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Conservation Planning for the Colorado River in Utah

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Abstract: Conservation Planning for the Colorado River in Utah

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Strategic planning is increasingly recognized as necessary for providing the greatest possible conservation benefits for restoration efforts. Rigorous, science-based resource assessment, combined with acknowledgement of broader basin trends, provides a solid foundation for determining effective projects. It is equally important that methods used to prioritize conservation investments are simple and practical enough that they can be implemented in a timely manner and by a variety of resource managers. With the help of local and regional natural resource professionals, we have developed a broad-scale, spatially-explicit assessment of 146 miles (~20,000 acres) of the Colorado River mainstem in Grand and San Juan Counties, Utah that will function as the basis for a systematic, practical approach to conservation planning and riparian restoration prioritization. For the assessment we have: 1) acquired, modified or created spatial datasets of Colorado River bottomland conditions; 2) synthesized those datasets into habitat suitability models and estimates of natural recovery potential, fire risk and relative cost; 3) investigated and described dominant ecosystem trends and human uses; and 4) suggested site selection and prioritization approaches. Partner organizations (The Nature Conservancy, National Park Service, Bureau of Land Management and Utah Forestry Fire and State Lands) are using the assessment and datasets to identify and prioritize a suite of restoration actions to increase ecosystem resilience and improve habitat for bottomland species. Primary datasets include maps of bottomland cover types, bottomland extent, maps of areas inundated during high and low flow events, as well as locations of campgrounds, roads, fires, invasive vegetation treatment areas and other features.

Assessment of conditions and trends in the project area entailed: 1) assemblage of existing data on geology, changes in stream flow, and predictions of future conditions; 2) identification of fish and wildlife species present and grouping species into Conservation Elements (CEs) based on habitat needs; and 3) acquisition, review and creation of spatial datasets characterizing vegetation, fluvial geomorphic and human features within the bottomland. Interpretation of aerial imagery and assimilation of pre-existing spatial data were central to our efforts in characterizing resource conditions. Detailed maps of vegetation and channel habitat features in the project area were generated from true color, high resolution (0.3 m) imagery flown September 16, 2010. We also mapped channel habitat features at high flow on 1.0-m resolution, publicly available, true color imagery. We obtained additional layers such as land ownership, roads, fire history, non-native vegetation treatment areas, and recreational use features from public sources and project partners.

Habitat suitability models were created for groups of terrestrial species by combining spatial datasets with the habitat needs of conservation elements, guided by literature, where available, and extensive use of expert knowledge. Conservation elements for endangered fish species life stages were identified but not modeled. Terrestrial CEs included:

- **Riparian Overstory** - yellow-billed cuckoo, Bullock's oriole, black-headed grosbeak, blue grosbeak, warbling vireo, Cooper's hawk, screech owl, saw-whet owl, and bald eagle, *(best: tall trees, dense canopy, diverse shrub understory, no tamarisk);*
- **Riparian Understory** - southwestern willow flycatcher, common yellowthroat, yellow warbler, yellow-breasted chat, beaver, northern river otter, black-necked garter snake, *(best: dense mesic shrubs near still water, no tamarisk);*
- **Bat Feeding** - Allen's big-eared bat, Townsend's big-eared bat, fringed myotis, Yuma myotis, big free-tailed bat, spotted bat *(best: diverse vegetation, close to still water);*
- **Bat Watering** - big free-tailed and spotted bats *(best: still water with no tall vegetation);*
- **General Diversity** - no target species *(best: diverse cover types and structure);*
- Other models - **Open Land Species,** and **Rocky Fringe Snakes**

In addition to relative habitat quality and distribution, we created supplemental models intended to assist reach and site-based planning. The Relative Cost of Restoration model includes ease of access to bottomland areas (e.g., by vehicle, on foot, or raft/camp), and presence and relative abundance of both woody and herbaceous non-native species. The Recovery Potential model is based on the presence of native species, absence of non-native species, and access to water from high stream flow. Two fire models, All Fire and Natural Fire models, highlight different aspects of fire risks. The Natural Fire Model reflects only the relative density of tamarisk and native trees, with ratings of 'high' showing where both are prevalent. The All Fire Model shows greater risks associated with human traffic (roads and campgrounds).

Watershed-wide trends in bottomland conditions (channel narrowing, loss of secondary channel habitats) are likely driven by extraction and impoundment of water in the Colorado mainstem and major tributaries and by expansion of native and non-native vegetation. Areas of high quality habitat are very limited for most CEs, in part due to the preponderance of simplified vegetation cover (e.g., tamarisk), and in part due to the rarity of particular habitat features such as tall trees or still-water channel types. For areas with moderate quality habitats, component layers of each model show the factor or factors lowering habitat quality, allowing identification of actions possible. Multiple habitat models can be overlain, showing reaches and locations where restoration activities may benefit more than one CE, or where activities benefitting one CE may decrease habitat quality for another. Mapping of rare or highly desirable habitats (e.g., still, warm water for young, endangered fish), can be evaluated for proximity to other habitat features and hazards (e.g., spawning areas or locations of potential fish stranding sites). Comparing habitat suitability models with supplemental models allows identification, for example, of high quality habitats that may be threatened by fire, moderate quality habitats that have high potential to recover without intervention, or areas that are so remote and weed infested that restoration would be cost prohibitive.

Data are available both in a summarized form in this document, and on a project website [https://sciencebase.usgs.gov/crcp]. Spatial data in the website is presented as downloadable layers and interactive thematic maps. Efforts here were intended to be a 'coarse first cut' at habitat characterization, rating of habitat quality, and identification of factors associated with restoration planning. Many opportunities exist for comparing relative suitability with species occurrence data, performing sensitivity analysis on model components, updating layers with current conditions, and improving model representations with higher quality data such as high resolution topography provided by LiDAR.

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Introduction

The natural dynamics of river bottomlands are frequently disrupted by human activities. Since the 1800s, land clearing for agriculture, housing, industry, transportation and recreation has altered bottomland habitats in much of the western US (Patten, 1998). In addition, dams and diversions have changed hydrologic regimes and sediment dynamics, commonly decreasing peak flow magnitudes and frequencies, increasing base flows, and shifting the timing of peak flows (Graf, 2006; Poff and Zimmerman, 2010). Further alterations to historic flow regimes are expected due to climate change (BOR, 2012; Deems et al., 2013). Changes in river flows combined with bottomland vegetation management and species introductions have created conditions favorable for colonization and spread of non-native riparian species including tamarisk (*Tamarix* spp.), Russian knapweed (*Acroptilon repens*), and Russian olive (*Elaeagnus angustifolia*) (Merritt and Poff, 2010; Stromberg et al., 2007; Katz and Shafroth, 2003). The net result of these factors has been widespread change in the quality and quantity of habitat for fish and wildlife species dependent on bottomland habitats (Graf, 2006; Poff and Zimmerman, 2010).

Poorly functioning riparian ecosystems impact a disproportionate number of fish and wildlife species and human concerns, relative to spatial extent (Gregory et al., 1991), prompting nationwide efforts to restore lost functions or attributes (Bernhardt et al., 2005). While past efforts have typically been small-scale and often narrowly focused (Bernhardt et al., 2005), restoration actions effective over the long-term require assessment of current conditions and trends in resources and human use. Effective approaches often involve assessing conditions at the scale of disturbance (e.g., basin-wide flow alteration, local fire, etc.) and applying treatments that target ecosystem processes rather than specific habitat features (Beechie et al., 2010; Kondolf et al., 2006; Jacobson et al., 2011).

The Colorado River is subject to locally- and globally-driven anthropogenic impacts and demands that are common in the southwestern US (Capon et al., 2013; Kim et al., 2006). Nineteen large dams and a vast network of diversions in the Upper Basin (above Glen Canyon Dam) deliver water to agriculture, industry, recreation, and millions of households in five western states and to both sides of the Continental Divide. Scientists predict that climate variability, already considerable in the Colorado River watershed, is poised to become even greater, changing precipitation patterns both in type and extent, and in different ways for headwater versus lowland tributaries (Seager et al., 2012). Changes in precipitation timing are projected to decrease streamflow (Das et al., 2011), likely with detrimental effects on stream processes and native biota (Richter et al., 1996; Deems et al., 2013). In the Colorado River Basin, water demand is already exceeding supply in some years due to population growth (BOR, 2012). Predicted declining and erratic streamflow (Seager et al. 2012) lends even greater urgency to preserving and restoring habitats for already-declining populations of fish and wildlife along the Upper Colorado River mainstem, and the riparian processes that sustain them (Seavy et al., 2009). Restoration planning requires consideration of this heavily regulated water management, as well as current resource conditions, ecosystem trends, projected impacts from climate change, and recognition of the interrelationships between human and riverine processes.

Our study focuses on the stretch of the Colorado River between the border of Utah and Colorado and the upper extent of Lake Powell (upstream of Hite, Utah and Canyonlands National Park southern border), and exemplifies the local, regional and global impacts to riparian ecosystems and the multi-agency, interdisciplinary approach needed to coordinate effective restoration in a large and complex landscape in the face of climate change (Hermoso et al., 2012; Capon et al., 2013). As a conduit delivering water from the Rocky Mountains to the desert Southwest, this river segment is a nexus of natural and human activity in the region, and integrates the effects of a multitude of flow management structures on hundreds of miles of tributaries and the mainstem. As such, its size and complexity offer an opportunity to strategize restoration efforts and develop tools that could be applied in other basins. To this end, the National Park Service (NPS), Bureau of Land Management (BLM), The Nature Conservancy (TNC), Utah Forestry, Fire and State Lands (UFFSL), and the U.S. Geologic Survey (USGS), are working together to coordinate information and management activities on the Colorado River corridor in Utah to benefit both natural resources and the public in San Juan and Grand Counties in Utah. This combined planning effort is called the Colorado River Conservation Planning project (CRCP). While most of these partners have been implementing restoration projects for years, the complexity, size and increasing urgency of restoration has called for greater coordination and larger scale strategic planning.

The current planning challenge is to determine the "where" and "how" of implementing riparian management treatments, prioritizing actions over time (Hobbs et al., 2003; Bottrill et al., 2008; Groves et al., 2012), and optimizing activities for the best possible outcomes for sometimes-competing benefits (Hermoso et al., 2012). Prioritizing restoration actions requires accounting for the perspectives and goals of multiple user groups across a diverse landscape with often-conflicting priorities, and an

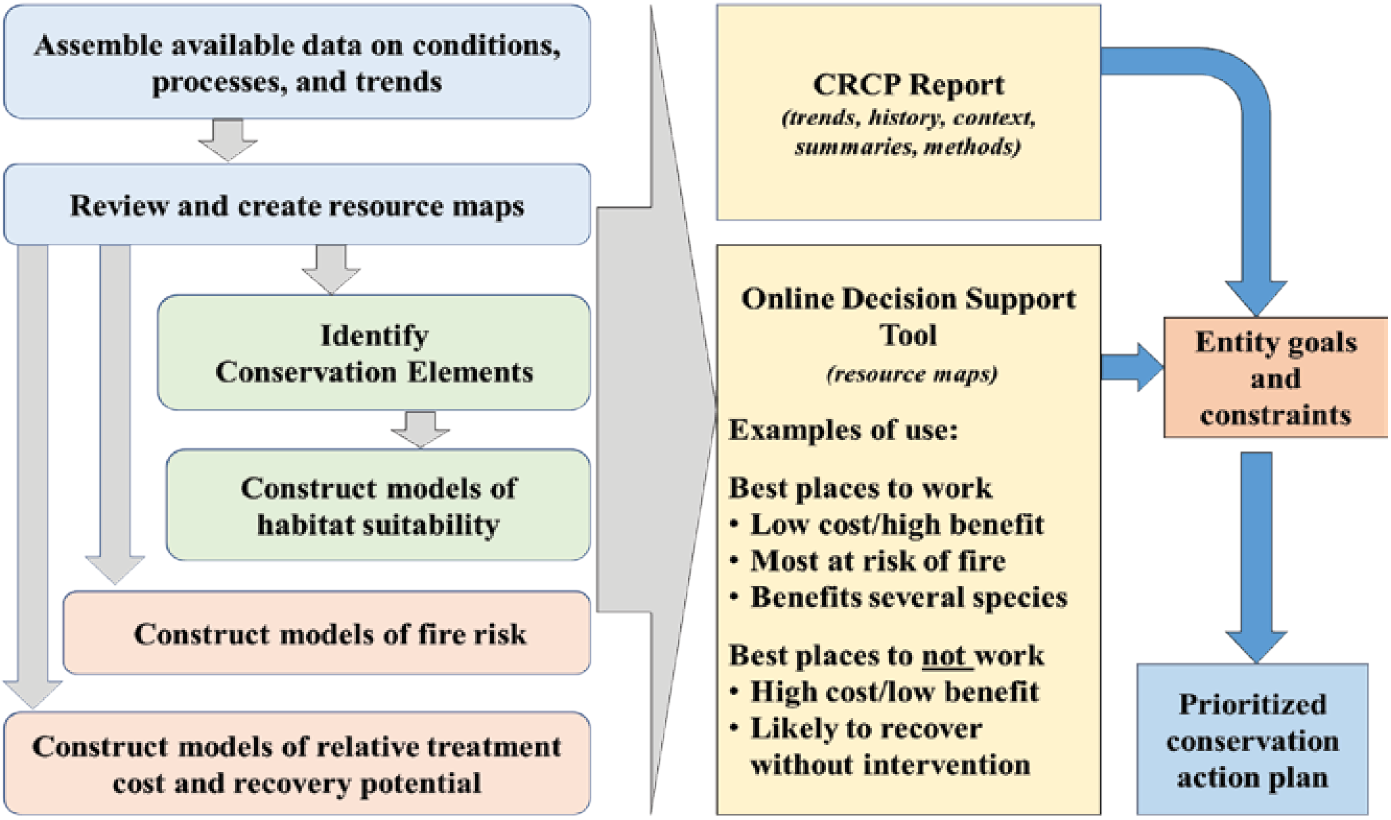

Figure 1 — Illustration of steps, resources, and outcomes associated with the Colorado River Conservation Planning Project.

understanding of primary river processes, conditions and trends. In the absence of extensive published data, we have relied heavily on the collective expert knowledge of local and regional resource specialists (Johnson and Gillingham, 2004; MacMillan and Marshall, 2005), as is increasingly common and necessary due to time constraints on gathering data and the diverse species in need of habitat restoration and conservation (Irvine et al., 2009; Kuhnert et al., 2010; Drescher et al., 2013).

Detailed resource maps can be used in project planning to help maximize the benefits of restoration dollars, minimize overlap of restoration efforts, and provide specificity in desired outcomes and estimated risk of failure (Groves et al., 2012; Shafroth et al., 2008). An assessment of fundamental resource conditions across a broad area (e.g., where are the trees, where are patches of dense shrubs near water) can show the relative distribution and abundance of habitats for groups of species with similar needs (Conservation Elements – CE's). In turn, these habitat maps can be used by resource managers to help 1) identify locations where actions could benefit multiple groups of habitat needs simultaneously (Hunter, 2005); and 2) prioritize actions based on relative cost, potential to recover without intervention, and risk of destruction by fire. Alternatively, these maps can show where quality habitats are relatively abundant or costs are prohibitively high, suggesting that work might be best performed elsewhere.

For this project we have:

1) assembled available data and identified basin trends,

2) reviewed and created additional spatial datasets as needed for assessing current habitat conditions,

3) grouped species into CEs based on habitat needs,

4) constructed models of habitat suitability for each terrestrial species CE,

5) constructed associated models showing risk of fire to ecological resources, relative cost of restoration, and potential for natural recovery (Figure 1), and

6) offered suggestions for restoration approaches and next steps.

This text is accompanied by a suite of condition assessment and habitat suitability maps accessible through an on-line decision support system available at https://sciencebase.usgs.gov/crcp. This work, created in concert with a suite of resource experts, provides a common foundation for devising strategies and priorities across agencies, and balancing the variety of needs for bottomland resources. While our work here is focused on the Colorado River corridor, the protocols developed and approach taken are potentially applicable to other river segments within the region and beyond.

Description of Study Area

The CRCP project area is located in Grand County and San Juan County, Utah and encompasses the adjacent riparian areas from the Utah-Colorado state line through Cataract Canyon, downstream of the confluence with the Green River (Figure 2). The National Park Service manages a majority of these lands in the lower third of the project area; the Bureau of Land Management and Utah Forestry, Fire and State Lands manage most of the upper two-thirds. Smaller, interspersed parcels are privately owned, including the Scott M. Matheson Wetland Preserve, co-owned by The Nature Conservancy and Utah Division of Wildlife Resources in Moab Valley. Land area and details of human use cover types and land ownership are summarized in Appendix A.

Riparian restoration and fire management efforts in the project area have covered more than 440 ha as of early 2013 (BLM, Moab District, Fuels Treatment spatial data, 2013). Resource managers have implemented projects controlling non-native plant species and revegetating with native species in an effort to build resilience in plant communities, decrease fire risk, and improve available habitats. Tamarisk leaf beetles (*Diorhabda* spp.), released in the Upper Colorado Basin in 2006 to provide biological control of the invasive shrubs tamarisk (*Tamarix* spp.), have spread throughout the project area, defoliating large tracts of tamarisk and altering floodplain habitat availability and quality (Nagler et al., 2014; Hultine et al., 2010). The spread of the tamarisk leaf beetle has altered restoration priorities as repeated defoliation and decline of tamarisk cover is releasing both native and non-native species from competition and changing fire risks and patterns of human recreational use (Dudley and Bean, 2012; Hultine et al., 2014; Ostoja et al., 2014).

