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Publication Date
1987-05-01

THE EFFECTS OF STREAMFLOW REGULATION ON RIPARIAN VEGETATION

WATER RESOURCES CENTER PROJECT-649

TECHNICAL COMPLETION REPORT

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ABSTRACT

A study of the effects of streamflow regulation on riparian vegetation focused on seedling establishment along 30 low-gradient, alluvial streams throughout central California. Initial establishment densities were generally lower on regulated streams than along non-regulated ones. However, prolific establishment occurred on the recently regulated streams as the vegetation adjusts to new stream conditions. Seedling survival was slightly greater on regulated streams than non-regulated ones following the 1985-1986 flooding. Survival was much higher on both regulated and non-regulated streams during the year of low discharges (1986-1987).

Seedling survival and growth were monitored in a controlled experiment simulating regulated and non-regulated conditions. Survival did not vary considerably among species. Growth was less in the fluctuating water level treatment than under simulated non-regulated conditions. Growth was higher for all four common species under the fluctuating treatment in a gravelly substrate but lower for cottonwood and sandbar willow in a sandy substrate.

July, 1987

INTRODUCTION

Within California's Mediterranean climatic region, riparian communities have developed in response to streamflow regimes with peak flows in the winter to late spring and declining flows in summer. Regulated flow releases are not synchronized with this natural regime: winter peak flows are reduced while summer flows are substantially higher than pre-regulation levels. Fluctuating summer hydroelectric releases alternately expose and inundate landforms. The germination of many riparian species is linked with declining water levels so the change in summer flows on regulated streams may be expected to alter initial seedling establishment. Since seedlings are generally intolerant of growing season flooding, seedling survival may also be affected.

This project was designed to measure and evaluate the impacts of streamflow regulation on riparian vegetation. Three objectives were designated to meet this goal: (1) assess the impacts of streamflow regulation on riparian forest stand structure, (2) quantify the effects that streamflow regulation has on seedling establishment and survival, and (3) identify patterns of streamflow regulation that can be utilized to either enhance riparian establishment or limit channel encroachment.

The study region comprised those streams draining into the Central Valley and the interior valleys of the central Coast Ranges of California. The streams flowing through this area are low gradient alluvial channels along which annual establishment periodically survives to form extensive riparian woodlands. The dominant woody riparian species are similar throughout the region: white alder (Alnus rhombifolia), mulefat (Baccharis viminea), sycamore (Platanus racemosa), Fremont cottonwood (Populus fremontii), Gooding's willow (Salix goodingii), sandbar willow (S. hindsiana), and red willow (S. laevigata). The species are typical colonizers: their abundant light-weight seeds germinate in late spring/early summer on moist, sunny landforms.

Potential study sites were selected from USGS (United States Geological Survey) gaging station locations with adequate discharge records. Stations with tributary inputs or diversions that affected the recorded discharge were eliminated. Sites with evidence of land use disturbance (agriculture, grazing, residential development or gravel operations) were also excluded. Of the remaining, 31 streams were selected. Twenty-two of these had regulation periods ranging from 4 to 69 years. The non-regulated streams were mostly in the upper Sacramento Valley as few such streams are non-disturbed in other sections of the state.

The study streams were the Russian River, East Fork Russian River, Dry Creek (Russian River Basin), Arroyo Valle, Alameda Creek, Coyote Creek, Arroyo Seco, Salinas River, Sacramento River, Cottonwood Creek, Battle Creek, Mill Creek, Thomes Creek, Deer Creek, Stony Creek, Big Chico Creek, South Fork Honcut Creek, Putah Creek, American River, Mokelumne River, North Fork Calaveras River, Calaveras River, Stanislaus River, Tuolumne River, Merced River, Chowchilla River, Fresno River, San Joaquin River, Kings River, Tule River, and the South Fork Kern River.

METHODS

Three approaches were used: (1) observations of riparian forest structure, (2) measurements of seedling establishment and survival and (3) an experiment to assess the response of riparian species to different water level regimes. The observations on forest structure began the first year of the project, 1984-1985. Seedling establishment along streams was studied during the second and third years, 1985-1987. The experiment was conducted during the summer of 1986.

