protection or interpretation of resources being preserved in the park (National Park Service, 1978).

In Petrified Forest National Park, justification for tamarisk control is based on its exotic status, and the aesthetic intrusion it presents in the "last undisturbed short grass prairie in Arizona" (Miller et al., 1977). The role of tamarisk in reducing the amount of free water present in the Park for other species is unknown. There is only one recorded active spring in the park now, but in the 1940's springs at Zuni Well and Agate Bridge were also active (Jones, 1986). Why these springs are no longer active has not been determined, although a loss of sand from the soil surface may be a factor (Wendorff, 1953). Tamarisk has not been considered as a factor in the drying of these springs, but it can not be ruled out in all cases until further investigation is done.

1968-69 PROGRAM

The first documented tamarisk control work in Petrified Forest National Park focused on the Painted Desert, before the establishment of the Wilderness Area in 1971. In 1968 and 1969, Emulsamine Brush Killer (2,4,5-T and 2,4-D) was applied from a "sprayer jeep" to attempt control of tamarisk along washes in the Painted Desert section of the park. In the 1968 program, 1,984 plants were treated with a 20% kill rate. In 1969, the survivors of the 1968 effort were re-treated, along with an additional 450 untreated plants. There is no summary of the effectiveness of the 1969 program. A follow-up survey in 1970 located 669 tamarisk plants that had been treated (as a result of both programs), with a summary kill rate of 73%. As a result of the 1970 survey, control work was discontinued (Johnson, 1970).

1978-80 PROGRAM

Another study project was carried out in 1978 and 1980 in the Rainbow Forest area, using mechanical removal and herbicides. Mechanical removal of 28 plants along the "Rainbow Canyon" branch of Jim Camp Wash in 1978 (using everything from shovels to a backhoe) was reported to be only 54% effective at the time (Johnson, 1985). However, in 1990, only six tamarisk had survived from the program, no tamarisk were known to have sprouted, and one plant could either be a survivor or a sprout. This data brings the long-term mortality of mechanical removal in this project to 75%-79% (Knight, 1990). In the 1980 program, a combination of cutting and cut stump herbicide application (using Garlon 3A and Garlon 4) on 36 plants was 77% effective in killing established plants. As part of the herbicide study, 13 plants were cut but not treated and showed a 23% mortality (Johnson, 1985). In 1990, the area was resurveyed, and 20 tamarisk were found growing, two more than survived in Johnson's report. Of the two, one may have been outside the original study area. Thus, only one or two sprouts have become established in the area over the last decade (Knight, 1990).

The long-term implications of this study are difficult to interpret. It is encouraging to note that the tamarisk reported dead in 1985 were still dead in 1990. Low recruitment into the population in these two study areas could be the result of a number of factors, acting either alone or together. These are summarized below:

1. The removal of most mature tamarisk plants from the drainage may have reduced the seed available for reproduction in the immediate area of treatment. However, because of the small size of tamarisk seeds and the

windy climate of the area, seeds from outside the study area could probably have arrived without undue difficulty.

2. They years since the study concluded may not have been favorable to tamarisk seedling establishment. Although 1981 and 1985 appear to have been good years for establishment in the Dry Wash drainage (Knight, 1989), the local nature of rainfall may have left the Jim Camp Wash drainage dry at critical times. Conversely, heavy rains could have triggered flooding, scouring out young plants in the drainage.
3. A residual effect of the herbicides used may have retarded or eliminated tamarisk growth at the treatment sites or all along the wash. No tests were conducted for pesticide residuals, but given the relatively short half-life of the herbicides used (only 30 days for Garlon 3A (Hoddenbach, 1989)), such a long term action seems unlikely.

THE PRESENT STUDY, 1987-1990

TECHNIQUES

From 1987 to 1990, tamarisk control in Petrified Forest was tried again. This study was carried out in the Dry Creek drainage in the central part of the Park. Mechanical removal of tamarisk plants without herbicide use was not attempted because of the reportedly poor success rate of this treatment (Johnson, 1985). Instead, control was attempted with cut stump herbicide treatment. As in Johnson's work, the plants were cut off at ground level, and the stumps painted immediately with the herbicide Garlon 3A. Phase One was carried out during June and July, 1987. Tamarisk plants in the East Fork of Dry Wash drainage, and those downstream from its mouth along Dry Wash were cut and treated.