Colorado River Hydrology

The Colorado River and tributaries upstream of the project area are intensively managed and impacted by human uses. Operations are regulated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the 'Law of the River' (BOR – Law of the River; accessed 5-1-2015). A multitude of impoundments and other structures divert flow within and out of the basin, changing both the volume and timing of flow. Dust-on-snow, relating to lowland land uses (Neff et al., 2008), is altering the timing and volume of snowmelt runoff to earlier in the spring, especially in dry years with strong spring winds. Projected changes in precipitation timing and intensity may further complicate flow management for human use and maintenance of stream processes (BOR, 2012).

The following section is intended to provide an overview of dominant factors and trends impacting the ecohydrology of the project area, recognizing that management and alteration of flows are complex, extensive, long-term, and likely to increase with growing human populations and predicted shifts in climate (BOR, 2012). Dams mentioned here are either on or very near the mainstem Colorado River or on the mainstem of a substantial tributary. A full inventory and description of diversion structures, water management and flow impacts is beyond the scope of this project.

Impacts of water diversion, impoundments, and consumption are discussed here with data from two separate sources: 1) the hydrologic record (1912-2013, USGS - NWIS) from the Cisco gage (number 9180500) downstream of the Dolores River confluence, and 2) Bureau of Reclamation reconstructed flow estimates, without human modifications, for the Cisco gage (BOR; Natural Flow data; www.usbr.gov/lc/region/g4000/NaturalFlow/current.html).

Impact of Dams

Many dams on significant tributaries and the mainstem Colorado alter the hydrology of this reach; some by storage of flows in reservoirs or hydropower generation, and others by diverting flow for consumption (BOR, 2014). Dams high in the upper watershed include Granby and Shadow Mountain (BOR; completion dates 1950 and 1946), Wolford Mountain (Colorado River District; completed 1996), and Williams Fork (Denver Water; completed 1959). Dillon and Green Mountain dams on the Blue River both store water, with Dillon diverting water across the Continental Divide to the Front Range (Denver Water, completed 1963; and BOR, completed 1943), while Green Mountain stores water for downstream users (http://www.usbr.gov/projects/index.jsp). Three BOR dams make up the Aspinall Unit on the Gunnison River which enters the Colorado River just upstream of the project area: Blue Mesa (completed in 1966); Morrow Point (completed in 1968); and Crystal (completed in 1977). Dams in the Grand and Uncompahgre valleys are smaller (height and impoundment volume), but are major diversions for irrigation. These lower watershed dams were built between 1883 and 1916 and mostly before measurements began at the Cisco gage. The Dolores River has one major storage dam, McPhee (BOR, completed 1984), which regulates flow into the channel downstream and redirects some flow to the San Juan River. Flaming Gorge Dam, completed in 1964, is a large dam on the Green River, which joins the Colorado River inside of Canyonlands National Park at the lower end of the project area, well downstream of the Cisco gage. The Dolores River joins the Colorado River just upstream of the Cisco gage. There are another 10+ substantial dams on tributaries to the Gunnsion and Green Rivers not mentioned here, and many other smaller dams upstream are associated consumptive

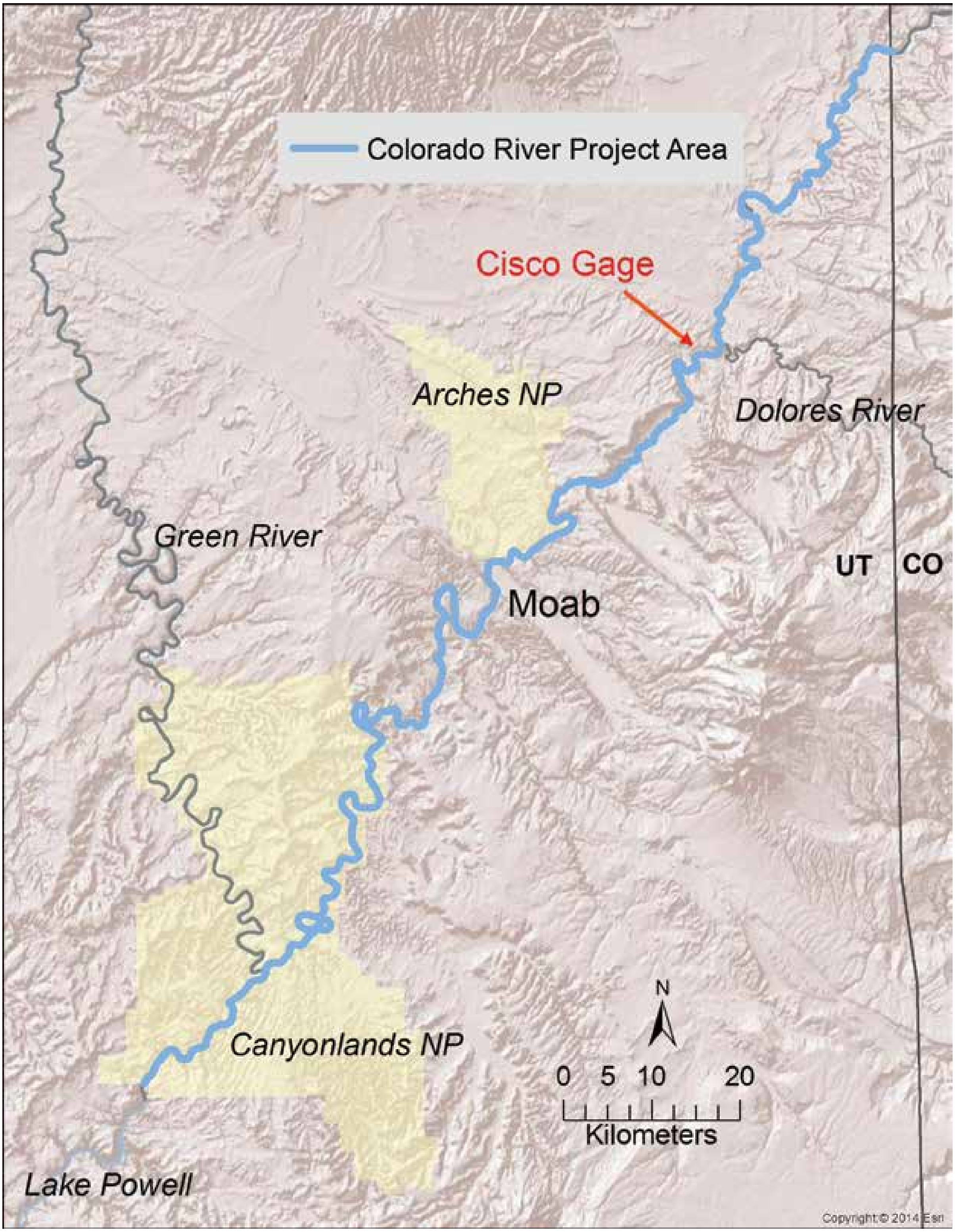

Figure 2 — The Colorado River Conservation Planning project area extends from the Utah/Colorado border to the southern boundary of Canyonlands National Park. Confluences of the Green and Dolores rivers with the Colorado are included within the project extent. The location of the Cisco stream gage (USGS gage #9180500), used for hydrologic analysis, is indicated.

uses (flow not returned to river channels). This analysis illustrates the combined impacts of upstream water diversion, impoundment, and consumption.

To evaluate the effects of these dams and diversions on flow in our study reach, we compared values for two simple metrics (1-day maximum annual flow, and the 1-day minimum annual flow) among two time periods (pre-impact, and post-impact). We defined the 'pre-impact' period as 28 years between 1914 to 1946 (including five years of missing gage data during the early 1900s) and the 'post-impact' period as 30 years from 1984 to 2013 (Figure 3). Although some dams were completed before 1946 and others after 1984, these two eras capture the gaged time periods before and after most of the significant dam construction. Impacts of the Flaming Gorge Dam on the Green River are not reflected in the Cisco gage. Dam construction dates are approximate, and, because most storage projects take several years to build and then several years to fill, there are variable impacts to river flows before the projects are fully operational. This analysis highlights the combined impacts of major dams and water consumption on the mainstem Colorado, Gunnison and Dolores rivers, recognizing that there are many additional dams on smaller tributaries with a range of completion dates and impacts. Because 1-day maxima of annual flow typically occur during the spring run-off, changes in 1-day maximum annual flow may reflect storage and consumption of spring runoff; changes in 1-day

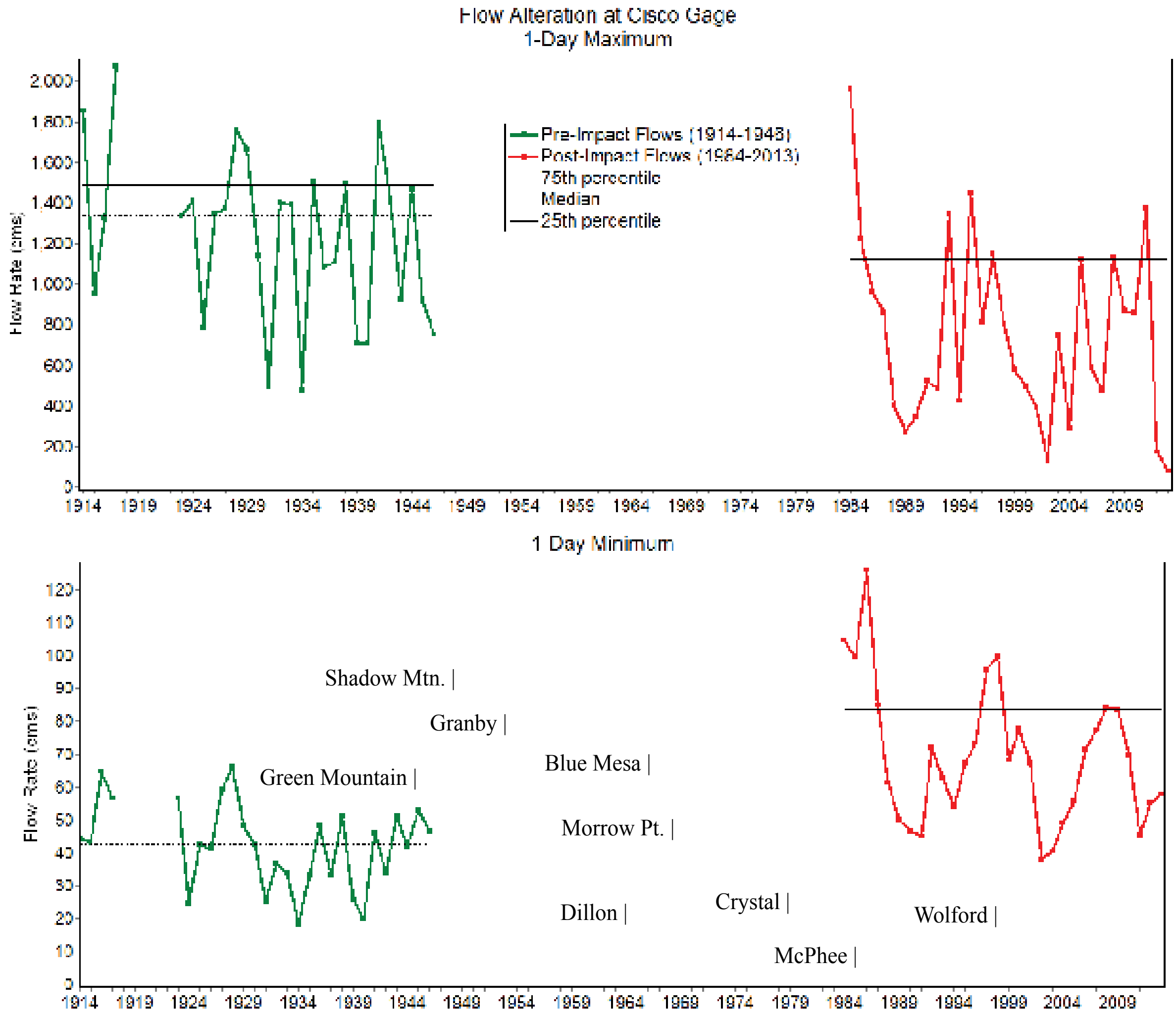

Figure 3 — One-day maximum and minimum flows for pre-impact (green line) and post-impact (red line) periods, as measured at the Cisco gage between 1914 and 2013, in m^3/s (cms). Five years of flow data were not recorded in the early 1900s, and years between 1946 and 1984 are excluded from the analysis. The approximate completion dates for some of the larger mainstem and tributary dams upstream of the Cisco gage are shown on the timeline of the lower graph. Shadow Mountain, Granby, Williams Fork and Wolford Dams are either on or very near the mainstem Colorado in the upper watershed; Blue Mesa, Morrow Point and Crystal Dams comprise the Aspinall Unit on the Gunnison River, and McPhee is on the Dolores River. Green Mountain and Dillon dams are on the Blue River in the upper watershed.

minimum annual flow may reflect storage releases, irrigation diversions, and return flows to the project area during the rest of the year. Changes in these metrics may also reflect climatic differences in the pre- and post-impact periods selected for analysis. We used the Indicators of Hydrologic Alteration (ver. 7.1.0.10; 2009) to facilitate the analysis.

Median 1-day maximum flows are 1,334 m^3/s (47,286 ft^3/s) in the pre-impact period, and 667 m^3/s (23,554 ft^3/s) in the post-impact period. Median values in the post-impact period are lower than the 25th percentile of values for the pre-impact period. The timing of these maximum flows (average for the 46 year period) has shifted only slightly earlier, peaking on average May 28 rather than May 30.

One-day minimum flows show the opposite trend, with a median value of 68 m^3/s (2,401 ft^3/s) in the post-impact period, a 62% increase over the 42 m^3/s (1,483 ft^3/s) in the pre-impact period. The timing of the 1-day minimum has shifted 40 days earlier in the season, with the lowest flows recorded averaging August 2 in the post-impact period rather than an average of September 10 in the pre-impact period.

Flow Depletion

To assess flow depletion, we compared pre- and post-impact period flows measured at the Cisco gage to estimate natural flow from reconstructions (BOR; Natural Flow data; www.usbr.gov/lc/region/g4000/NaturalFlow/current.html). Water used to meet human needs within the basin and east of the Continental Divide, including the Front Range urban corridor (BOR, 2012) and agricultural land in the South Platte and Arkansas Basins (https://issuu.com/cfwe/docs/cfwe_cgtb_web), appears to be diverted primarily during snow melt runoff and summer (Table 1, Figure 4). Water is impounded and diverted to the Front Range by dams and collection systems very high in the watershed (e.g., Granby, Shadow Mountain, Williams Fork). The greatest reductions in flow volume are in May, June and July (Table 1), with low flow months of October to March showing median values that are higher than those expected under natural flow conditions. Note that average June peaks for reconstructed flows are about 15% higher in the pre-impact period, reflecting a wetter series of years in the early 19th century (Woodhouse et al., 2006).

Table 1 — Comparisons of averages of monthly median flows at the Cisco gage (acre feet per month) between actual flow (gaged flow) and reconstructed flow from Bureau of Reclamation.

Comparison of Monthly Average Median Flows, 1984-2010*

Flow Month	Reconst. Flow (ac ft)	Gaged Flow (ac ft)	% Difference from Reconst. Flow	Gaged Minus Reconst. Flow (ac ft)
Jan	175989	214454	+22	38465
Feb	168762	222249	+32	53487
Mar	260462	271744	+4	11282
Apr	578478	477120	-18	-101357
May	1539798	992576	-36	-547223
Jun	1688214	993175	-49	-695040
Jul	877343	471705	-46	-405638
Aug	446644	273770	-39	-172875
Sep	285913	266498	-7	-19415
Oct	274878	282930	+3	8052
Nov	243545	258317	+6	14772
Dec	199028	221408	+11	22380
Total	**6739056**	**4945945**	**-27**	**-1793111**

*The same post -impact period for the IHA analysis was not used because the natural flow reconstruction by the BOR does not include 2011-2013.

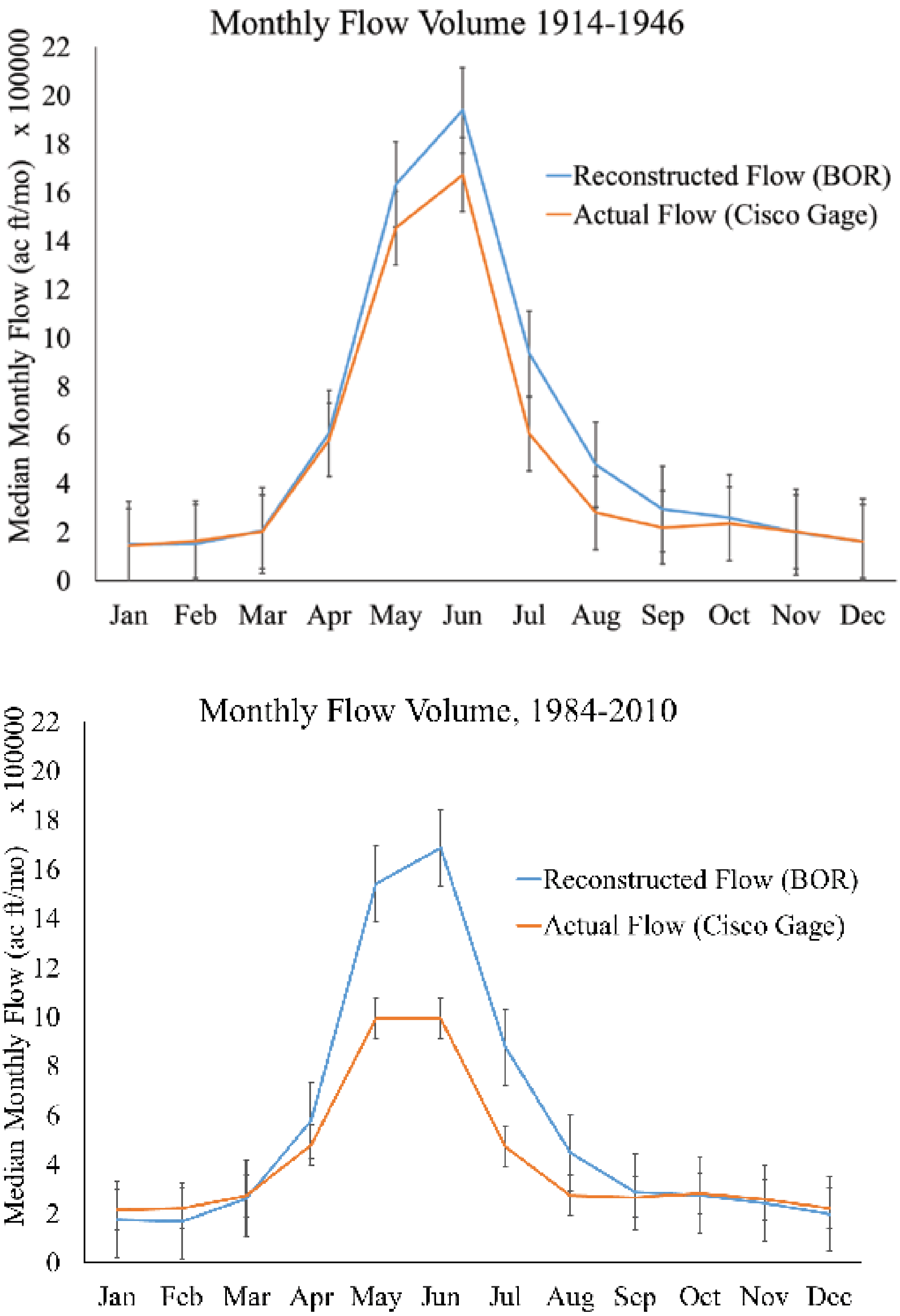

Figure 4 — Changes in median monthly flow as shown by comparing: 1) the total reconstructed flow calculated by the Bureau of Reclamation [blue lines show monthly median flow in acre feet/month] with 2) monthly average flows from USGS Cisco gage data [orange lines] for both the pre- and post-impact eras (1912-1946; 1984-2010). The same post -impact period for the IHA analysis was not used because the natural flow reconstruction by the BOR does not include 2011-2013; two additional years were added to the pre-impact period).