Field Studies.

Many streams are regulated by a series of dams and/or diversions, but our analysis was confined to regulatory structures within the foothill zone. We delineated three potential survey segments on each regulated stream: immediately below the dam ("IBD": dam to the first tributary), below the dam ("BD": below the first tributary) and above the dam ("AD": above the reservoir drawdown zone). Some of the latter sites were non-regulated but most had a dam several miles upstream. Non-regulated rivers were studied near gaging stations at comparable elevations. Many regulated segments were not surveyed due to changes in vegetation between "BD" and "AD" segments or access problems: 32 regulated segments and 12 non-regulated segments were surveyed.

We began our surveys of each segment by a qualitative evaluation of stream characteristics, forest composition and size structure relative to fluvial landforms, and the extent of establishment within the segment. We also recorded the extent of potential landforms suitable for establishment and their availability for colonization.

Next we sampled seedling density within establishment zones on different reaches. Where there were sufficient seedlings, 10 consecutive plots (1m) were sampled parallel to the flow on 4 reaches. Initial measurements were completed shortly after germination in 1985. Sampling locations were recorded precisely for monitoring. Survival was monitored twice during the first year: a post-summer measurement provided information on drought and/or growing-season inundation losses and the post-winter survey reflected winter inundation/scour losses and total annual survival. A similar procedure was undertaken during 1986. Final monitoring of the 1985 and 1986 cohorts was in June, 1987.

Environmental data was also collected for each study site. Plot data recorded included canopy cover and surface particle size (distribution based on sampling 20 points per plot). Reach information included: the establishment landform, flow velocity, depth to water level from the band of establishment, channel width:depth ratio, and distance to the nearest seed tree of each species. Gradient, elevation and the channel:valley width of each segment were interpreted from USGS topographic maps. Pre- and post-regulation discharges were calculated from USGS gaging station records. Linear correlation and multiple regression were used to statistically evaluate the relationships between vegetation and environmental conditions.

Seedling Experiment.

The response of four common riparian species to different water tables was investigated in a controlled experiment. The purposes were to identify the response of species to simulations of regulated and non-regulated flow conditions in different substrates and to identify conditions that are either conducive or limiting to seedling establishment. The species investigated were: Alnus rhombifolia, Populus fremontii, Salix hindsiana, and S. laevigata.

Twenty seedlings of each species were grown in barrels under six treatment combinations: two substrates (sand, gravel-sand) and three water level treatments (a fluctuating level which simulated a regulated stream, a 1cm per day receding level which simulated a non-regulated stream with a slow daily drop in water level and a 2.5 cm/day recession rate which simulated a rapid summer water level decline). The treatments were replicated three times.

Measurements were taken every 10 days throughout the summer to monitor species response in terms of percentage of summer survival and average shoot growth. Root morphology and length was examined when the seedlings were removed in the fall of 1986. ANOVA was used to test for statistically significant differences in survival and growth among treatments.

RESULTS

Stream Conditions and Forest Structure.

Regulation by dams and diversions has altered both the volume of discharges and flow regimes of the study rivers. Over their periods of record, winter peak flows have decreased on every river. Substantially higher summer flows occurred on all regulated study streams except the San Joaquin River and Stony Creek. Releases on these two streams simulated the natural regime of high winter flows and receding summer flows. Dry Creek, the Russian River and the Salinas River were converted from intermittent to perennial streams by regulation. Peak flows on the Kings, Tule, Merced, Tuolumne, Stanislaus, and Mokelumne Rivers occur later in winter than in their pre-regulation periods. The flow regimes of Putah Creek, the Merced River and the Tuolumne River are reversed: summer is the period of highest flows and winter the lowest.

The differences in rainfall during the two winters were reflected by the stream discharges. Flooding during the winter of 1985-1986 resulted in scouring of many landforms. The most dramatic changes in channel configuration occurred on several of the smaller non-regulated streams: bars, islands, and sections of bank washed away. Many large trees were uprooted and transported downstream. Several regulated streams had extensive new deposits but the effects of flooding were not as damaging. During the winter of 1986-1987, the flows were relatively low. Most segments received minor deposition of fine sediments. Seedlings were washed away in a few locations but landforms generally remained stable. No evident difference in flood damage was observed between the two sets of streams.