During Phase Two, in June and July of 1988, all plants in the remainder of the Dry Wash drainage in the Park were cut and treated. The same methodology was used, with greater attention to technique.

Phase Three began in 1988 and continued through 1990. After Phases 1 and 2, many of the treated tamarisk continued to sprout new growth. These remaining live tamarisk stumps and sprouts were assumed to have been weakened by the control work, even though not killed. These factors made re-treatment of the area relatively easy, providing the possibility to experiment on secondary treatment procedures as well. The possibility of killing the remaining root stock through repeatedly pruning of any new growth was tested. It was hoped this treatment could induce carbohydrate starvation of the root stock and death (Smith, 1988), while avoiding the use of herbicides. The study area was divided into two tracts, with the tamarisk survivors along Dry Wash and East Fork downstream from the Park road being cut and retreated with Garlon 3A, and all other tamarisk survivors only cut back. Tamarisk initially cut in 1987 received these treatments in 1988, and all tamarisk in the study area received the treatments in 1989 and 1990.

In conducting the study, tamarisk were counted. Given the shrubby nature of the plant, these counts are somewhat subjective. The growth habit of the plant in Petrified Forest could be described as "clumpy", with numerous branches radiating from a small area (up to about 50 cm. in diameter), or rarely, from a single trunk. On the basis of growth habit and examination of flood-toppled plants, such clumps were counted as one plant. In a few areas, several clumps of tamarisk were growing in close proximity. Breaking these tamarisk "groves" into individual "plants" was again subjective, but was based on canopy breaks and how many centers of growth appeared on the ground beneath the grove.

During all phases of the study, tamarisk sprouts were also removed. These tamarisk sprouts were generally one to two years old. They usually grew in heavy concentrations on sand bars in and along the wash bottoms. To control these wands, they were simply pulled out of the ground. Usually, there were roots 2 to 3 times as long as the above ground shoot. No herbicides were applied.

RESULTS

Kill Rates

Initial results of the 315 plants cut and treated in Phase 1 (1987) showed a 21% kill rate by that September (Bowman, 1989). Initial results of the 485 plants cut and treated in Phase 2 (1988) were much more encouraging, with a kill rate of 71% (Knight, 1989). Phase 3, by 1990, increased the average kill rate for all 800 plants to 66% (Knight, 1990). However, this composite kill rate masks some important differences in results obtained with differing techniques. The following table presents a breakdown of observed results:

Number of Tamarisk Treated and Cumulative Kill Rate by Year							
		Phase 1, 1987			Phase 2, 1988		
		Total Plants	Re-treatment		Total Plants	Re-treatment	
			Cut	Herbi.		Cut	Herbi.
1987	plants	315	229	86			
	% kill	22.54	21.83	24.42			
1988	plants	244	179	65	485	419	66
	% kill	40.00	39.74	40.70	71.55	71.12	74.24
1989	plants	189	138	51	138	121	17
	% kill	45.71	34.06	76.74	80.82	79.95	86.36
1990	plants	171	151	20	93	84	9
	% kill	no 1991 survivor data collected yet					

In addition to data on overall kill rates, the initial kill rates for tamarisk cut and treated in Phase 2 before and after the start of the summer rainy season were recorded. Along the main channel of Dry Wash before the rains started, 62 tamarisk were treated with an initial kill rate of 69.4 %. After the rains began, 204 tamarisk were treated, with a kill rate of 67.7%.

Costs

Actual costs for the present program are summarized in the table below. Figures for Phases 1 and 2 work include supplies and materials, transportation, and wages for the Youth Conservation Corps cutting crews and Range Technicians (herbicide applicators). Phase 3 costs include only wages for one Range Technician and transportation, since supplies and materials were used from Phases 1 and 2.