Dust-on-snow

Dust-on-snow events, which have occurred since the 1800s (Neff et al., 2008), have changed the hydrograph of the mainstem by shifting snowmelt up to three weeks earlier and increasing losses of mainstem flow to evapotranspiration (Painter et al., 2010; Deems et al., 2013). Researchers expect this phenomenon to increase with expected climate change, potentially shifting snowmelt runoff an additional three weeks earlier during years with extreme dust events such as those seen in 2009 and 2010 (Deems et al., 2013), and further complicating predictions for future Colorado River flows. Intensification of various land use activities following Euroamerican settlement of the West was well underway (Neff et al., 2008) before the advent of stream gaging (1912) used for the flow comparisons described above. Changes in flows due to extreme dust-on-snow events seen in 2009 and 2010 (Deems et al., 2013) are but two out of 28 flow years used for this analysis; a separate analysis comparing the relative magnitudes of dust-on-snow events relative to the effects of flow diversions, consumption and regulation would be warranted.

Fluvial Geomorphology

Sediment dynamics strongly influence channel form, riparian vegetation and habitats for fish and wildlife. These dynamics are dependent on both sources of sediment entering the bottomland and the capacity of the river to mobilize sediments. With decreasing peak flows and reduced sediment movement, channels narrow, become more simplified in planform, and become disconnected from their floodplain (Allred and Schmidt, 1999; Grams and Schmidt, 2002, Grams et al., 2007; Graf, 2006; Magilligan and Nislow, 2005).

Sediment Supply

Channel narrowing is a likely effect of the combination of lower high flows (described above) and no changes to sediment supplies from tributaries (assumed for the project area). The Colorado River mainstem within the project area has a reasonably intact (unregulated) sediment supply coming in from its smaller, lowland tributaries. Large tributaries, the Green, Gunnison and Dolores Rivers are dammed relatively high in their respective watersheds, so that their effects on sediment supplied to the mainstem may be dampened. Sediments from the smaller, lowland tributaries are typically delivered out of phase with the peak of snowmelt from uplands. Summer convective storms locally affect turbidity, but do not significantly impact stream flow volumes in the mainstem upstream of the project area (Van Steeter and Pitlick, 1998; Laub et al., 2013). A detailed study of the extent, effects and magnitude of changes to sediment supplies and mobility is warranted.

Sediment Mobility

With the reduction in frequency of flushing high flows, sediment mobility in the Colorado mainstem is compromised. Van Steeter and Pitlick (1998) documented that the suspended sediment load in the Colorado River upstream of the project area from 1964 to 1978 was 40-68% less than the long-term average. Suspended sediment is the dominant type of sediment (98%) moved through the project corridor (Butler, 1986; Pitlick and Van Steeter, 1998). In lower gradient reaches, suspended sediment is dropped from the water column, building up stream banks and creating mobile channel bars; these bars are associated with backwaters, side channels and isolated pools used by native fish (Williams et al., 2013; Valdez and Nelson, 2006). Without sufficient flushing flows, vegetation colonizes and stabilizes what would be transient (unvegetated and mobile) bars or open channel features, simplifying habitats available (Grams and Schmidt, 2002). More specific investigation of sediment and channel dynamics in the project area for current and future flows is warranted.

Channel Narrowing

Channels have narrowed dramatically since the 1950s (Figures 5 and 6). Figure 5 shows a series of photos from the fluvial geomorphically active Ruby-Westwater area in the uppermost portion of the project extent, upstream of confluences with the Green and Dolores Rivers. The filling of side channels and secondary channels is clear, as is the narrowing of the main channel by vegetation encroachment. The time sequence includes a 9-year span (1979 to 1988) containing the very high flows of 1983 and 1984, which were adequate to scour channels upstream of the project area (Pitlick and Van Steeter, 1998); and a 22-year span between 1988 and 2010 with minimal channel movement. The moderately high flow of 2011 had virtually no effect on channel configuration or vegetation based on field observations of the stream channel in 2012, and comparisons with 2012 aerial photographs available on Google Earth (source information unavailable). The 1953 photos were taken early in the dam building era with greater volume and peak flows (1,076 m^3/s in 1953; 1,594 m^3/s in 1952); 2010 photos were taken 26 years into the post-impact era of lower peak flows (858 m^3/s in 2010; 869 m^3/s in 2009).

Channel encroachment is also pronounced in the low gradient reaches downstream of Potash between 1953 and 2010 (downstream of Gunnison and Dolores Rivers, upstream of Green River), with the portion of the bottomland covered by dense riparian vegetation increasing over time (Figure 6).

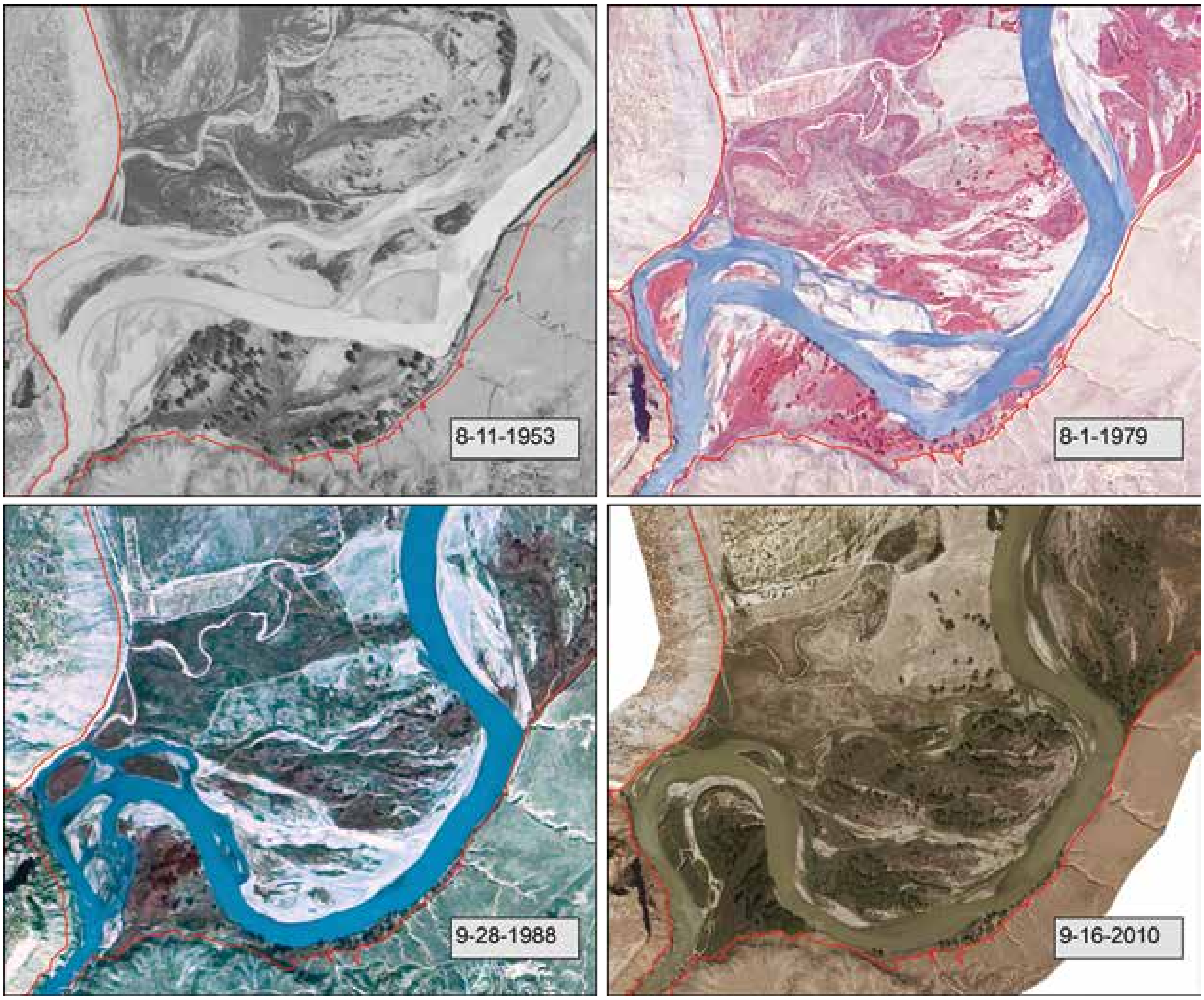

Figure 5 — A series of historical aerial photographs (1953 to 2010) shows the nature and extent of channel and bottomland changes just above Westwater Canyon, in the upper project area. Vegetative cover has expanded greatly over the time period shown, with associated reduction in bare soil near channel areas and reduction of secondary channel features. The upper portion of the photograph extent is farmed; note the dynamic near-channel areas in the lower 2/3 of the photographs. Discharge at Cisco gage (m^3/s) on photo days: 1953, 108; 1979, 165; 1988, 100; 2010, 97.

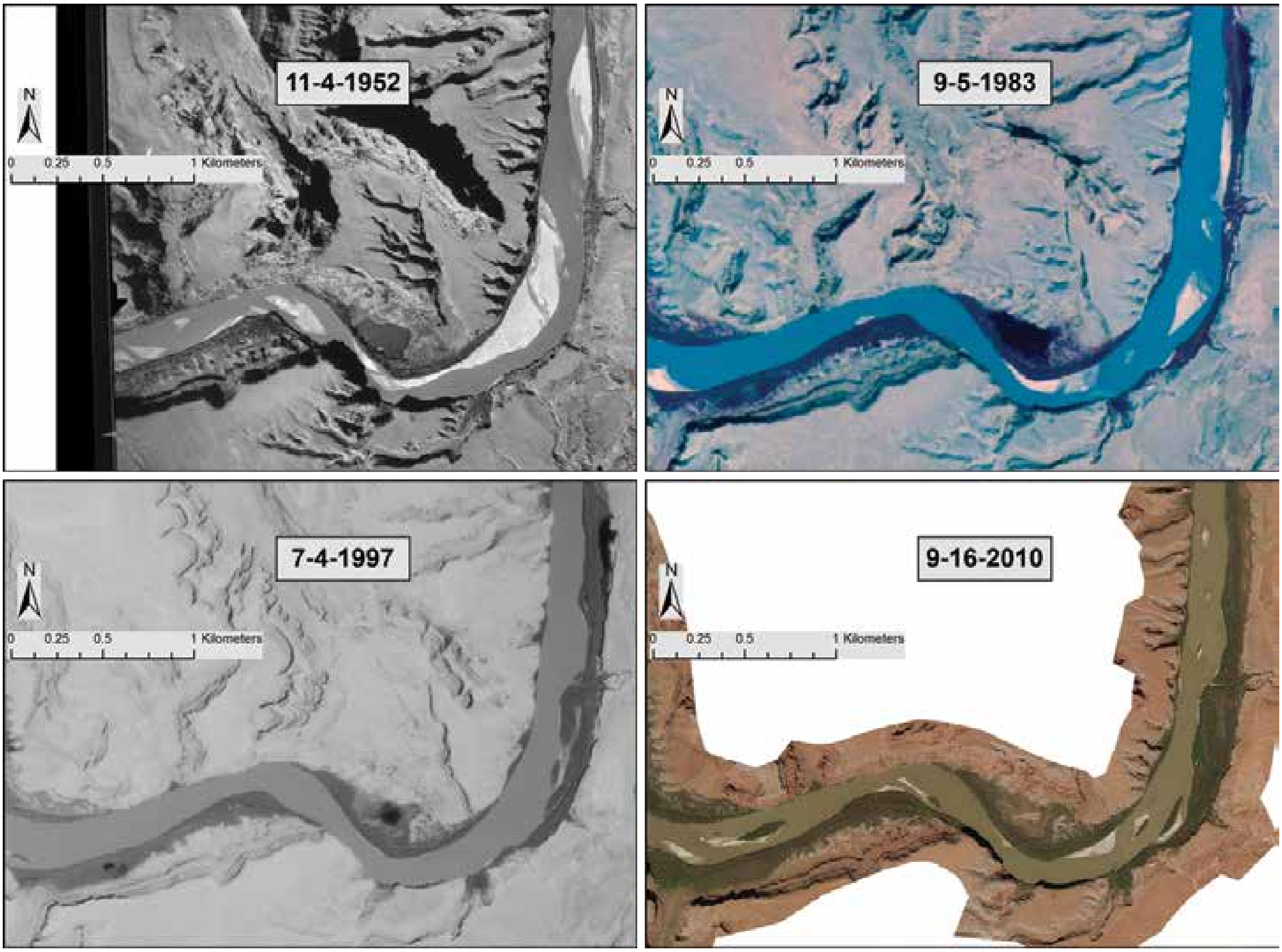

Figure 6 — A series of historical aerial photographs (1952 to 2010) shows the nature and extent of channel and bottomland changes in the Upper Meander Canyon downstream of Moab and within the boundary of Canyonlands National Park. Vegetative cover has expanded greatly over the time period shown, with associated reduction in bare soil near channel areas and secondary channel features. Discharge at Cisco gage (m^3/s) on photo days: 1952, 82; 1983, 174; 1997, 470; 2010, 97.

Looking Forward

The combination of increasing water demand, predictions of changing and erratic precipitation, and changes in timing of runoff, suggest that current trends of channel narrowing and ecosystem change will continue. Concerns about water supplies for human uses have spurred large studies of current and predicted demands for both the State of Colorado and the Colorado River Basin (CWBC, 2010; BOR, 2012) with ongoing and predicted drought conditions. Both studies indicate large 'imbalances' between available water and demands at current population levels, and increasing discrepancies with growing populations. Effects of climate change are expected to be pronounced in the Upper Colorado River Basin (Christensen and Lettenmaier, 2007; Clow, 2010; Seager et al., 2012). Predictions include increased warming and decreased effectiveness of precipitation in generating stream flow (Das et al., 2011; McCabe and Wolock, 2009 and 2007; Seager et al., 2012); precipitation is expected to fall as rain rather than snow, and at a time when it can evaporate or evapotranspire more readily. Timing of flow, determined largely by snowmelt, has already shifted to earlier in the spring and is projected to shift even more with temperature increases and extreme dust-on-snow events (Deems et al., 2013; Stewart et al., 2005; Clow, 2010; Rood et al., 2008). The Four Corners area is expected to experience an increase in overall precipitation falling in summer months, likely with high energy convective storms (Seager et al., 2012), suggesting that habitats at or near confluences of lowland tributaries, as well as sediment dynamics downstream of them, may change.

General interpretation of predictions of increased human demands, further lowered peak flows, earlier flows, and increased potential for drought suggests that the mainstem Colorado River is unlikely to regain historic channel mobility in the foreseeable future. Without changes in water management, large flooding, or extensive land treatments, further narrowing of the primary channel, filling of off-channel habitats, and simplification of riparian habitats are highly probable. These processes could be offset, however, by system 'reset' (by scour and deposition) associated with high flows in years with heavy snowfall and fast melt, as seen in the years 1983 and 1984. Very high flows, like 1983 and 1984, can be channel-changing; however, the interim periods between such rare events allow sediment deposition and vegetation encroachment to occur rapidly, and benefits from such high flows can dissipate rather quickly.

Studies of paleo floods within the project area (Greenbaum et al., 2014) suggest that estimates of the volume and timing of large floods has been badly skewed by the use of current and highly modified flow records in generating predicted flows. Thirty-four floods during the last 2140 +/- 220 years have been greater than 2,730 m^3/s (96,409 ft^3/s), and 26 floods above 3,400 m^3/s (120,070 ft^3/s) (Greenbaum et al., 2014). The peak flow of 1984 was 1,991 m^3/s (70,300 ft^3/s) and the peak flow of 2011 was 1,388 m^3/s (49,000 ft^3/s) at the Cisco gage. High flows of paleo magnitudes will undoubtedly have considerable impacts on bottomland ecology, as well as the conversation about restoration approaches.