Regulated and non-regulated streams also displayed different environmental conditions. The channels of non-regulated rivers were generally shallow and wide. They were slightly degraded but had numerous open bars containing a mix of coarse to fine sediments. Undisturbed low gradient segments occurring in wide valleys had forested floodplains and terraces. Most cottonwood-willow forests were composed of several size classes as were the sapling strips along the bars. Some intermittent streams were too dry for extensive periodic establishment. Non-regulated segments above dams generally had narrower valleys with coarser bed material and less bar development. A linear strip forest comprised of relatively more abundant alders was common.

Most of the regulated segments immediately below dams had substantial channel degradation: narrow and deep channels with minimal bar development resulted. The banks were steep and usually forested. High velocity flows of clear water released from the dams scoured out the fine material on some streams; others had a thin film of silt covering cobbles and gravels. The pre-regulation terrace was forested by mature cottonwoods and willows while the post-regulation streamside forest was dominated by younger alders and/or sandbar willow. Streamside forests were often composed of a single size class of trees. Saplings occasionally fringe the water's edge.

Segments not in the immediate zone of influence of the regulatory structure were generally intermediate between the "IBD" segments and non-regulated segments. Below dam segments were similar to "IBD" segments but had greater bar development. Regulated segments above the study dams varied greatly depending on the amount of alteration imposed by the dam upstream. Most of the bed material was cobbles and boulders: the few bars that formed were relatively small.

Forest structure appears to have changed as a result of the altered stream environments. The mature forests of all study segments were dominated by Fremont cottonwoods and one or more species of willows. Old sycamores were common on the high terraces of many streams. However, alders were uncommon on most non-regulated streams except for occasional clumps along steep banks and near overflow channels. Most of the forests on non-regulated streams contain trees in all size classes. Sapling and pole cottonwoods were missing from many of the regulated stream study segments. On these streams, strips of pole alders were common along the banks and seedling and sapling alders were common on bars. Since most regulated stream segments were not migrating laterally, the alders are restricted to a streamside position.

Seedling Establishment and Survival Along Streams.

A greater proportion of the non-regulated segments had establishment than did regulated segments: 92% vs. 31% in 1985 and 92% vs. 22% in 1986 had seedlings. The extent of establishment was generally lower on regulated streams than on non-regulated ones. Many of the reaches did not have a strip of seedlings sufficiently long to sample 10 plots on any reach or all 4 reaches. Most non-regulated streams had more than enough seedlings to do so. Consequently, despite the larger number of stream segments surveyed along regulated streams (32 vs. 12), many less seedling plots were located on regulated segments. The ratio of regulated stream plots to non-regulated plots surveyed was approximately 1:1.7 each year.

Establishment was limited by one or more factors: a reduced sediment supply (which restricts bar formation); high summer flows (which inundated bars during the establishment period); summer fluctuating flows (which scour out or bury seedlings); or mature forests lining the channel (which create a dense shade and limit establishment sites). Bars which were not drowned or were periodically inundated were often colonized by herbaceous species rather than tree seedlings. These limiting factors were common along regulated streams. The low sediment supply was also associated with limited establishment along non-regulated segments. Some intermittent non-regulated streams also had limited establishment due to seedling dessication. The lower number of regulated streams with establishment in the second year (31% vs. 22% of the total) was attributed primarily to the higher spring-summer flows in 1986.

The density of establishment was usually lowest on "IBD" segments but mostly moderate on "BD" segments and moderate to high on non-regulated streams in both years. Overall establishment densities were similar for both years: there was an average of 30-35 seedlings per square meter on regulated streams and 45-50 seedlings per square meter on non-regulated streams. Despite this similarity, establishment varied greatly on individual streams each year: many regulated streams had lower establishment in 1986 than in 1985. Some of the intermittent streams had double the amount of establishment in 1986 while several perennial non-regulated streams had lower densities.