Program Costs, Tamarisk Control 1987-1990					
Year	Phase	Cost	# Miles	# Tamarisk	# Days
1987	1	\$ 8,471	6	315	27
1988	2	\$ 8,462	15	485	22
1988	3	\$ 642	6	244	2
1989	3	\$ 920	21	327	7
1990	3	\$ 887	21	264	7

CONCLUSIONS

Initial Treatment (Phases 1 and 2)

The low kill rate obtained in Phase 1 (1987) was originally reported as a result of the following factors (Bowman, 1989):

1. **Herbicide Used:** According to Dow Chemical (1987 telephone conversation), manufacturers of Garlon, a kill rate of 42% should be expected from the Garlon 3A treatment used (higher rates would be expected with Garlon 4 or Tordon RTU).
2. **Time of treatment:** Control work was done in the early summer drought. During this time, it was thought the plants may be dormant, reducing translocation of the herbicide. Rainfall from the 1987 summer monsoon was light, and did not begin until after control work was completed.
3. **Treatment technique:** Although plants were to be cut at ground level, the height of stumps varied from 0 to 30 cm. This stump height may have reduced the effectiveness of the treatment.

Phase 2 (1988) shed further light on these factors. In the 1988 program, tamarisk plants were consistently cut at (or even below) ground level. A higher ratio of pesticide applicators to cutters allowed quicker herbicide application to the cut stumps. Finally, the onset of the rainy season in 1988 occurred during the project, allowing comparison of kill rates before and after the rains began. The herbicide used in both programs was Garlon 3A.

Based on data from the two phases of the study, it appears that factors 1 and 2 were not critical, and that most of the improvement from Phase 1 to Phase 2 was accomplished through factor 3, improvements in technique.

1. **Herbicide Used:** Treatment with Garlon 3A seems to be capable of producing the 76% kill rate reported by Johnson (1985). However, the 1980 data set was not large enough to calculate a critical Z value to further refine this comparison. Subsequent retreatment of surviving plants in the present study raised the kill rate as high as 86%. While this rate is much higher than the rates communicated from Dow Chemical (42%), it is still lower than the 95% reported by Neill (1989). The improved Petrified Forest rate is within the range obtained in nearby national parks: 88% reported from Zion National Park (Hays & Mitchell, 1989) and 85-92% from Wupatki National Monument (Cinnamon, 1989). Some of the differences in kill rates between these studies may be explained by differences in counting methods (see tamarisk counting discussed above).
2. **Time of treatment:** Early summer (late May through early July) is the driest part of the year in Petrified Forest. The possibility that tamarisk may become somewhat dormant during this period may have contributed to lowered kill rates. While dormancy was not studied directly, the onset of the rainy season midway through of Phase 2 allowed comparison of the kill rates before and after the rains started. No statistically significant difference in kill rates was observed using calculation of critical Z values, even at the 99.9% significance level. Thus, any "dormancy" on the part of the tamarisk does not appear to play a role in the effectiveness of the herbicide. Because the plants grow along washes where subsurface water is present through most of the year, no dormancy may occur at all. Or, reductions in plant metabolism may not affect translocation of the herbicide.
3. **Method of treatment:** The dramatic difference between the initial kill rates obtained in Phases 1 and 2 are statistically significant to the 99.9% level (critical Z value). The difference appears to be the result of technique used. Two major changes appear to be responsible for the improvements seen in Phase 2:
 1. Greater attention was given to cutting the tamarisk at or below ground level, facilitating herbicide absorption by the root crown, and increasing mortality.
 2. Fewer cutters worked with one herbicide applicator. In Phase 1, as many as 6 cutters worked ahead of the applicator, while in Phase 2, there were not more than 3 cutters. Fewer cutters meant the applicator could stay closer to cutters, insuring prompt herbicide application. In

addition, closer contact reduced the potential to overlook some cut branches, especially smaller ones.

Retreatment

After initial cut stump treatment of tamarisk, two methods of retreatment were carried out as Phase 3 of the project. All regrowth was cut off at or below ground level. One group received no further treatment, while the other group was retreated with Garlon 3A.

The cumulative effect of these two type of treatments are shown on the accompanying graph (Figure 2). As would be expected, retreatment with cutting and herbicide application increased the kill rate above merely cutting off new growth.

The increased kill rate was especially pronounced for the Phase 1 plants (initial treatment in 1987). The difference was statistically significant to the 99.9% level (Z test). This result is not unexpected, since many of the Phase 1 plants receiving retreatment had a significant stump removed. This resulted in more surface area to absorb herbicide, and placed the applied herbicide closer to the root crown than the initial treatment.