River Reaches

For this study, we present and interpret results within 20 river reaches within the full 230 km-long river segment, previously described and delineated by Dohrenwend (2012), (Figure 2, Table 2, and Appendix B). Reach boundaries were typically placed at major tributary junctions and where there were substantial changes in geomorphic character such as bottomland width or channel gradient (Dohrenwend, 2012; Figure 7). For this project, the bottomland extent is delineated by a strong slope break indicating contemporary (including pre-dam era) fluvial activity, and incorporates tributary mouths where either: 1) mainstem flows inundate tributary channels, or 2) tributary confluence habitats may be considered for conservation actions. We present detailed reach descriptions in Appendix B.

The character of reaches contained within the project area varies widely (Table 2 and Figure 7). Reaches extend from 3 km to nearly 40 km in length, with bottomland widths ranging from an average of 70 m in Westwater Canyon to over 1400 m in Moab Valley. The strongest contrast in geomorphology is between reaches 1 and 2, Ruby-Westwater and Westwater Canyon; the former covers the greatest area and is characterized by broad bottomlands, multiple channels and diverse vegetation. Westwater Canyon is extremely narrow, with very limited vegetation, no trees, and a steep gradient. The area of transition between these two reaches (Figure 7) is possibly the most geomorphically active section in the project area with extensive evidence of lateral channel mobility and channel complexity, relatively coarse sediments, and a moderate gradient; all likely due to backwater effect from the entrance of Westwater Canyon. Reaches 3-8 represent a complex section of river with numerous tributary junctions, significant changes in valley width, and a mix of vegetation types and structures. The confluence with the Dolores River at the upstream end of Reach 8 marks the beginning of narrower and simpler reaches downstream. Professor Valley (10 PV), unlike most other reaches, has gently tapering upland slopes on one or both sides of the river and is influenced by a series of tributaries entering on the south bank of the river. Big Bend Reach (11 BB) is narrower than Professor Valley, and constrained by sandstone cliffs on both sides of the valley. Negro Bill Reach (12 NB) is the first of a series of eight low gradient, low energy reaches that extend 118 km downstream to the upper portion of Cataract Canyon (20 CC), the last and highest gradient reach in the project area. Moab Valley (13 MV) is short and wide and highly distinct in terms of habitat conditions. Lowland portions of Moab Valley function as backwater wetlands in years with higher spring runoff, sometimes persisting well into summer. Bottomland widths are narrower at the beginning of Lower Meander Canyon (18 LMC) to the downstream end of the project area. The Green River enters the Colorado River at the upper end of Reach 19 (19 GC).

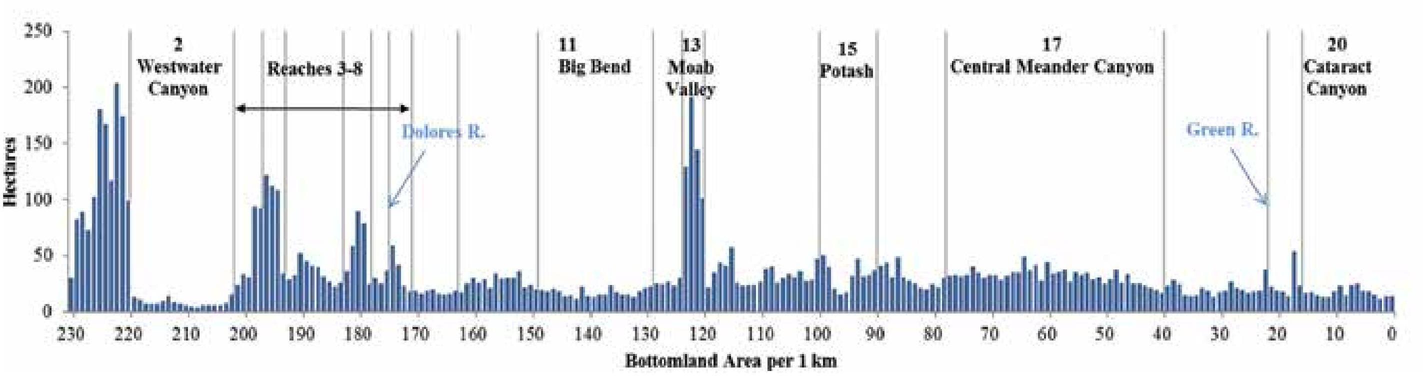

Figure 7 — Relative width of the Colorado River bottomland at 1-km intervals for the project area. Locations of reach breaks, and significant landmarks are indicated. The left edge of the horizontal axis is the Utah-Colorado border; the right edge is the southern boundary of Canyonlands National Park.

Table 2 — Location and general characteristics of 20 river reaches within the Colorado River Conservation Planning Project area, based on Dohrenwend (2012).

River Reach	Reach Code	Bottomland Kilometer (BL km)	Reach Length (from BL kms)	Reach Gradient (%)
Ruby-Westwater	1 RRW	230 – 220	10	0.104
Westwater Canyon	2 WWC	220 – 202	18	0.218
WW-CL transition	3 WWCL	202 – 197	5	0.057
Cisco Landing	4 CL	197 – 193	4	0.076
Cisco Wash - Dry Gulch	5 CWDG	193 – 183	10	0.057
McGraw Bottom	6 MGB	183 – 178	5	0.038
Dolores – McGraw Bottom	7 DMGB	178 – 175	3	0.076
Dewey Bridge	8 DB	175 – 171	4	0.076
Dewey	9 D	171 – 163	8	0.114
Professor Valley	10 PV	163 – 149	14	0.095
Big Bend	11 BB	149 – 129	20	0.076
Negro Bill	12 NB	129 – 124	5	0.028
Moab Valley	13 MV	124 – 120	4	0.028
Gold Bar	14 GB	120 – 100	20	0.028
Potash	15 P	100 – 90	10	0.028
Upper Meander Canyon	16 UMC	90 – 78	12	0.023
Central Meander Canyon	17 CMC	78 – 40	38	0.023
Lower Meander Canyon	18 LMC	40 – 22	18	0.023
Colorado – Green	19 CG	22 – 16	6	0.023
Cataract Canyon	20 CC	16 – 0	16	0.275

[Reaches are shown from upstream to downstream. Bottomland kilometers (BL km) are numbered from downstream to upstream. Reach length is calculated from the bottomland centerline. Reach gradient is calculated from elevations at the upstream and downstream boundaries of each reach.]

Vegetation Character

Robust woody vegetation (predominantly shrubs) covers most of the bottomland area (Table 3). Xeric native shrubs such as greasewood and saltbush (*Sarcobatus vermiculatus* and *Atriplex* spp.) occupy more distal and higher elevation portions of the bottomland along with occasional patches of rabbitbrush and sagebrush (*Chrysothamnus* spp. and *Artemesia* spp.). Coyote willow (*Salix exigua*) and tamarisk (*Tamarix* spp.) dominate areas near the channel. Cottonwood (*Populus fremontii*) woodlands with scattered Goodding's willow (*Salix gooddingii*) are common in wide reaches of the upper project area and the Moab Valley, but trees are limited or absent in other reaches, especially downstream of Moab Valley and in very narrow reaches. Hackberry (*Celtis reticulata*), Gambel oak (*Quercus gambelii*), and boxelder (*Acer negundo*) are scattered throughout the project area. New Mexico (NM) privet (desert olive -- *Forestiera neomexicana*) and skunkbush sumac (*Rhus trilobata*) extend through the project area; NM privet mostly downstream of Moab Valley, sumac mostly upstream of Moab Valley. Seepweed (*Suaeda* spp.) is found downstream of Moab often in areas where standing water on the floodplain evaporates behind natural levees.

The non-native species, Russian knapweed (*Acroptilon repens*), Russian olive (*Elaeagnus angustifolia*) and tamarisk cover broad portions of the bottomland corridor. Tamarisk is the most extensive non-native species on the bottomland, but is declining rapidly due to effects of the tamarisk beetle. Russian olive and Russian knapweed are two common non-native species that have potential to expand their ranges with the decline in tamarisk (Hultine et al., 2010). Siberian elm (*Ulmus pumila*) and Catalpa (*Catalpa speciosa*) are also present on the bottomland, but they occur infrequently; trends under current conditions or with climate change predicted for the Southwest are unknown (Iverson et al., 2008).

Table 3 — Typical dominant cover types found in the project area.

Common Name	Scientific Name	Native/Non Native
Coyote willow	*Salix exigua*	Native
Cottonwood	*Populus fremontii* *Populus angustifolia*	Native
Goodding's willow	*Salix gooddingii*	Native
Hackberry	*Celtis reticulata*	Native
Gamble oak	*Quercus gambelii*	Native
Boxelder	*Acer negundo*	Native
NM privet (desert olive)	*Forestiera neomexicana*	Native
Skunkbush sumac	*Rhus trilobata*	Native
Seepweed	*Suaeda spp.*	Native
Tamarisk	*Tamarix spp.*	Non-native
Russian knapweed	*Acroptilon repens*	Non-native
Russian olive	*Elaeagnus angustifolia*	Non-native
Siberian elm	*Ulmus pumila*	Non-native
Catalpa	*Catalpa speciosa*	Non-native

Terrestrial Wildlife in the Project Area

The density and complexity of vegetation in the project area provide habitat for a variety of wildlife including birds, mammals and reptiles (Table 4). Over 70% of all bird species that occur in Utah use riparian habitat for most or some portions of their life cycle (Pope et al., 2015). The project area is home to many bird species and subspecies of concern, including the Mexican spotted owl (*Strix occidentalis lucida*) and Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) which are federally threatened, and Southwestern willow flycatcher (*Empidonax traillii extimus*) which is endangered. Several raptor species are on the Utah Sensitive Species List (2011), including ferruginous hawk (*Buteo regalis*), short-eared owl (*Asio flammeus*), and burrowing owl (*Athene cunicularia*). Many other raptors use the bottomland area, such as: peregrine falcon (*Falco peregrinus*), wintering bald eagle (*Haliaeetus leucocephalus*), and golden eagle (*Aquila chrysaetos*). The bottomland provides habitat for other bird species of concern including Virginia's warbler (*Vermivora virginiae*) and Lucy's warbler (*V. lucia*), yellow-breasted chat (*Icteria virens*), and blue grosbeak (*Passerina caerulea*).

The Utah Sensitive Species List (2011) designates several mammal species and one reptile as species of concern, including Townsend's big-eared bat (*Corynorhinus townsendii*), spotted bat (*Euderma maculatum*), Allen's big-eared bat (*Idionycteris phyllotis*), fringed myotis (*Myotis thysanodes*), and the big free-tailed bat (*Nyctinomops macrotis*); all of which are increasingly threatened by habitat loss and disease (UBCP, 2008-2013). Beaver (*Castor canadensis*), found extensively in the project area, have their own management plan (Utah Beaver Management Plan, UDWR, 2010) and some of the last remnant populations of North American river otters (*Lontra canadensis*) occur in this reach. Cornsnake (*Elaphe guttata*) is also on the Utah Sensitive Species List (2011) as a species of concern.

Table 4 — Terrestrial species of concern in the project area.

Common Name	Scientific Name	Species Status
Allen's big-eared bat	*Idionycteris phyllotis*	Utah Species of Concern[1]
Bald eagle	*Haliaeetus leucocephalus*	Utah Species of Concern[1]
Beaver	*Castor Canadensis*	Utah Beaver Management Plan, UDWR 2010
Big free-tailed bat	*Nyctinomops macrotis*	Utah Species of Concern[1]
Blue grosbeak	*Passerina caerulea*	Locally uncommon
Burrowing owl	*Athene cunicularia*	Utah Species of Concern[1]
Cornsnake	*Elaphe guttata*	Utah Species of Concern[1]
Ferruginous hawk	*Buteo regalis*	Utah Species of Concern[1]
Fringed myotis	*Myotis thysanodes*	Utah Species of Concern[1]
Golden eagle	*Aquila chrysaetos*	Locally uncommon
Lucy's warbler	*Vermivora lucia*	Priority Species, Utah Partners in Flight[2]
Mexican spotted owl	*Strix occidentalis lucida*	Threatened (Federal)[1]
North American river otter	*Lontra Canadensis*	Northern River Otter Management Plan, UDWR 2010
Peregrine falcon	*Falco peregrinus*	Locally uncommon
Short-eared owl	*Asio flammeus*	Utah Species of Concern[1]
Southwest willow flycatcher	*Empidonax traillii extimus*	Endangered (Federal)[1]
Spotted bat	*Euderma maculatum*	Utah Species of Concern[1]
Townsend's big-eared bat	*Corynorhinus townsendii*	Utah Species of Concern[1]
Virginia's warbler	*Vermivora virginiae*	Priority Species, Utah Partners in Flight[2]
Western yellow-billed cuckoo	*Coccyzus americanus*	Threatened (Federal)[1, 3]
Yellow-breasted chat	*Icteria virens*	Locally uncommon

[1] – Utah Sensitive Species list (2011), [2] – Utah Partners in Flight Avian Conservation Strategy (2002), [3] – Federal Register Listing of Western yellow-billed cuckoo (2012).

Fish Species in the Project Area

The Colorado River mainstem in Utah supports four endangered fish species (Table 5): Colorado pikeminnow (*Ptychocheilus lucius*; USFWS, 2002a), razorback sucker (*Xyrauchen texanus*; USFWS, 2002b), humpback chub (*Gila cypha*; USFWS, 2002d), and bonytail (*Gila elegans*; USFWS, 2002c). Portions of the project area are designated critical habitat for the humpback chub and bonytail (UDWR, 2012), and the length of the project area is designated critical habitat for Colorado pikeminnow (USFWS, 2002a) and razorback sucker (USFWS, 2002b). Flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*Catostomus discobolus*), and roundtail chub (*Gila robusta*) are listed as Utah Sensitive Species (2011). While habitat loss is a serious concern for these species, competition and predation from non-native fish are also driving population declines (Osmundson et al., 2002; Osmundson and White, 2009).

Most native fishes in the project area need clean cobble and gravel substrates for spawning (Valdez and Nelson, 2006). Clean spawning beds require sufficient shear stress to mobilize sediments and wash out finer-sized grains, conditions that are lacking in sites sampled in the Gunnison River (upstream of the project area; during a flow event with a 5-10 year return interval) and on sites in the Green River (2-5 year return intervals, at least in stream beds with less than 20-30% sand) (Williams et al., 2013). Both of the areas for these studies are upstream of our project area, but may serve as spawning sites for Colorado River fish populations. Under the current flow regime, effective discharges do exist for moving spawning-sized substrates on the Colorado River mainstem just upstream of the project area (begins between 440-620 m^3/s for the 18-Mile and Ruby Horsethief reaches). Effective discharge flows were exceeded for approximately 26 days/yr during high flow of the study period (1993 and 1995), in areas where Colorado pikeminnow spawn (Pitlick and Van Steeter, 1998). The same geomorphic study also states that while these flows were adequate to move gravels and cobble and wash away embedded fine sediments in upstream reaches, flows were not adequate for scouring vegetation, widening channels, and flushing sediments from off-channel habitats in these reaches (Pitlick and Van Steeter, 1998). Average recurrence intervals for peak flows (daily) capable of mobilizing cobble at most (>50%) sites in the 18-mile reach were estimated to be once per 4.6 to 13.5 years based on a study period of 1966-2000 (Osmundson et al., 2002). Values reported above are for reaches upstream of the project area; similar studies have not been conducted throughout the project area for all native fishes, or for flow regimes predicted with climate change.

Cultural Importance

This segment of the Colorado River is culturally significant at both regional and national levels, with high levels of human use during prehistoric, historic and current eras. During prehistoric times archaic peoples occupied the Colorado River corridor, utilizing the available resources for food, clothing, shelter and art. A wide variety of sites attest to this long-term occupation including alcoves, rock shelters, lithic scatters, rock art and open campsites. European-American homesteads and mining operations have also left a legacy in this section of the river. Today, recreationists from all over the world come to this region to raft and kayak, with non-motorized water recreation from non-local visitors generating an estimated economic impact of $8.5 million per year for Grand County (Headwater Economics, 2011).

Table 5— Native fish species of concern occurring in the project area.

Common Name	**Scientific Name**	**Species Status (Utah Sensitive Species List; 2011)**
Bonytail	*Gila elegans*	Endangered (Federal)
Humpback chub	*Gila cypha*	Endangered (Federal)
Pikeminnow	*Ptychocheilus lucius*	Endangered (Federal)
Razorback sucker	*Xyrauchen texanus*	Endangered (Federal)
Bluehead sucker	*Catostomus discobolus*	Species of Concern
Flannelmouth sucker	*Catostomus latipinnis*	Species of Concern
Roundtail chub	*Gila robusta*	Species of Concern

Methods

The above section described status and trends of Colorado River hydrology, sediment, riparian vegetation, fish and wildlife in the project area. With an understanding of those trends and larger basin context, the following section will describe our methods for characterizing: 1) fundamental resource conditions including vegetation and fluvial geomorphic features (as of 2010-2011 based on imagery dates), and human developments such as roads and campgrounds; 2) the relative condition of habitats for groups of species (Conservation Elements) that occupy bottomland habitats; and 3) associated models of relative costs of treatment, fire risk and recovery potential. Also included in this section is a description of our approach for summarizing and describing data derived from aerial imagery. We present the results of resource and habitat modeling in the following section (Results).

Fundamental data layers

Interpretation of aerial imagery and assimilation of pre-existing spatial data were central to our efforts in this analysis. We generated detailed maps of vegetation and channel habitat features (Figure 8c) in the project area from true color, high resolution (0.3 m) imagery flown September 16, 2010 (Figure 8a). We cross-checked vegetation and channel features with aerial imagery at lower resolution (NAIP 2011 for Grand and San Juan Counties, Utah, 1.0-m resolution [accessed via EarthExplorer.usgs.gov]; and Google Maps 2012, unknown date and resolution). We also mapped channel habitat features at high flow (Figure 8d) on 1.0-m resolution true color imagery (NAIP, 2011). We obtained additional layers such as land ownership, roads, fire history, non-native vegetation treatment areas, and recreational use features (see Appendix C for a complete list of data layers used and contributing organizations). We clipped the additional layers to the project area extent (bottomland boundary, described below) for editing and analysis. To assess available habitats, we mapped fundamental features including the bottomland boundary, vegetation types and bare areas, and channel boundaries at high and low flow (Figure 8). We used ArcGIS (versions 9.2-10.2) for all spatial data creation and analysis.