Summer seedling survival was relatively high on non-regulated streams except for large drought losses on intermittent streams. Most regulated streams had quite low summer survival. Segments immediately below dams generally had fewer survivors than did "BD" segments. Of the regulated streams, survival was highest on recently regulated streams (e.g., Dry Creek) or on those which were only partially regulated (e.g., Russian River). Dry Creek was converted from intermittent to perennial flow by regulation. It had extensive bands of high density establishment both study years. Survival appears to have been high every year since regulation as saplings of various size classes now cover most of the formerly open bars.

The survival of seedlings through the first winter reflected the differences in discharges between the two years. Of the streams with establishment, seedlings survived the high winter flows of 1985-1986 on only one non-regulated segment (9%) and 40% of the regulated segments. The 1985-86 winter flows were sufficient to either scour out the seedlings or wash away these landforms entirely. The higher discharges during the 1986 establishment period resulted in seedlings growing relatively high on the bars and banks. Because of the higher summer discharges, less of the 1986 cohort succumbed to dessication. Many seedlings were above the 1986 winter flows so were not removed by scouring. Consequently, 80% of the non-regulated streams and 71% of regulated segments had survival following the mild winter storms of 1986-1987. The 1987 establishment is currently germinating low in the channel in response to the low 1987 flows: they could easily be scoured out next winter.

The 1985 and 1986 cohorts had very different survival patterns. Only 2% of the 1985 cohort survived the 1986 winter on non-regulated streams; by 1987 less than 1/2% was alive. Approximately 3% of the 1985 cohort along regulated streams survived in 1986 with less than 2% alive by 1987. In contrast, first year survival of the 1986 seedling cohort was significantly higher: 29% of the regulated stream cohort and 14% of the non-regulated stream cohort survived the 1987 winter.

The frequency and density of establishment and survival varied considerably by species. Alder seedlings were much more frequent on regulated streams. They represented a moderate proportion of total survival on regulated streams each year and on non-regulated streams in 1985. Red willow seedlings had very high densities on both sets of streams in 1985, comprising over 50% of the total surviving on regulated streams. In 1986, only 10% of the total were red willow seedlings. Cottonwood and mulefat formed approximately 85% of the total survival on non-regulated streams the first year and 70% the second year. These two species were much less abundant on regulated streams in 1985; however, cottonwood densities were comparable on regulated and non-regulated streams in 1986. Sandbar and Gooding's willow establishment was low on both sets of streams each year. Neither species survived on non-regulated streams in 1985 but both did in 1986. Sandbar willow survival was augmented by extensive sprouting. A few sycamore seedlings were observed along Arroyo Seco and Mill Creek. Their regeneration is limited by factors such as a low seed supply.

Some streams did not follow the general trends presented above for regulated versus non-regulated streams. Despite the presence of alders upstream, the Calaveras River has sandbar willow rather than alders entering immediately below the dam. Big Chico Creek is a non-regulated creek lined by alders. It has fairly stable summer flow levels and a greater amount of fine sediments than the other non-regulated streams surveyed.

The information presented about the effects of regulation on riparian vegetation is directly applicable to areas within the immediate influence zone of dams. The impacts of regulation often diffuse as tributaries below the dam contribute additional sediments and non-regulated flows. However, distance cannot be used as a predictor of the level of regulation: the degree of impact reduction is influenced by the type of flow releases and the sediment supply. For example, large clear-water releases originating from dams several miles upstream scoured seedlings in several regulated "AD" segments. Conversely, the additional water appeared to increase survival along those low gradient "BD" segments having sufficient substrate for annual high density establishment. This situation occurred primarily on partially regulated streams or where many non-regulated tributaries enter, for example, along the lower Russian River and lower Sacramento River.

Nor was it possible to correlate the period of time a stream was regulated with the amount of establishment. Although there is a general trend for decreased establishment over time, some streams which had been regulated for 20 years or more did not have establishment, while some regulated for more than 60 years had a few seedlings. Again, the degree of impact the regulation has on the sediment supply and flows is more influential on the establishment potential.