For plants initially treated in 1988 (Phase 2), the difference between the two retreatment methods is not statistically significant. This result may be due to the initially high kill rate for Phase 2. However, the plants retreated with herbicide showed less vigorous regrowth than those that were only cut. The statistics only cover the first retreatment of the Phase 2 plants, while those in Phase 1 received two retreatments. In 1989, the Phase 1 plants did not show a statistically significant difference between the two methods after one retreatment, either. All plants were retreated in 1990, so additional data pertaining to this question can be collected in 1991.

Uprooting Tamarisk Shoots

The young tamarisk shoots pulled up in the course of other control work are not included as part of the numeric data for Phases 1, 2 or 3. However, hundreds of

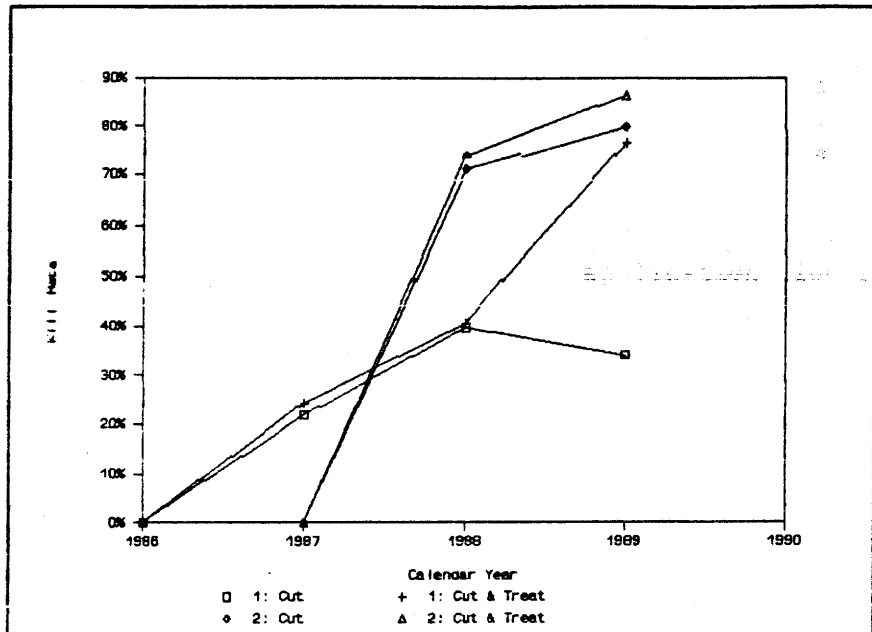


Figure 2: Cumulative Tamarisk Kill Rates, Petrified Forest National Park

these small shoots were pulled out. Only one or two survived, giving an apparent kill rate of over 99%. Some authors recommend ignoring such small tamarisk plants, on the assumption that they will be washed away in floods (Neill, 1989). However, removal of tamarisk shoots is fast, easy, and requires no herbicides. It also provides a means of control that does not rely on floods, which may not be frequent enough in the Petrified Forest area to remove the plants. Park watercourses are small enough that heavy flooding is relatively infrequent.

RECOMMENDATIONS

The data collected with the present study included not only the kill rates for various tamarisk control techniques, but other information on tamarisk populations in the Park. This included ages for tamarisk growing in the study area (Dry Wash drainage), occurrences of tamarisk elsewhere in the Park, and long-term effects of previous control programs. This information has been integrated to allow modeling of tamarisk population growth (Figure 1) and modeling the effects of various control strategies for long-term control.

MODELING THE EFFECTIVENESS OF CONTROL STRATEGIES

Various tamarisk control strategies were modeled to compare the effectiveness and cost of a long term program. A strategy consists of two components, the method of control, and the cycle (frequency) of control applications. The modeling was based on the known population of the Dry Wash drainage. Modeling was done using a Lotus 1-2-3 spreadsheet. Growth curves were projected using the slope and intercept figures derived from linear regression analysis of the log of observed population growth. Starting population levels were derived as if the current study had not occurred, that is, that all the tamarisk in the drainage were still alive and reproducing. All control cycles start (receive their first application of either control method) in summer, 1991. In the model, two control methods were used:

1. **Uprooting young tamarisk:** Uprooting young tamarisk shoots was found to be very effective. For modelling purposes, it was assumed that such treatment killed 99% of all tamarisk 1-2 years old. Costs were estimated using the actual costs averaged from Phase 3 of the current study. Phase 3 also involved cutting regrowth from previously cut tamarisk as well as uprooting young shoots, but experience has shown that most of the cost involved in this phase came from the time expended walking the washes. Consequently, cost estimates derived from Phase 3 are probably slightly high, but are a reasonable estimation. Inflation was not calculated into projecting cost figures.
2. **Cut stump herbicide application:** Following the design of the present study, this method consists of cutting off tamarisk and treating the stump with Garlon 3A. Because of the variability in the results of Phases 1 and 2, a conservative kill rate of 60% was used. Costs were obtained by averaging the cost of initial treatment for Phases 1 and 2. In actual practice, Phase 1 was more expensive, both by mile treated and by cost per

tamarisk treated, by a factor of 2. Thus, the cost estimates for this method are probably slightly inflated, but reasonable. Inflation was not calculated in predicting costs.

Each control method was modelled cyclicly. Method 1 (uprooting) was modeled on a two year and a five year cycle, that is, that uprooting of all young tamarisk would occur every two years or every five years. Method 2 (cut and treat) was modeled on a 15 and 20 year cycle. On years when treatment cycles coincided, the model used Method 2. The resulting population projections for different control strategies using one method are presented in Figure 3, those using combinations of methods are presented in Figure 4. Each figure also contains the predicted population growth in the absence of control (the same plot as shown in Figure 1).

Strategies using one control method

Populations

Various control strategies using only one method are shown in Figure 3. Of the four strategies, only one, using Method 2 (cut and treat) on a 15-year cycle, is capable of reducing tamarisk populations. Two single-method strategies, a biannual cycle of Method 1, and Method 2 on a 20-year cycle, maintain tamarisk

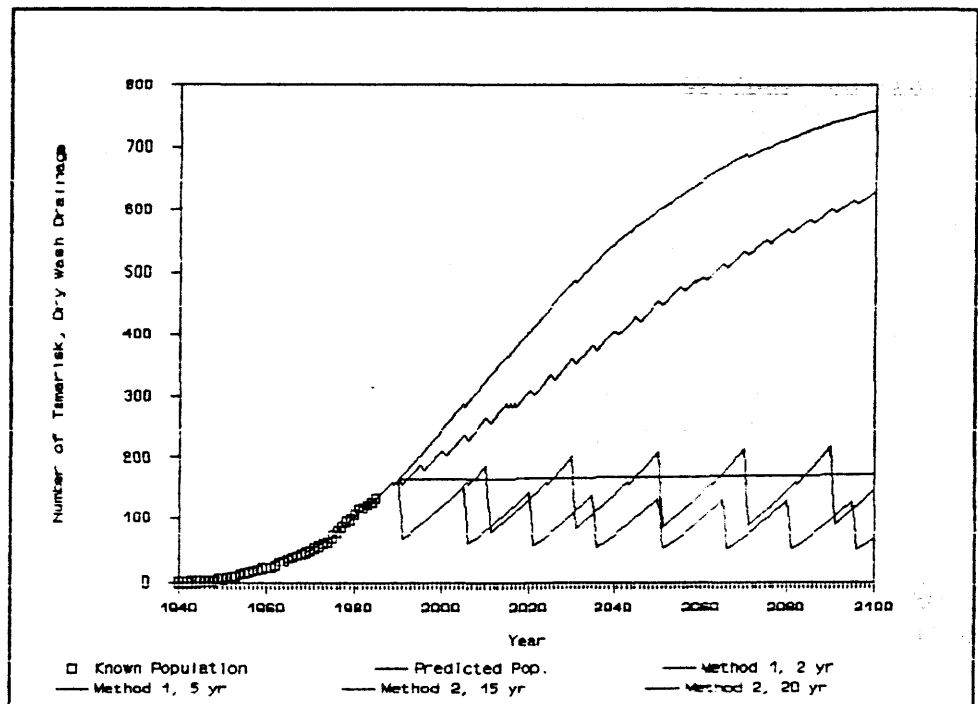


Figure 3: Effect on Tamarisk Population by Control Methods Acting Alone

populations at a constant level. Use of Method 1 every two years essentially "freezes" the tamarisk population at current levels by eliminating reproduction. Use of Method 2 every 20 years produces widely fluctuating tamarisk populations, peaking above the current population but bottoming below current levels and averaging somewhat below current population levels. One method, the use of Method 1 on a five-year cycle, allows continued tamarisk population growth, but at a slower rate than natural population growth.