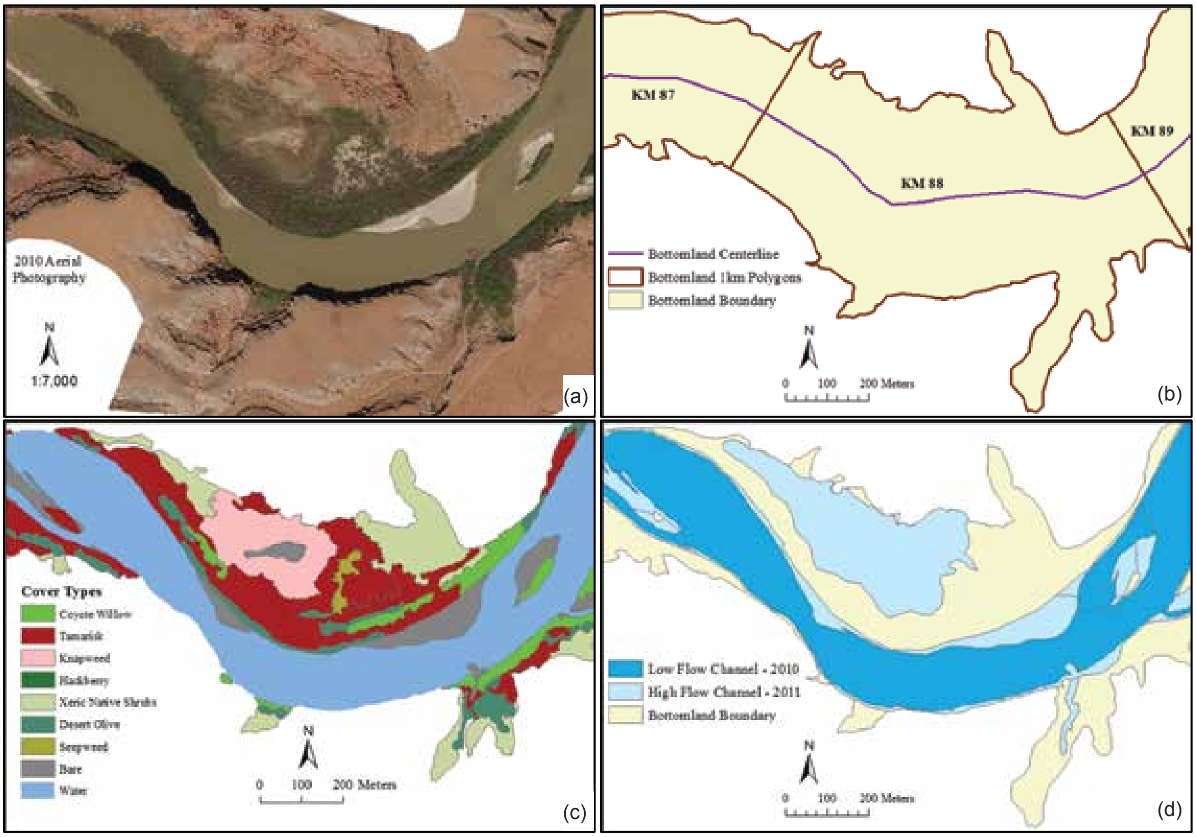

Figure 8 — Examples of: (a) aerial imagery used for most mapping; (b) bottomland boundary, centerline and 1km bottomland polygons; (c) vegetation map of dominant cover types; and (d) mapping of low flow (2010) and high flow channels (2011), with bottomland boundary.

Vegetation Mapping

The National Park Service (Canyonlands National Park) created initial vegetation maps by digitizing vegetation patches (areas of relatively homogeneous cover types) on the 2010 high resolution imagery (Figure 8c), and describing the composition of each patch by assigning up to four constituent species to one of four rank order, relative abundance classes (A-D). Category A, or 'Dominant', was assigned to the species with greatest cover; category B, or 'Common', was assigned to the species with the next most cover; categories C and D, where included, were assigned to species that were 'Present', but not contributing greatly to the vegetative cover of the patch. The four classes represent a relative order, with no thresholds of percent cover, and should be interpreted as 'mostly A', with 'some B', and 'less or very little cover of C or D'. For example, a patch may be described as: mostly willow with some privet, a little knapweed and very little tamarisk. If a patch was an equal mix of different cover types, the taller of the cover types was considered dominant (i.e., Category A) and the shorter cover type common (Category B). In addition to vegetation classes, we mapped non-vegetation cover types such as bare areas, as well as developed areas and most roads (Table 6). We also assigned height classes to cover types, reflecting typical mature stand heights within the project area (Table 6). Finally, we noted current and historic agricultural use, describing the presence and type of agricultural activity including: irrigation (ditches or sprinklers), plowing, mowing or clearing. Grazing could not be detected or recorded consistently. Hydrologic preference of each cover type (Table 6) reflects spatial relationships to saturated soils and high flow extent, as generally seen during mapping and field checks. Native or non-native plant origin was determined by National Park Service botanists, local practitioners, and the USDA Plants database (https://plants.usda.gov; accessed 8-17-2014). We edited the initial vegetation maps based on extensive field checking by road and raft in summer and fall of 2012. We checked portions of approximately 207 of the 238 river kilometers in the study area, excluding Westwater Canyon (Reach 2), which is very sparsely vegetated. A high flow event in 2011, which occurred between the 2010 aerial photographs and 2012 field checking, had surprisingly little effect on channel configuration or vegetation patches. Defoliation effects of the tamarisk beetle were clear, however, with vegetation dominance shifting away from tamarisk in many patches. Changing dominance was noted during field checks, but designation as recorded in 2010 vegetation mapping was not changed.

We also applied quantitative mapping standards as part of the process of editing and revising the initial vegetation maps. All editing was consistently done at a scale of 1:1,500 to 1:2,000. We applied a minimum mapping unit of 300 m^2; we merged patches smaller than this minimum into adjacent patches. Individual trees could not comprise a patch, even if they exceeded the 300 m^2 minimum. In areas with widely spaced trees, trees had to be less than 30 meters apart to be considered dominant in a patch.

Table 6 — Cover classes used for bottomland surface mapping.

[Descriptions include growth form, preference for soil moisture (Hydrologic Preference), native or non-native status, and list of species included in cover classes. Tall trees have a height range of 8-18 m, short trees 1.5-12 m, tall shrubs 2.5-7.5 m, short shrubs 0.6-2.4 m, and all herbaceous classes <1 m.]

River Reach	Structural type, and height range	Hydrologic Preference	Native/ Non-native	Description
Cottonwood	Tall Tree, 12-18 m	Mesic	Native	Cottonwood (*Populus* spp.)
Goodding's Willow	Tall Tree, 12-18 m	Hydric to Mesic	Native	Goodding's Willow (*Salix gooddingii*)
Box Elder	Short Tree, 9-12 m	Mesic	Native	Box Elder (*Acer negundo*)
Hackberry	Short Tree, 4.5-9 m	Xeric	Native	Hackberry (*Celtis reticulata*)
Gambel's Oak	Short Tree, 1.5-11 m	Xeric	Native	Gambel's Oak (*Quercus gambelii*)
Invasive Trees	Short Tree, 3.5-15 m	Mesic	Non-native	Mostly Russian olive (*Eleagnus angustifolia*), some elm (*Ulmus pumila*) and mulberry (*Morus alba*), and very few catalpa (*Catalpa bignonioides*)
Tamarisk	Tall Shrub, 3-7.5 m	Mesic	Non-native	Tamarisk (*Tamarix* spp.)
Coyote Willow	Tall Shrub, 2.5-4.5 m	Mesic	Native	Coyote Willow (*Salix exigua*)
NM Privet (Desert Olive)	Tall Shrub, 2.5-3.5 m	Mesic	Native	NM Privet (Desert Olive) (*Foresteira neomexicana*)
Skunkbush Sumac	Short Shrub, 1.8-2.4 m	Mesic	Native	Skunkbush Sumac (*Rhus trilobata*)
Xeric Native Shrubs	Short Shrub, 0.6-2.1 m	Xeric	Native	Greasewood (*Sarcobatus vermiculatus*), saltbush/shadscale (*Atriplex canescens*), rabbitbrush (*Chrysothamnus nauseosus*), and big sagebrush (*Artemesia tridentata*)
Seepweed	Short Shrub, 0.6-0.9 m	Hydric and Xeric	Native	Seepweed (*Suaeda* spp.)
Native Grasses	Herbaceous, <1 m	Mesic to Xeric	Native	Salt grass (*Distichlis spicata*) and alkali sacaton (*Sporobolus airoides*)
Mesic Vegetation	Herbaceous, <1 m	Hydric to Mesic	Native, Unk.	Mix of mesic herbaceous species, typically native but sometimes unknown
Wetland Herbaceous	Herbaceous, <1 m	Hydric	Native	Mix of wetland herbaceous such as bulrush, sedge and rush
Knapweed	Herbaceous, <1 m	Mesic to Xeric	Non-native	Knapweed (*Acroptilon repens*)
Non-native Herbaceous	Herbaceous, <1 m	Mesic to Xeric	Non-native	Variety of non-native species such as kochia (*Bassia* spp.), cheatgrass (*Bromus tectorum*), and agricultural species
Sand Bar or Bare	Bare	--	--	Exposed soil whether due to fluvial processes, human actions, or other means, with the exception of dirt roads and developed areas
Water	Water	--	--	All water surfaces
Transportation Corridors	Bare	--	--	Some of the larger roads within the project area
Recreational /Residential Development	Bare	--	--	Areas developed for recreational or rural residential use.

Wetted Channel and Bare Area Mapping (2010 Low Flow)

We mapped surface water and bare sediment areas (bars) from high resolution photography taken on September 16, 2010, at a stream flow of 96.5 m^3/s (3,410 ft^3/s, Cisco gage, Figure 2). This flow has a 67% exceedance probability based on all daily flow values from the post-impact period of 1984 to 2013, meaning that 33% of flows are likely to be lower than those in the 2010 photographs. We subdivided surface water into six categories: primary channel, secondary channel, split flow channel, backwater, isolated pool, and tributary channel (Table 7), similar to that of fish habitat methods used extensively in Oregon (Moore et al., 2012). Channel types that are not primary channel are considered 'off-channel'. 'Bare' sediment areas included any unvegetated and undeveloped areas on the bottomland.

Table 7 — Classification of channel types mapped at high (2011) and low flow (2010). [All channel types that are not primary channel are considered as 'off-channel'.]

River Reach	Relative Velocity	Characteristics
Primary Channel	Moving	Either the only channel when one channel is present or the widest channel when there are multiple channels
Secondary Channel	Moving	Separated from primary channel by a vegetated (permanent/woody vegetation) island; flow is connected at upstream and downstream ends
Split Flow (low flow only) Channel	Moving	Separated from primary channel by an un-vegetated island (channel bar); flow is connected at upstream and downstream ends
Backwater	Still	Zero velocity channel feature, no through flow, connected to moving water; separated from channel by permanent or impermanent features (bars or islands)
Isolated Pool	Still	Zero velocity feature with no surface connection to a channel; may be fed by subsurface flow or remain after high water; may be separated from channel by permanent or impermanent features (bars or islands)
Tributary Channel	Still	Mouths of tributary canyons that connect to the Colorado River bottomland; tributary channel habitat is most extensive during spring high flow when tributaries are often at lower flow or dry, providing zero-velocity refuge habitat

Channel Mapping (2011 High Flow)

High flow channels were mapped from imagery flown on June 28, 2011, at a flow of 886 m^3/s (31,300 ft^3/s) at the Cisco gage; a 1:2.5-year event for the 1984 - 2013 time period. This was two weeks after the peak flow of 1,388 m^3/s (49,000 ft^3/s) at the Cisco gage on June 9, 2011 (a 1:7.25-year event for the time period 1984 to 2013; Figure 8d). We subdivided surface water types into the same categories as with the low flow mapping. Split flow channels were all under water on these images. Any return interval calculation should be interpreted with caution, given the highly controlled nature of Colorado River flows, and distortions noted above regarding paleo flood events.

Bottomland Boundary, Centerline and Polygons

For this project, the bottomland boundary served two purposes: 1) to delineate the extent of current fluvial activity and influence, including areas where Colorado River flood flows inundate tributary channels, and 2) inclusion and assessment of tributary deposits that may be potential sites for habitat treatments. To serve the first purpose, we placed the bottomland boundary at the bottomland/upland interface, delineating the extent of current fluvial activity and influence (Colorado River alluvial surface). We constructed the boundary using vegetation (e.g., upland versus riparian vegetation), topographic (e.g., inflection points on hillslopes, flat areas) and hydrologic indicators (e.g., changes in sediment size, inundation in high flow events) and included alluvial landforms at confluences of tributaries and the Colorado River (with some guidance from Poole et al., 2002). For the second purpose, we included fine-grained surfaces contributed by tributaries, as they are often included in project planning. These alluvial surfaces from tributaries are subdivided from Colorado River alluvial valleys in a layer available on the project website. Steep, dry, coarse-grained alluvial fans were excluded from the bottomland boundary, as were high, dry terraces on the Colorado bottomland, out of reach of contemporary very high flows such as the 1984 flood.

From the bottomland boundary we created a bottomland centerline, bisecting distances across the valley bottom for the length of the project area (Figure 8b). We then divided the bottomland boundary into smaller polygons at 1-kilometer intervals, with divisions placed perpendicular to the bottomland centerline, and used these bottomland polygons for reporting spatial data results. The bottomland boundary was also cut into larger polygons at the 20 reach breaks.

Analysis

For analysis, we combined the vegetation, bare areas, and low flow channel layers using a Union function in ArcGIS 10.0 (All Cover layer). This "All Cover" layer was then combined with the bottomland boundary reach polygons (Union function), and the bottomland boundary 1-km polygons. For vegetation and channel cover types, we summarize data in the form of total hectares and percent of reach total. Modeling data results are shown by river reaches and by 1-km bottomland polygons. Many of the figures and tables use a reach code (Table 2) rather than a reach name, for brevity.

Conservation Elements and Habitat Suitability Modeling

In the project area, like most riparian areas, different types of habitats occur in close proximity to each other, controlled by small changes in either distance to or elevation above the channel, with variable access to water, currently or in the past. Relatively small changes in elevation can determine if a patch of ground will be scoured bare, fully occupied by native willow or other shrubs, or home to a variety of xeric species that prefer deep, well-drained soils. Grouping animal species by habitat needs acknowledges both the variety of habitat types occurring within a very geographically limited area, and also the large number of species (birds, mammals, and reptiles) that use bottomland habitats. Long-term changes in hydrology and sediment processes, discussed in the previous section, have shifted the proportion and character of habitat types available, and therefore, the suites of species likely to thrive or diminish. In some cases, it is possible to serve multiple habitat types with one action; for example, the replacement of tamarisk stands with native shrubs serves both terrestrial species that prefer native shrub habitat, and those that like a diverse shrub understory. In other cases, increasing one habitat type will decrease another proportionately.

Several challenges drive the need to prioritize restoration actions for the CRCP: the breadth of species to address, the variety of habitat needs, and the size and diversity of the project area (Coppolillo et al., 2004). To address these challenges, we first asked resource specialists to group diverse species into Conservation Elements (CEs) based on habitat needs (Kintsch and Urban, 2002; Esselman et al., 2013; MacNally et al., 2008), recognizing that there will be differences among the species, both in the details of their needs and the quality of information available for each species (Lindenmayer et al., 2002). Second, to address such a wide array of species and habitat needs at a landscape scale (Amici et al., 2009; Sanderson et al., 2002), we started with generally known habitat features and derived probable habitat quality from GIS data. Third, in the interest of capturing site-specific habitat conditions and species needs, we incorporated relevant information provided by natural resources experts (MacMillan and Marshall, 2005; Dresher et al., 2013). The strength of the modeling effort shown here is its generality and application across almost 8,000 hectares (approx. 20,000 acres) of bottomland habitat (Sanderson et al., 2002).

In March 2013, we convened a workshop in Moab, Utah, for local and regional natural resource professionals familiar with the Colorado River and the project area (Appendix D). We tasked the group with: 1) reviewing information compiled and data created for the planning project; 2) refining selection of terrestrial and fish CEs; 3) identifying quality habitats and/or components of quality habitat for each of the CEs in the project area, and; 4) identifying threats to habitat quality and opportunities for restoration. Since the workshop, we have called on the same pool of experts, and others as needed, for review and revision of project products. In this section, we first describe the process of determining CEs for terrestrial species and provide thorough descriptions of each habitat suitability model created for terrestrial CEs, followed by description of fish CEs.

Terrestrial Conservation Elements

Terrestrial CEs represent a broad diversity of wildlife species (mammals, reptiles and birds) that depend on Colorado River corridor habitats, and are designated as sensitive or of special concern or interest. To identify habitat attributes and thresholds for quality, we and the resource experts referred to literature (Table 8) on individual species available from various sources, primarily The Nature Conservancy (TNC) and Utah Division of Wildlife Resources (UDWR) (Oliver and Tuhy, 2012). Where literature was not available, resource experts estimated necessary habitat attributes and quality. We did not include amphibian or invertebrate species in CEs due to lack of life history and population data. We identified seven terrestrial conservation elements as shown in Table 8. More information regarding these CEs is provided below and in detailed model descriptions (Appendix E).

Table 8 — Descriptions of Terrestrial Conservation Elements for the Colorado River Conservation Planning Project.