However, there does appear to be a regeneration sequence along regulated streams which differs from that along non-regulated streams. Instead of the typical periodic pulses of establishment displayed as even-aged bands across the floodplain, the altered stream conditions apparently induce a pulse of establishment for the first few years following regulation with little subsequent establishment. Dry Creek is an example of a stream at the first stage of regulation: it has numerous bars and substantial establishment. The stage following this initial pulse, has small patches of seedlings establishing on the remaining available substrates, provided they are not flooded. Some streams reach the final stage where there is little potential for additional establishment of pioneer species rather quickly while others do not. Over a long period of time, the forests along regulated streams may become quite different in size structure and composition than their non-regulated counterparts.

Ecological Implications.

The field studies illustrates the dependence of riparian vegetation on streamflow and associated stream conditions. The data from the two years depict the variation in establishment along different streams in any particular year and the variation in establishment along one stream under different flow conditions. The substantial stream to stream establishment variability resulting from different flows and sediment supply was not clearly separated on the basis of "regulated" versus "non-regulated" streams. The question which arises is: How can the differences in establishment be attributed to regulation rather than some other factor?

The wide variation among non-regulated streams suggests that a portion of the differences in establishment must be attributed to the underlying environmental conditions of the watersheds. The difference in establishment clearly reflects the spectrum of environmental conditions of the streams studied: from dry intermittent channels with relatively low establishment to perennial channels with frequent establishment and periodic survival. Regardless of flow regime, some streams have conditions which may never allow prolific establishment. For example, the banks of both Stony Creek (regulated) and Arroyo Valle (non-regulated) are so loosely consolidated that seedlings succumb to either drought or wash outs. The study segment along South Honcut Creek (a non-regulated stream) has a low supply of sediment due to its proximity to the upstream bedrock channel. This makes it similar to regulated streams with their lack of available habitat for initial establishment.

However, in several situations, the differences in establishment were obviously linked with the changed flow and channel conditions following regulation, e.g., higher summer flow releases causing bars to be inundated during the establishment period; large fluctuating flows released during the growing season scouring or burying young seedlings; high releases prior to winter storms inundating growing seedlings and restricting sediment transport thereby limiting bar formation and sometimes resulting in too few fines for germination. Over time, the limited sediment supply causes the channel to deepen and narrow. This reduces the rate of lateral migration, typically leading to an incised channel with fewer sites for establishment.

The complicating factor in this study are the land and water uses which affect establishment/survival patterns. Such uses include livestock grazing, groundwater pumping, deposition of silts from agricultural lands and gravel mining and dredging. Although sites with disturbance were avoided during the study, impacts are generated both up and downstream from their origin. For example, gravel mining causes channels to widen and extensive bars to form. The exposed bars are often too dry to support seedlings under the natural flow regime. However, once such a stream is regulated, the increase in summer flows makes these exposed areas suitable for abundant colonization.

Flow Management.

Water project managers are faced with two concerns when considering riparian vegetation management along low gradient streams: the encroachment of vegetation into channels following regulation and the need for enhancement of riparian vegetation, particularly to ensure periodic establishment over the long-term. The vegetation responds to both the altered flow regime and the changes in channel morphology/sediment supply following regulation. Thus, if regulation causes the channel to narrow and deepen, the riparian vegetation maintains its position relative to water level by colonizing closer to the middle of the old channel. These problems can be partially addressed through flow management techniques, similar to instream flow requirements developed to maintain fisheries on regulated streams.

The prolific establishment following regulation appears to be a consequence of both increased summer moisture eliminating dessication losses and reduced scouring and flooding during the winter. Thus, the encroachment problem might be minimized along newly regulated reaches by releasing periodic flushing flows. The disadvantage to this technique is that flushing flows could possibly increase the regeneration problem by accelerating the removal of the remaining fine sediments. A period of summer drought would partially reduce encroachment but would be ineffective without flushing flows. This latter appproach would not be compatible the purposes of some regulatory structures (i.e., irrigation water supply) or with instream flow requirements for fisheries.

Flow management regimes could be devised to provide periodic establishment. This would entail reversing the flow-associated conditions which limit establishment under regulation, such as eliminating those high flows during the establishment period that drown landforms. The effectiveness of this technique would be dependent upon the amount of habitat available for colonization: if most bars are depleted due to restricted sediment supply, establishment sites will be limited.