Costs

Costs associated with this program were calculated for 2051, when all cycles coincide again (assuming a 1991 start). Natural population growth occurs with the "No Action" alternative. Reduction in the 2051 population below the natural level are given for all strategies. Program costs and costs per tamarisk removed from the expected natural level are calculated based on expenses in the present study. Population and cost/tamarisk removed figures for each strategy are given for both the year 2051, and for the average of the treatment application cycle (2, 5, 15 or 20 years) ending in 2051 are given.

Costs for Control Strategies Using One Method								
Strategy		Total Cost \$ K	Status in 2051		Cost/ Plant	Average for Cycle Ending in 2051		Cost/ Avg. Plant
Method	Cycle in Years		Tamarisk			Cycle Average		
			Alive	Reduc- tion		Plants Alive	Reduc- tion	
No Action		\$ 0.0	605	0	\$ 0	605	0	\$ 0
1	2	\$ 49.8	174	442	\$ 59	167	438	\$ 60
1	5	\$ 10.6	444	161	\$ 66	441	164	\$ 65
2	15	\$ 42.3	56	550	\$ 77	92	513	\$ 83
2	20	\$ 33.9	87	518	\$ 65	143	463	\$ 73

These figures are based on the actual cost of the present study, and are useful for predicting relative future costs, rather than actual costs. The analysis of these cost figures will be done in conjunction with the results obtained from the study of control actions acting together (below).

It is important to remember that monetary costs are not the only factor to consider in evaluating the data obtained in this study. The disruption of native ecosystem operations are another factor. In addition to its widely known water consumption, tamarisk in Petrified Forest alters the vegetative structure of plant communities. It is a tall shrub/short tree in an environment that does not have any native plants reaching this size. As such, tamarisk may provide habitat for species (especially birds) which may have not used the area naturally. It may also displace native vegetation and its associated fauna.

As an introduced species, tamarisk is also "evidence of human actions" (albeit indirectly) and thus may not be appropriate in wilderness areas. The philosophy of this concern has not been explored in depth.

Strategies using two control methods:

Populations

All combinations of two control measures modeled predict decreases in tamarisk populations (Figure 4). The strategies using Method 1 (uprooting shoots) on a five year cycle cause the decrease in populations to be cyclic, gradually rising after each application of Method 2 (cut and treat), but with an overall downward trend.

Strategies using biannual application of Method 1 hold tamarisk populations constant between applications of Method 2, at which point the population drops 60%. The difference between the 15 and 20 year cycles of Method 2 applications determines how rapidly the decline in tamarisk population occurs, and how large the variation in tamarisk population ranges between applications.

Costs

Cost figures for control strategies using two methods acting together were calculated as they were for the one method strategies (above) for the year 2051, when all of the cycles coincide again. Results are tabulated below:

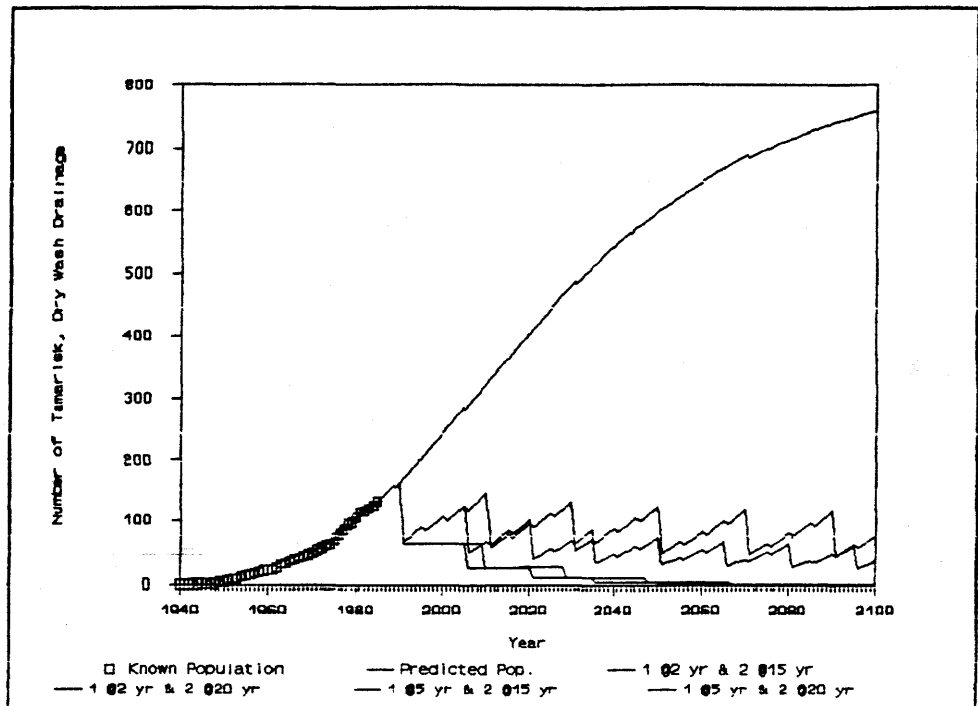


Figure 4 Effect on Tamarisk Population by Control Methods Acting Together

Costs for Control Strategies Using Two Methods								
Strategy		Total Cost \$ K	Status in 2051		Cost/ Plant	Average for Cycle Ending in 2051		
Method	Cycle in Years		Tamarisk			Cycle Average		Cost/ Avg. Plant
			Alive	Reduc- tion		Plants Alive	Reduc- tion	
No Action		\$ 0.0	605	0	\$ 0	605	0	\$ 0
1/2	2/15	\$ 66.0	3	602	\$110	6	599	\$110
1/2	2/20	\$ 56.7	8	597	\$ 95	16	589	\$ 96
1/2	5/15	\$ 48.9	33	572	\$ 85	55	550	\$ 89
1/2	5/20	\$ 41.2	52	553	\$ 74	87	518	\$ 79

The same caveats applying to the previous cost/effectiveness table apply to this one as well.

ANALYSIS OF THE VARIOUS STRATEGIES

Recommendation of a particular strategy depends on the ultimate goal of tamarisk control for Petrified Forest. Obviously, the least expensive monetary option is to do nothing, and allow tamarisk populations to increase until Park washes are dominated by solid, virtually impenetrable tickets. While cheap, the biotic costs of inaction are prohibitively high. Therefore, it is assumed that at least maintenance of the status quo is desired, if not an actual reduction in tamarisk populations.

The least expensive strategy for maintaining the status quo is the biannual uprooting of tamarisk shoots. This strategy requires no herbicide use, and can be maintained easily by one person. At a rate of 3 miles/day (the average rate of Phase 3 in the present study), approximately 50 miles of washes in the Park thought suitable for tamarisk growth could be covered in about one month.

Reductions in tamarisk populations is desirable for maintaining and improving the natural conditions of plant communities in the Park. Not only should the population be reduced, but the reduction should be done in such a manner as to allow native vegetation to move back into those areas where the tamarisk was removed. In comparing the strategies discussed above, the average tamarisk population during a cycle is a more important indicator than the actual population in 2051 (when all control cycles are "bottomed out").

Using the biannual application of Method 1 in combination with a 20 year cycle of Method 2 will reduce average tamarisk populations to 2% of their expected (natural) population in 2051. Population levels will be kept low by the 2 year

cycle of Method 1, allowing native species to reclaim tamarisk sites. The 20 year cycle of Method 2 could be shortened, if funding is available, to hasten the decline in tamarisk populations. On the other hand, if funding were not available for application of Method 2, the population reduction already achieved can be maintained by biannual application of Method 1.

The slow recovery of tamarisk populations along Jim Camp Wash after the 1978-1980 study suggest that control work be carried out drainage by drainage. Although the reason for the poor recovery of tamarisk along Jim Camp Wash is not known, it is reasonable to capitalize on the observed effect to gradually clear the Park of tamarisk. Control in those drainages already cleared (Dry Wash and Jim Camp) should continue so that gains made will be maintained. Additional drainages should be treated based on the availability of funding to treat the area, the sensitivity of the area to tamarisk colonization, and management needs. Sensitivity should be based on the biological aspects of tamarisk population growth. Those drainages with a small tamarisk population but extensive available habitat should have a high priority. Examples include Cottonwood Wash and tributaries to the Lithodendron Wash. Management needs, on the other hand, should focus on the non-biotic implications of tamarisk growth. Examples include wilderness areas, where tamarisk may represent human actions, or at high visitor use areas, where tamarisk presents a non-native vegetative community for (or detracting from) visitor impressions of the Park biota.