Terrestrial Conservation Element	Characteristic Species	Key Attributes or Processes	Data Gaps	Key Literature for Models
Riparian Overstory/ Woodland Raptor	Yellow-billed cuckoo[1,2,4], Bullock's oriole, black-headed grosbeak6, blue grosbeak[6], warbling vireo6. Cooper's hawk6, screech owl6, saw-whet owl6, and bald eagle[2, 4]	Large trees, large patch size, diverse understory structure (based on heights of shrubs), dense canopy, not tamarisk dominated.	Tree heights, patch density, snags	1=Ecological Integrity Tables (Oliver and Tuhy, 2010) 2=Utah Partners in Flight (Parrish, et al., 2002) 3=Western Bat Working Group (2013) 4=Utah Sensitive Species List (UDWR, 2011) 5=Utah Bat Conservation Plan (Oliver et al., 2008) 6=Utah Conservation Data Center (respective species, website: dwrcdc.nr.utah.gov) 7=Utah Beaver Management Plan (UDWR; 2010a) 8=Northern River Otter Management Plan (UDWR; 2010b) Plus extensive use of expert knowledge
Riparian Understory	Southwest Willow flycatcher[1,2,4] yellow throat6, yellow warbler[6], yellow-breasted chat[2], other birds; beaver[7], northern river otter[8], black-necked garter snake[6]	Dense, mesic riparian shrubs (sumac, privet, willow); close proximity distance to water; stillness of water (low velocity at best); not tamarisk dominated	Patch density, vegetation heights, absolute velocity of water (relative velocity is available)	
General Diversity	No target species	Diversity of riparian cover and diversity of structural types	--	
Bat Feeding[5]	Allen's big-eared bat[1,3,4] Townsend's big-eared bat[1,3,4] fringed myotis[1,3,4], Yuma myotis3, big free-tailed bat[1,3,4], spotted bat[1,3,4].	Diversity of riparian vegetation, close proximity to water, stillness of water	Absolute velocity of water (relative velocity available)	
Bat Watering[5]	Mostly non-agile: big free-tailed bat[1,3,4] and spotted bat[1,3,4]. Some utility for agile bats, also.	Areas of low velocity water with no vegetation or short vegetation surrounding water	Patch density, vegetation heights, absolute velocity of water (relative velocity available)	
Open Land	Prairie falcon[6], rough-legged hawk (winter)[6], short-eared owl[1,4] (winter), burrowing owl[1,4], milksnake	Open lands/ag fields and pastures; low growing vegetation (except prairie falcon); relatively long distance to water.	Patch density, detailed surface topography	
Rocky Fringe Snakes	Cornsnake[1,4], Smith's black-headed snake[6]	Surface complexity; cover type diversity; complex woody structure; refuge areas adjacent to vegetated areas-large rocks ideal; proximity to perennial water	Topography showing presence of rocky slopes	

Habitat Suitability Models for Terrestrial Conservation Elements

Based on input from the workshop, we developed seven digital habitat suitability models representing relative habitat quality for each of the CEs identified. These habitat models and associated datasets, described in detail below, are incorporated into a publicly accessible website designed to support restoration planning (https://sciencebase.usgs.gov/crcp). All models include the entire project area of 7,849 ha (19,395 acres), at 2-meter resolution. Each model represents a total weighted value of a set of component habitat layers; each component layer shows a single habitat feature (example: Figure 9).

Several species and critical habitat features are not represented by the habitat models for CEs. Roosting habitat data for cavity nesting birds or bats, for example, are either unavailable (e.g., no tree heights or condition), or are beyond the spatial extent of the project area (e.g., bats roosting in rock crevasses or caves in surrounding cliffs). Habitats for larger raptors such as golden and bald eagles and red-tailed hawks are not modeled here; their ranges are so expansive as to lessen their dependence on bottomland habitats. Bald eagles are often sighted in the Colorado bottomland, but difficulties in modeling habitat suitability remain. Instead of full habitat suitability, we have modeled general diversity of habitats as a surrogate for availability of prey species (General Diversity model, described below).

We intend for the models to be general representations of habitat quality, with often coarse estimates of thresholds of values (e.g., between good/fair/poor) for component layers. We estimated threshold values for each component layer, sometimes using obvious values such as many trees/few trees/no trees. Where possible, we used threshold values described in literature. In many cases, we assigned values based on obvious thresholds assuming 'more is better' or 'less is better'. For example, of four possible mesic shrub species present, we assigned 4 of 4 as excellent, 0 of 4 as poor.

To create the models, we reconciled the format of available data with habitat needs and determined the geoprocessing steps for each component layer. We summarize the geoprocessing details in Appendix F. We typically converted habitat attributes for component layers from vector to raster data for analysis, and back to vector for display. We used Focal Statistics (ArcGIS 10.0, Spatial Analyst) for calculating sums, averages, counts, and performing maximum and minimum functions, assigning values to a cell based on a moving 'window' of cells surrounding it. The size of the analysis window varied depending on the typical home range or relative mobility of the species or group of species being modeled. We aggregated the values from all component raster layers for a given model using a Weighted Sum function (ArcGIS 10.0 Spatial Analyst), which added the values of overlapping cells in each component layer, applying weighting factors for individual component layers, if needed.

We used weighting of models initially to equalize the influence of each component layer. Without weighting, component layers with more categories (e.g., 0 to 4 shrubs present, 5 categories) would have substantially more influence on model results than component layers with only two categories (e.g., still water and moving water). We also used weighting to accentuate habitat attributes that were clearly more important than others, based on literature and guidance from resource experts.

During model construction, we made many decisions, such as which component layers to include or exclude, how to best geoprocess the data, and what threshold values and model weights to use. An uncertainty analysis table is shown in the Discussion section of this report (see Table 13). Table 8 summarizes models created, species represented, primary attributes represented, data gaps encountered and literature used for defining habitat quality thresholds. In the detailed model descriptions provided below, we describe reasoning and assumptions for each model, values assigned to habitat attributes for component layers, and weights used. The results of each habitat model are divided into general habitat quality categories: Very Low or No Habitat, Low, Moderate, and High quality.

Fish Conservation Elements

Native fish in the Colorado River corridor use a variety of habitat types, at different times of the year, and at different life stages. Fisheries biologists at the workshop organized the life stages of native fishes by habitat needs (Table 9), shown here as Tiers 1, 2 or 3.

Tier 1 CEs are those life stages that depend on habitat at the interface between the channel and bottomland features (e.g., floodplains, tributary mouths, backwaters and side channels). Habitat for CEs in this tier can be improved with restoration of the bottomland through vegetation treatments and possible reconnection of floodplain surfaces. Habitats for CEs in this tier are represented with a GIS layer or model derived from channel and vegetation mapping and input from fisheries specialists at the Expert Workshop.

The first Tier 1 CE listed, Late Season Rearing, represents habitats needed by young fish: still and warm water in backwaters and tributary mouths. Early Season Rearing emphasizes habitats present at high flows including overbank flow areas, backwaters, and tributary mouths. High Flow Refuge habitat, shown as the third Tier 1 CE, is needed to escape main channel velocities (young and adult fish) and for staging in warm water in preparation for spawning. Tier 2 CEs are more directly tied to in-

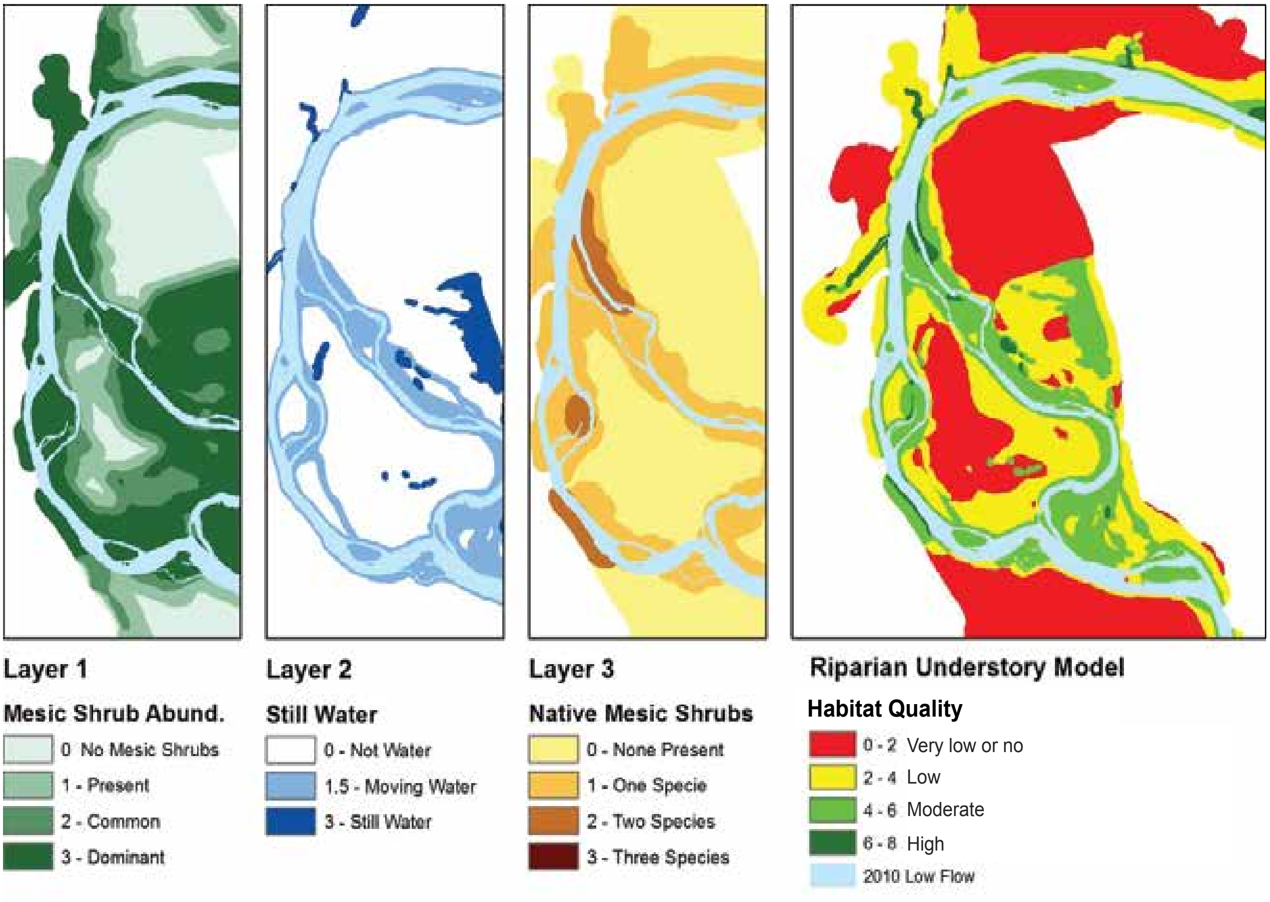

Figure 9 — An example of construction of a model (right panel) from values assigned to component layers (three left panels). Final model scores (Riparian Understory Model example) are a sum of component scores, by 2 m pixel, and are assigned to categories of habitat quality; in this example, 0-2 very low or no, 2-4 low, 4-6 moderate, 6-8 high.

channel hydraulic and substrate conditions and are more affected by basin wide processes (e.g., flow modification, sediment dynamics, and channel mobility) than by small, local modifications to vegetation cover. Actions needed for improving habitat for Tier 2 CEs are beyond the goals of this planning project, though maps of geology, geomorphic and channel conditions (e.g., bars, secondary channels, overbank flows, swift water), could provide general insights regarding available habitats that would be of value to fisheries managers. Tier 3 CEs are either very unlikely to be affected by bottomland or vegetation treatments, or are so rare that their life histories and habitat needs are unknown.

For all of the fish CEs, additional work is needed to relate current habitat needs with the known biology of these fishes. These habitat and biology linkages should be examined in light of current trends in river conditions, changes in human water use, and projections of precipitation and volatility of river flows. Additional information on water depth at higher flow in seasonally dry areas, critical to several CEs, may be derivable from LiDAR data taken during low flow conditions (elevations of flooded surfaces relative to low flow river surface). Detailed information on substrate is likely more problematic to obtain.

Associated Models of Relative Cost of Restoration, Fire Risk, and Recovery Potential

Effective planning of restoration actions requires not only knowing the quantity and quality of habitats available, but also other factors that may impact prioritization. For this project area, we focused on factors that could be mapped, including: 1) the relative costs of restoring those habitats, 2) where ecological damage from fire can be prevented or minimized, and 3) which areas are likely to recover naturally and need no intervention.

Table 9 — Fish Conservation Elements identified and described by fisheries biologists at the Expert Workshop.

Species	Life Stage	Key Habitat Attribute or Process	Data Gaps	Proposed Model
TIER ONE				
Late Season Rearing Model Pikeminnow, bluehead, flannelmouth sucker, and roundtail chub	Rearing	Backwaters and flooded tributaries (zero velocity), warm water, depositional areas. Adequate depth (cover from avian predators, not too deep (aquatic predators).	Water Depth	Channel habitat types at low flow.
Early Season Rearing Model Razorback sucker	Rearing	Flooded bottomlands, backwaters and flooded tributaries (zero velocity), depositional areas, warm water. Adequate depth for cover, not too much depth (predators).	Water Depth	Channel habitat types at high flow
High Flow Refuge Model Pikeminnow and razorback sucker	High Flow Reugia	Warm, > 1 m deep, zero velocity water (i.e., flooded tributaries, partly connected side channels, backwater habitat)	Water Depth	Channel habitat types at high flow
TIER TWO				
Pikeminnow	Spawning	Loose cobble surface with deep interstitial spaces (spawning bar) in proximity to a pool habitat for staging habitat - e.g., < 15 m	Sediment type and quality, water depth	No modeling
Bluehead, flannelmouth sucker, roundtail chub, razorback sucker, bonytail, humpback chub	Spawning	Gravel/cobble substrates	Sediment type and quality, water depth	No modeling
Pikeminnow	Foraging	High productivity of prey fish; complex/diverse habitat; Gravel/ cobble substrate	Sediment type and quality, prey base	Complexity model combining fluvial & vegetative cover at high flow
Razorback sucker	Foraging	Widespread, not likely to be limiting		No modeling
Flannelmouth sucker	Foraging	Runs, widespread; gravel / cobble substrates	Sediment type	No modeling
Roundtail chub	Foraging	Gravel / cobble reaches	Sediment type	No modeling
Bluehead	Foraging	Cobble substrates and riffles	Sediment type	No modeling
TIER THREE				
Humpback chub	Foraging	Eddies associated with swift, deep water	Water Depth	No modeling
Bonytail	Rearing	Unknown		No modeling
Bonytail	Foraging	Unknown		No modeling
Humpback chub	Rearing	Unknown		No modeling

In March of 2014, we convened a workshop of restoration practitioners from several local land management organizations to identify factors that influence restoration decisions, which of those factors could be mapped effectively with available data, and how those factors might be organized for the best practical application. Following this workshop, we constructed preliminary models of restoration cost, fire risk, and recovery potential, obtained reviews of these models from local restoration practitioners and resource specialists, and then revised models. These three associated models are designed to be used in conjunction with habitat suitability models, informing actions such as: construction of fire breaks to protect valued habitats, areas to exclude from work plans due to high cost or low need, and where small expenditures might improve habitat quality.

Construction of Associated Models

Construction of the associated models included the factors listed in Table 10 and involved geoprocessing in the same manner as the habitat suitability models described above. Geoprocessing of associated models did not include weighting of individual factors, or use of an analysis window for aggregating values within a radial area; values mapped are simple sums of factors for each 2 square meter cell. Geoprocessing details and threshold values for each model are provided in Appendix F.

Relative Cost of Restoration

In addition to knowing the habitat gains possible in a given area on the floodplain, it is critical to know the relative cost of implementation. This model accounts for some of the fundamental, site-based costs identified by practitioners.

Easy vehicle access to a site means that equipment can be readily available for crew use. Access would be slightly more difficult for a four-wheel drive vehicle adjacent to a road, even more difficult for sites where hiking in is the only option, and most difficult for sites that must be accessed either by raft only or where camping is required. The density and height of non-native species determine the amount of material that needs to be treated with herbicide, and biomass that needs to be mulched, burned, spread, or removed from sites. Without vegetation height information, we used relative abundance as a rough proxy for effort involved. Woody species require different removal techniques than herbaceous species (e.g., herbicides used, equipment, crew capabilities [e.g., chainsaw certified vs. herbicide sprayers only]), with sites having one structural type or the other translating to simpler planning than sites with both. This model does not account for many factors that influence costs such as land use permitting, re-planting or seeding efforts, or differences in the types of labor used (Martin, 2012). Also, we acknowledge that many herbaceous non-native species were not easily seen from the aerial photos (knapweed is an exception), and that site visits for confirmation are highly recommended.

Fire Risk

Risk of fire in bottomland tamarisk stands is an ongoing threat to human infrastructure and ecological assets; 64 fires occurred within the project area between 1980 and 2011 (Interagency Fire data, acquired from BLM Fire Program, 2012). Careful placement of fire breaks can reduce risks from human and natural ignition sources, and minimize risk of large, catastrophic fires. Of the species that comprise riparian plant communities, tamarisk is among the most flammable (Brooks et al., 2008), whether dead or alive (Drus et al., 2012). Stands of tamarisk are often tall enough and thick enough to carry flames into crowns of desirable riparian trees, and tamarisk re-sprouts more readily than native species post-fire (Brooks et al., 2008; Shafroth et al., 2005). The Fire Risk model presented here combines the capacity of the riparian community to burn (density of tamarisk), the proximity to ecological assets (native riparian trees), and ignition sources. Ignition sources are treated in two ways: 1) areas where recreational use is likely to include campfires or roads that provide easy access for arsonists, thrown cigarettes, or hot exhaust systems in dried herbaceous vegetation; and 2) natural ignition sources (lightning) which are assumed to be evenly distributed across the project area.

Recovery Potential

In addition to knowing relative cost and fire risk, comprehensive planning also includes knowing where work is not needed: where plant communities are dominated by native species, are free from non-native species, and are exposed to both water and seed sources from seasonal high flows. Areas likely to scour are typically best avoided in re-planting efforts, though management of non-native species may be warranted. Mixed patches of tamarisk and willow mapped in 2010 are increasingly dominated by willow due to the effects of the tamarisk beetle. Tamarisk stands with native shrub communities in slightly drier positions (NM privet and sumac) are similarly changing, though with greater uncertainty due to colonization by knapweed and other herbaceous weeds. The process of tamarisk defoliation, while releasing existing plants from competition for light, water, and nutrients, may also moderate microclimate for germination and establishment of replacement vegetation.

Table 10 — A summary of factors included in cost, fire risk, and recovery potential models including relative values used for mapping and data gaps.

Model	Key Attributes	Valuation	Data Gaps
Costs	Access	Truck access, easy; flat and open, moderate; day hike in, difficult; raft in or camp, very difficult	Local topography (e.g., ditches, minor topographic breaks)
	Non-native cover types	Dominant, Common, Present or Not Mapped	Height and density of vegetation.
	Type of non-native species (woody or herbaceous)	Woody only, herbaceous only, woody and herbaceous	--
Other factors not included: private vs. public lands (requires differing levels of planning, replanting, differing labor types, etc.); management restrictions on public lands (BLM vs. NPS vs. State) due to costs of land use permitting, archeological clearances needed, restrictions of mechanical or chemical weed control.			
Fire Risk	Tamarisk presence/density	Dominant, Common, Present or Not Mapped	Height and density of vegetation
	Proximity to people traffic	Roads and campgrounds as ignition points; closer distance is higher risk.	Intensity of use for roads and campgrounds; complete trails inventory for project area
	Proximity to ecological assets (i.e., riparian trees)	Native riparian trees: Dominant, Common, Present or Not Mapped	Heights of trees and heights of surrounding tamarisk
Other factors not included: some herbaceous species are flammable (especially knapweed) though flammability is variable through the year; flame lengths of herbaceous species are shorter than in tamarisk stands; patches of non-native herbaceous stands often have less use by campers than tamarisk stands. Assets considered included human structures, archeological sites, and ecological resources. Human structures are often adjacent to the project area, at risk of fire, but are not mapped in this project; archeological sites have variable risk from fire and locations may be sensitive, but are not modeled here; ecological assets are listed as native riparian trees only, as other cover types are either abundant or fire resilient.			
Recovery Potential	Overbank flooding	Vegetation inundated in 2011 high flow event	--
	Non-native cover types present	Dominant, Common, Present or Not Mapped	Density of vegetation
	Native cover types present	Dominant, Common, Present or Not Mapped	Density of vegetation
Other factors not included: seed dispersal mechanisms and distances for the various non-natives in the area (too complex to map effectively), or for native species; scoured areas (active sand bars) are likely to be colonized with variable success, and would not be high priority for intervention activities			

Results

In this section we present the results of bottomland and human feature mapping, along with values of habitats for Conservation Elements as estimated by the habitat suitability models described above. First, we introduce general project area geography and vegetation. Next, we summarize channel features from both the 2010 low flow and 2011 high flow channels, highlighting attributes most critical to various life stages of Fish Conservation Elements. Lastly, using a mix of reach and bottomland polygons, we estimate the relative quality of habitats for each of the identified Terrestrial Conservation Elements.

Human Activities on the Bottomland

Human activities visible on the bottomland range from buildings and roads, recreational sites (campgrounds and boat ramps), agricultural development, fires and vegetation treatment; these impacts are summarized by type and by reach in Appendix A. The intensity of activities varies with the characteristics of the reach (narrow to wide), ownership and management. Road densities (km/ha) are greatest (>0.06 km/ha) in Dewey Bridge, Negro Bill and Gold Bar reaches (8 DB, 12 NB, and 14 GB respectively). Dewey Bridge and Negro Bill are short reaches influenced by Highway 128 and side roads related to residential, agricultural and recreational use. Gold Bar reach, downstream of Moab, has paved roads on both sides of the bottomland (Potash Road and Kane Creek Boulevard), plus many smaller roads.

Landownership is a mix of federal, state and private. The high percentage of the State of Utah owned land in each reach is due to the Sovereign Lands designation for the river bed up to the average high water line. Sovereign Land jurisdiction begins at the Colorado state line and continues downstream to the northern Canyonlands National Park boundary downstream of Potash. Federal lands are a mix of those administered by the BLM and the NPS (Canyonlands and Arches National Parks). Private land holdings are concentrated in the wider valley reaches and are often associated with agricultural activities. Much of the Moab Valley reach is privately owned and managed by The Nature Conservancy and the Utah Division of Wildlife Resources.

Vegetation treatment areas for fuels reduction and non-native vegetation control are most common in the mid-project area reaches near Moab, the uppermost reaches of the project area, and in selected areas of Canyonlands. Recreation development is high in the mid-project area reaches. Campgrounds are numerous in the lower four reaches.

Vegetation Characteristics

Vegetation cover is a mix of shrubs, trees, and herbaceous species, with some bare areas and human development (Appendix E). A mix of shrubs dominates bottomland habitats: xeric native species in distal and higher elevation areas; sandbar willow and tamarisk in near channel areas; and tamarisk, NM privet and sumac in mesic habitats. Cottonwood galleries are common in the wide valley reaches in the upper project area and in the Moab Valley (13 MV), sparse in moderately narrow reaches, and nearly absent in the narrow canyons, though occasionally found a short distance up tributary mouths. Gambel oak occurs in the middle reaches just above and below Moab Valley, with the largest and most frequent patches in the Big Bend reach (11 BB) upstream of Moab Valley. Box elder trees occur most often below the Potash Reach (15 P) with some sparsely scattered above Moab; these trees are short, and often grow singly or in small groups. NM privet is most common in reaches below Moab; sumac is most common in reaches above Moab. Based on observations during field checking, all three mesic native shrubs (willow, sumac and NM privet), are expanding in response to reduction in tamarisk vigor (observed during cover field checking). Dominant structural classes vary longitudinally with the character of reaches (Figure 10). Tall trees (cottonwood and Goodding's willow) are not prominent structural types in any reach, with less than 20 percent cover in any one reach and absent in many. Short trees (Russian olive, hackberry, Gambel oak, and box elder) are most common in the mid- and lower reaches, though not strongly so. Tall shrubs (coyote willow, tamarisk and NM privet) are abundant in all but the narrowest reaches (Westwater Canyon [2 WWC] and Cataract Canyons [20 CC]). Short shrubs, found throughout the reaches, are nearly all xeric shrubs in reaches downstream of Moab Valley (13 MV), with xeric shrubs and some skunkbush sumac upstream of Moab Valley. Herbaceous cover types are concentrated in the upper two thirds of the project area and are often associated with agricultural activities. Bare areas are not prominent in any reach. The proportion of bottomland covered by water increases with distance downstream, with the exception of Westwater Canyon and Moab Valley.

Dominant tall tree cover comprises no more than 20% of any reach (Figure 10), and the composition of trees changes considerably in upper versus lower reaches of the project area and with position on the bottomland. Downstream reaches generally contain fewer hectares of trees (less than 25 ha, except Moab Valley [13 MV]), but are comprised of more species of trees. Of the trees found within the project

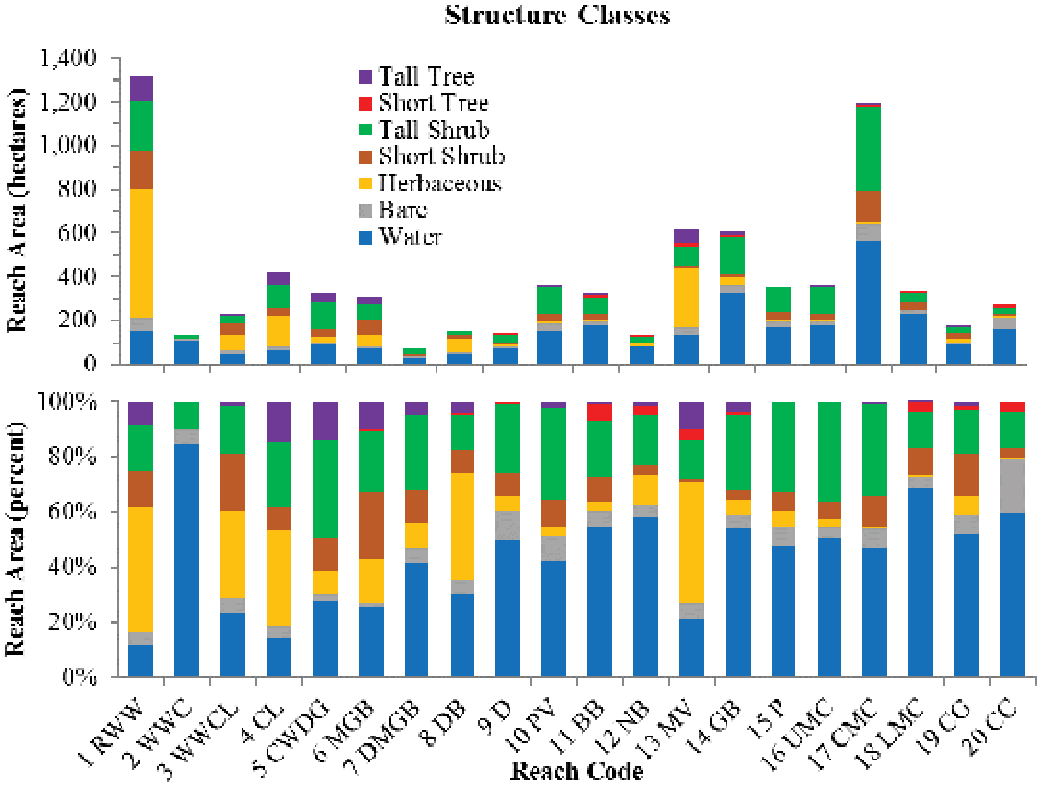

Figure 10 — Area (upper figure), and percentage of reach area (lower figure) dominated by different vegetation structural classes mapped from 2010 aerial photographs. Refer to Table 6 for list of plant species associated with each structural class and reach names.

area, cottonwood is easily the most common (appearing in all but two reaches) and the most broadly distributed within the bottomland. Goodding's willow seems to prefer wetter habitats than cottonwood in the project area, and occurs typically as individual trees or small patches. Sizeable areas of Goodding's willow are found in Moab Valley, only. Box elder is found in the lower two thirds of the reaches, generally in moderately narrow canyons, though never in great abundance and usually in mesic portions of the floodplain (not close to channel, not xeric). Gambel oak is common in two reaches, Big Bend (11 BB) and Negro Bill (12 NB), with some patches in Gold Bar (14 GB) and a very minor presence in Central Meander Canyon (17 CMC). Gambel oak and hackberry are typically found in the highest margins of the bottomland boundary, away from river scour and flooding. Patches dominated by non-native trees (mostly Russian olive) are very limited in all but Moab Valley. Russian olive prefers wetter habitats, and in the few patches where it occurs in upstream reaches, it grows immediately adjacent to stream channels.

Mesic shrubs are abundant throughout the project area (Figure 11). Of the four mapped species, tamarisk was the most prevalent, dominating 1,226 ha of bottomland habitats, followed by coyote willow at 498 ha, NM privet at 118 ha, and skunkbush sumac at 68 ha. Most of the 1,226 ha of tamarisk is in poor condition, allowing species in or around failing patches to increase or colonize. During field checks in 2011, dominance of mixed patches of shrubs (e.g., tamarisk and another mesic shrub) was already shifting away from tamarisk, with native shrub crowns exceeding the cover of tamarisk crowns. Willow stands are actively competing with declining tamarisk, though willow stands are more restricted to the lower and wetter portions of the bottomlands (Figure 12). In higher and drier elevations above the channel, sumac and NM privet may expand to fill some of the released habitat, as well as Russian knapweed and other non-native herbaceous species.

Patches dominated by xeric shrubs (Figure 13: greasewood, rabbit brush, saltbush, shadscale or big sagebrush) represent areas that are typically difficult to re-vegetate due to challenging conditions such as relatively high soil salinity and low soil moisture. Ruby-Westwater (1 RWW) has the greatest expanse of xeric shrubs, with large areas just downstream of the Utah-Colorado border (May Flat area). Many of the herbaceous dominated areas now converted to agriculture were likely dominated by one or several of these xeric shrub species before conversion.

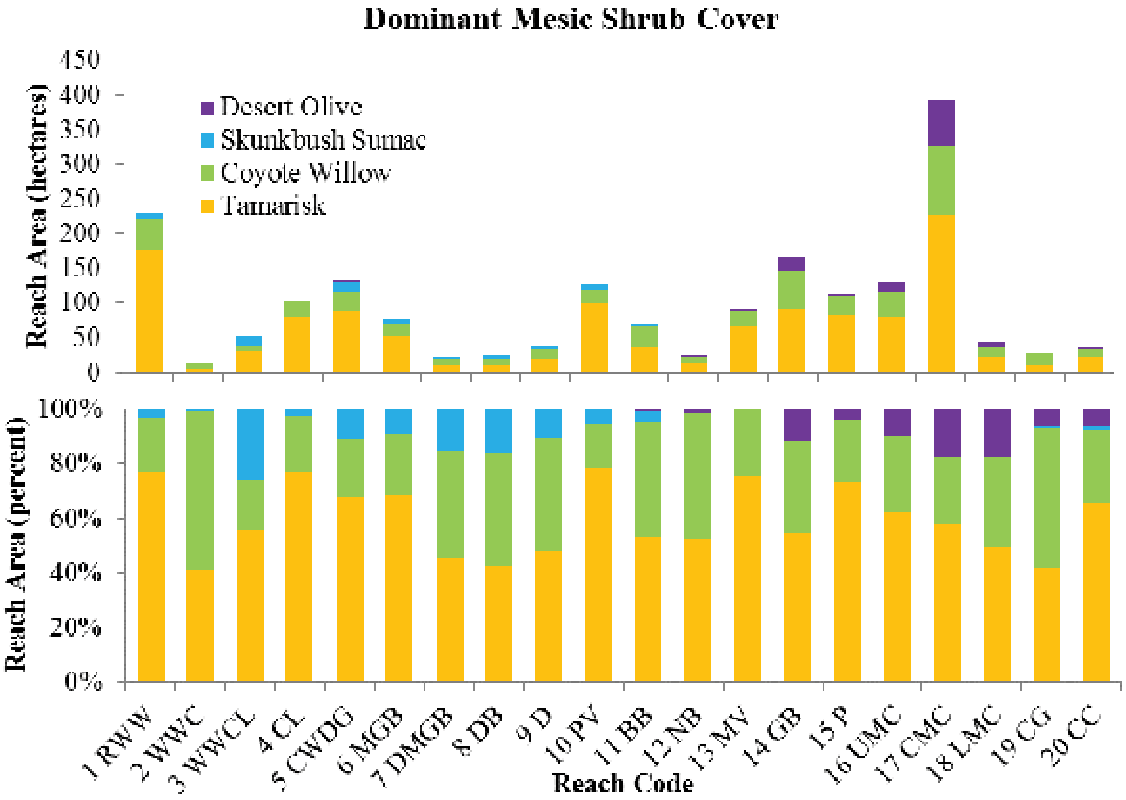

Figure 11 — Area (upper figure) and percentage reach covered (lower figure) occupied by four species of mesic shrubs. Desert olive = NM privet.

Figure 12 — Riparian vegetation in Reach 5, near Cisco Landing, consisting of poor condition tamarisk with overstory cottonwood on the bottomland and vigorous coyote willow adjacent to the river channel.

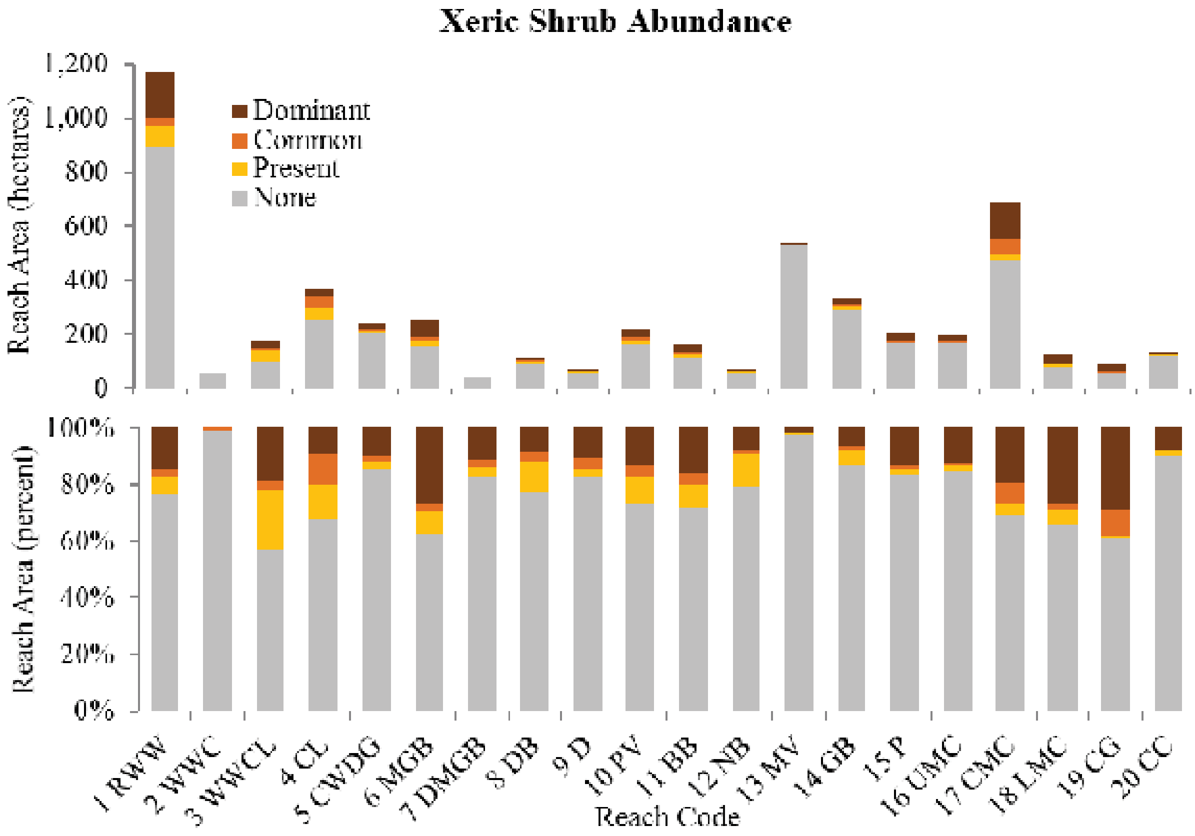

Figure 13 — Area (upper figure), and percentage of reach covered (lower figure) occupied by xeric shrubs. Dominant cover is listed first in a description of patch vegetation (category A), common cover is listed second (category B), and present is listed third or fourth in patch description (category C or D). Grey bars represent non-water, non-developed, vegetated areas without xeric shrubs.