Limitations of the Modeled Predictions

A major drawback to predicting long-range control strategies is the assumption that control techniques will remain constant well into the next century. This assumption is certainly not correct. Improvements are likely to be seen in the effectiveness of herbicides. Even now, Garlon 4 is probably more effective than the Garlon 3A used in this study. Herbicide effectiveness will mean greater population reductions when Method 2 is used. The development of effective biological controls could take the place of Method 1, by naturally limiting reproduction.

However, waiting for future improvements in control programs (Shenk, 1977) is probably no longer warranted. Although it is not possible to completely eliminate tamarisk from Petrified Forest National Park, it is possible to reduce the population. Such reductions must be used to keep the Park's wash-side environment from being degraded into tamarisk-dominated thickets. From a biological standpoint, there is a tremendous difference between tamarisk as an occasional component of the wash-side environment, and tamarisk as the dominant member of the plant community there (see Stevens, 1989; Brown, 1989 and Gay, 1989).

REVEGETATION

Revegetation has been seen as a possible deterrent to further tamarisk introduction and spread in Petrified Forest National Park. Review of the plant tolerance data (Bowman, 1987) provides some insight as to the plants that could be successful in the "tamarisk niche", replacing or delaying the return of the tamarisk after its removal.

In larger washes, where subsurface water is available year-round, the introduction of willows (Salix exigua) may be practical. However, field observations to date show all willows encountered in the park have been planted, perhaps as part of earlier erosion control projects (Bowman, personal observation, see also Johnson, 1970). Those along Dry Wash and Lithodendron Wash are in rip rap, probably placed in the 1930's. Along the Puerco, willows were planted to help stabilize the riverbanks (Superintendent's Monthly Report, 9/13/51). Until a natural role for willow can be determined in the park, planting willows may be equivalent to substituting one exotic for another.

Willow is not the only shrub considered. The presence of black greasewood (Sarcobatus vermiculatus) in riparian environments made it another candidate. Greasewood naturally occurs in swales and poorly drained areas. In Petrified Forest it is not common along the washes where tamarisk is found. It may be that the greasewood is already keeping tamarisk from colonizing those areas where greasewood is established. However, if greasewood is a suitable replacement for tamarisk throughout the Park, more greasewood plants would be expected along washes. Thus, greasewood may be suitable for some, but not all or even many, areas.

The planting of shrubs gives the best hope for long term replacement of tamarisk. Preliminary analysis of transect data from 1987 shows the most common native shrub along washes is the rubber rabbitbrush (Chrysothamnus nauseosus). A seed source for this plant could be located to allow planting on tamarisk sites. However, the species is highly variable, with botanists reporting up to 20 subspecies (Weber et al., 1985). The native subspecies has/have not been determined for Petrified Forest, a step necessary before planting this shrub.

Western wheatgrass (Agropyron smithii) is another candidate for revegetation. It is common along the washes and may be naturally reseeding, especially given the disturbances of control efforts. The wheatgrass is a cool season grass, which means it could provide cover, shade, and use water in the spring, whereas most native grasses in the area perform these functions in the summer and fall. Since tamarisk is a cool-season plant, the wheatgrass could compete directly with the tamarisk. Natural reseeding of the plant should be noted when monitoring transects.

Natural revegetation may be sufficient to recolonize tamarisk sites after its removal. Transects of vegetation were run as part of all phases of the present study, although the data has not been analyzed. Preliminary observation of the data collected seems to indicate most plant losses with the removal of tamarisk are related to the loss of shade and trampling. However, by piling the cut tamarisk in the area of the stump, enough shade may be generated to encourage other species to recover or recolonize the area. No examples of tamarisk sprouting from cuttings was found in the present study, so brush piling may not only help establish native species, but also be a beneficial means to dispose of cuttings.

CONCLUSION

Results of the 1987-1990 tamarisk control program at Petrified Forest provide data on effective methods and realistic expectations for control of this exotic species. The data also allows projections of tamarisk populations in the Park, and development of a long-term strategy for tamarisk control. It appears the tamarisk population in the Park has only begun a rapid population growth. Action now can slow or stop this growth, limiting the biotic changes that would result from such a major change in Park wash-side vegetation.

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