Non-native Vegetation Cover Types – Dominence and Abundance

Non-native species often dominate vegetation patches in the bottomland area. Russian knapweed occurs throughout the project area but is particularly abundant in the upper reaches of the project area, especially where land use has been disruptive (i.e., abandoned or lightly managed agricultural fields). Russian olive is sparse but increasing in the Ruby-Westwater Reach (1 RWW), presumably due to propagules washing down from heavy infestations in the Grand Valley (upstream of the project area), and is also abundant in the Moab Valley. Tamarisk is abundant, but declining, throughout the project area. Non-native herbaceous species include xeric weedy species such as cheatgrass (*Bromus tectorum*), but also more mesic weeds like kochia (*Bassia scoparia*), and agriculturally grown species (e.g., alfalfa or hay crops).

In this section, we present both the total extent of non-native cover types (Figure 14) and the abundance of each group of non-native species (dominant, common, present, or not mapped). Agricultural designation includes both current and past agricultural use as evidenced by plow lines and ditches. Knapweed is present in most of the reaches, though it is often in the understory of woody cover types (described below). Non-native trees are rarely dominant, with the exception of substantial stands in the Moab Valley (13 MV).

Non-native herbaceous species make up a large portion of most reaches (Figure 15), often related to current or past agricultural activities mentioned above. These herbaceous species are both mesic and xeric, and in some reaches appear to expand following disturbance associated with tamarisk removal projects. Lowest dominance values are in the narrower bottomland areas, and especially in the reaches downstream of Potash (15 P) within the boundary of Canyonlands National Park, with the exception of Spanish Bottom in the Green-Colorado Reach (19 CG).

Tamarisk is either dominant or common in the greatest number of hectares in Central Meander Canyon (309 ha, 17 CMC) and Ruby-Westwater (273 ha, 1 RWW), with between 100 and 150 ha occupied in Reaches 4 CL, 10 PV, 13 MV, 14

GB, 15 P, and 16 UMC (Figure 16). Tamarisk is present and declining in nearly 80% of the Cisco Wash-Dry Gulch reach (5 CWDG); therefore, vegetation is likely to be particularly dynamic in future years.

Knapweed is dominant in relatively small areas in most reaches (Figure 17), but is common or present in substantial areas. Ruby-Westwater (1 RWW) has the greatest number of hectares impacted by knapweed (618 ha), followed by Moab Valley (13 MV, 239 ha), Cisco Landing (4 CL, 174 ha), Central Meander Canyon (17 CMC, 147 ha), Westwater-Cisco Landing (3 WWCL, 113 ha), and McGraw Bottom (6 MGB, 97 ha). Knapweed is very uncommon in the lowest three reaches and Westwater Canyon (2 WWC).

Non-native trees, mostly Russian olive, are of greatest concern in the upper reaches of the project area and in the reaches near Moab (Figure 18). The upper boundary of the project area is only 20 miles downstream of the heavily-infested Grand Valley. Russian olive, and occasionally Siberian elm, are often present as single trees or scattered small trees growing very near the channel margin. Ruby-Westwater (1 RWW), the first reach of the project area, has less than 1 ha with Russian olive as dominant, 3 ha as common, and almost 40 ha with Russian olive as a minor component of the vegetation patch. Other upstream reaches with notable non-native tree area include Cisco Landing (4 CL) and McGraw Bottom (6 MGB) with 12-13 ha, Westwater-Cisco Landing (3 WWCL) with 8 ha, and Dewey Bridge (8 DB) with 6 ha.

Non-native trees, abundant in Moab Valley and reaches immediately upstream and down, are often well-established and mature. Moab Valley has a total of 69 ha of non-native tree influence; immediately downstream of Moab Valley, Gold Bar (14 GB) has 36 ha, followed by Potash (15 P) with 4 ha. Two reaches upstream of Moab Valley (Big Bend, 11 BB and Negro Bill, 12 NB) have 2 ha each.

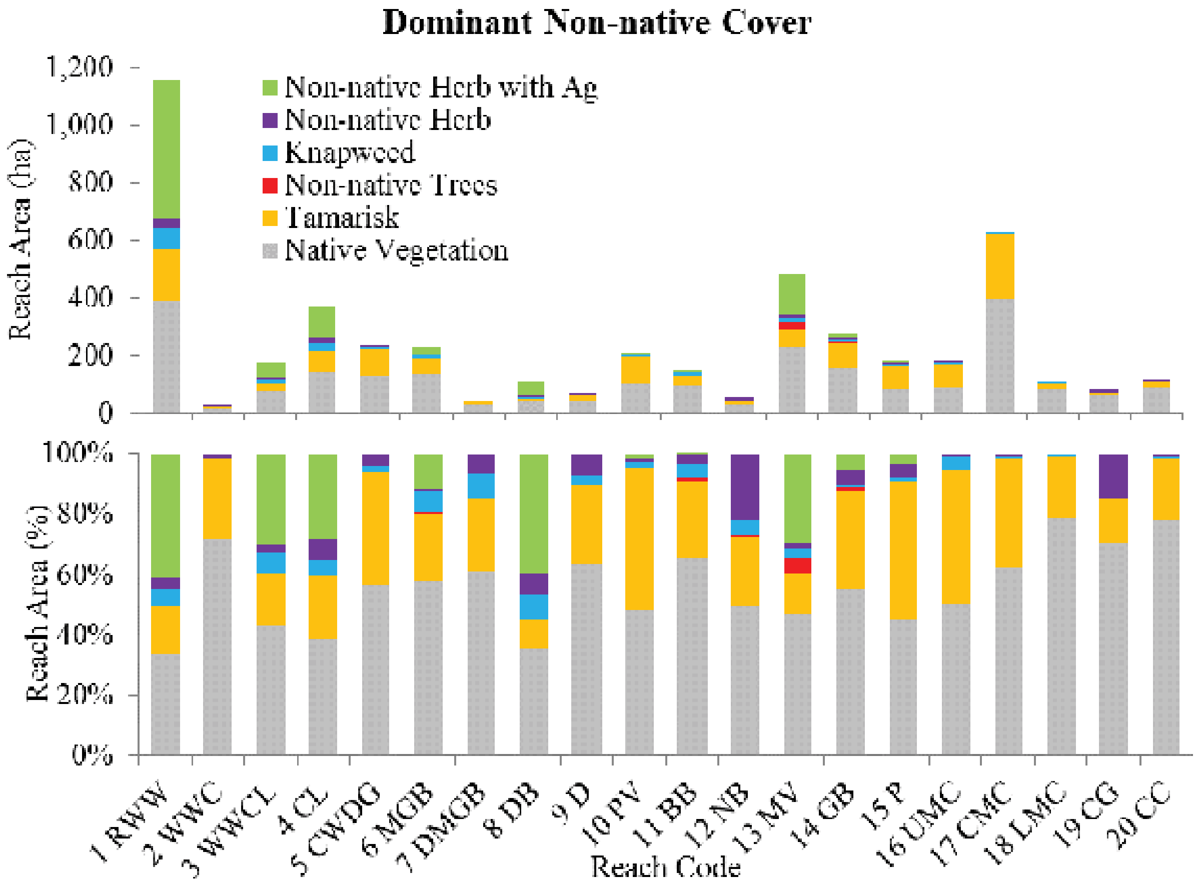

Figure 14 — Area (upper figure), and percentage of reach (lower figure) occupied by non-native cover types.

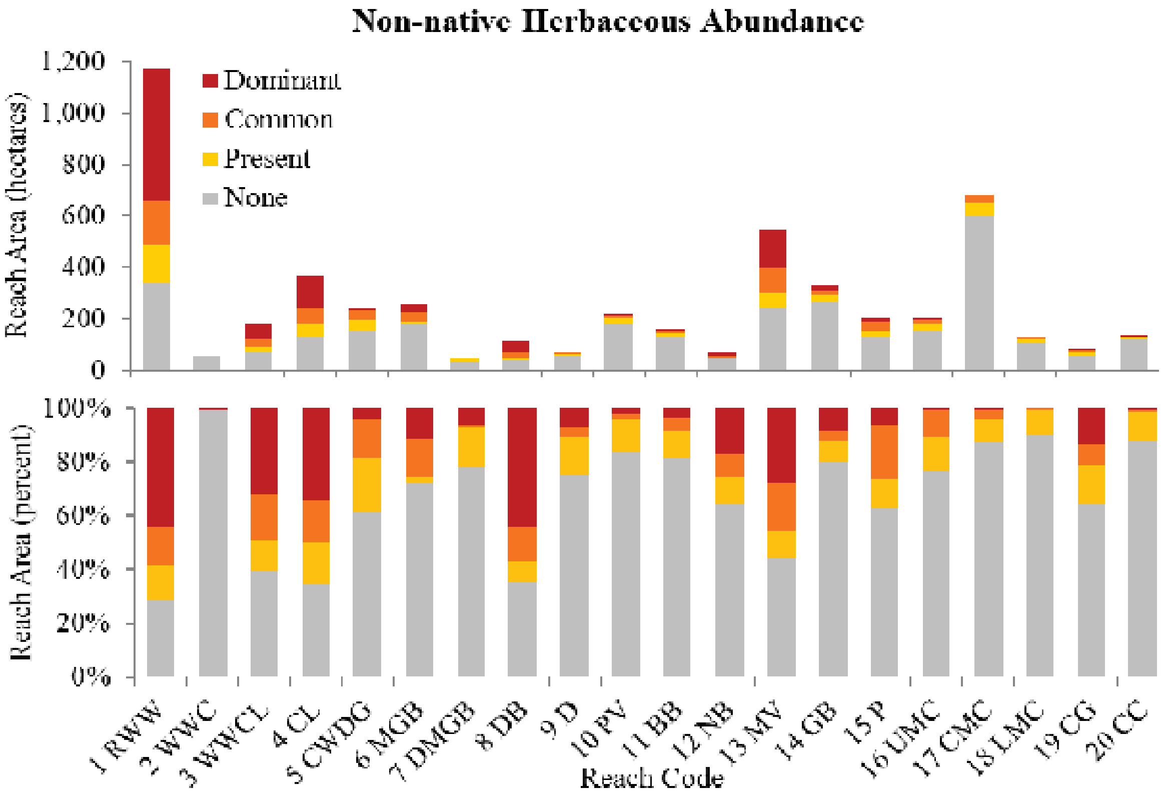

Figure 15 — Area (upper figure), and percentage of reach (lower figure) occupied by four relative abundance classes of non-native herbaceous species.

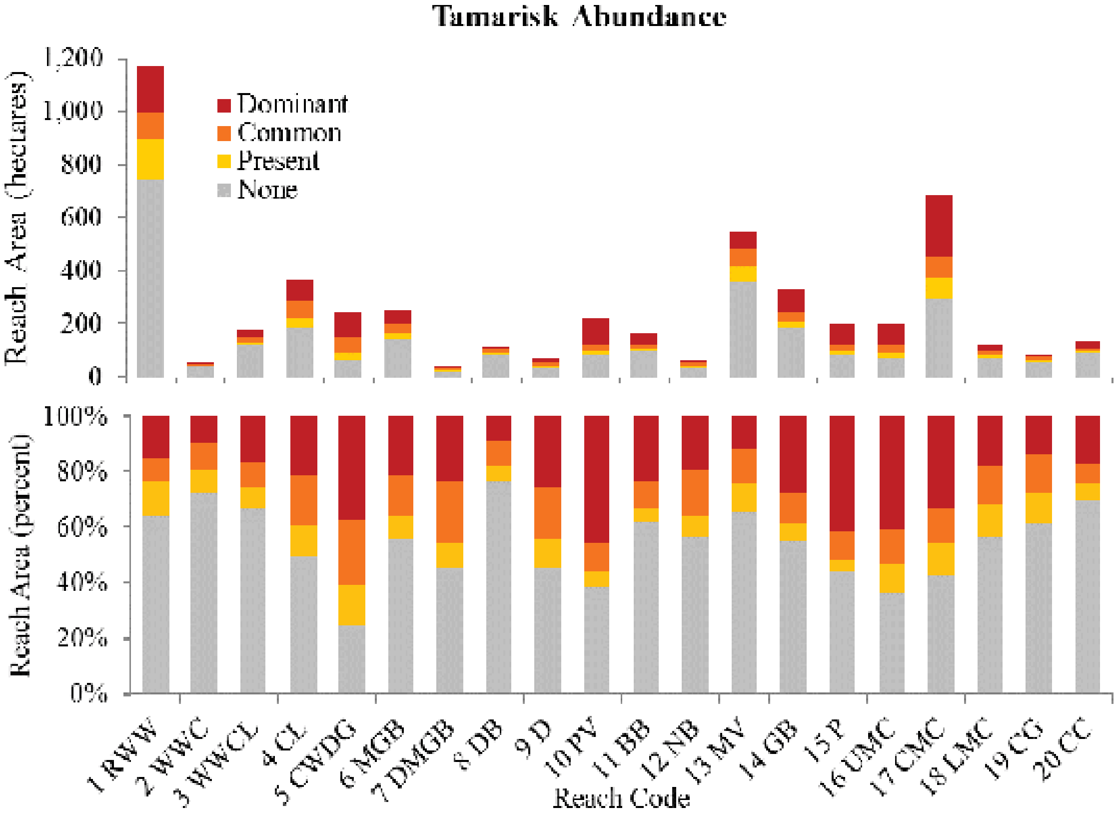

Figure 16 — Area (upper figure), and percentage of reach (lower figure) occupied by tamarisk.

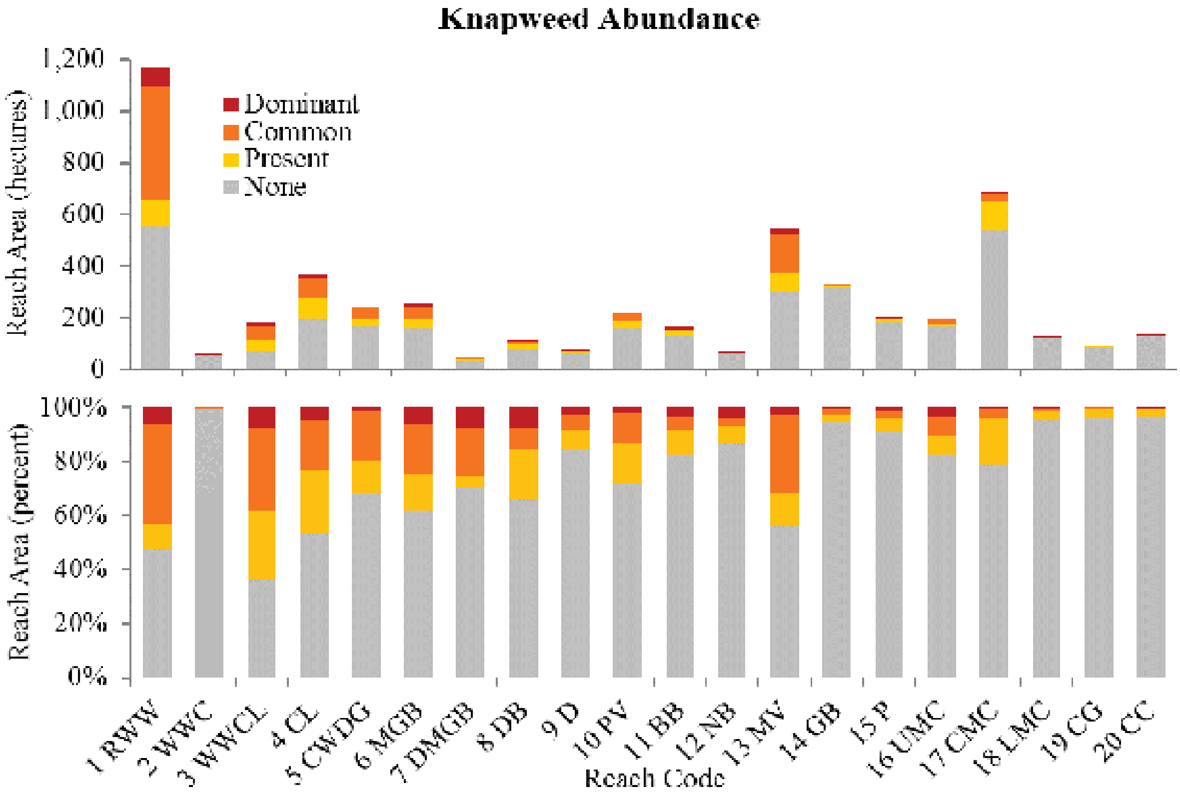

Figure 17 — Area (upper figure), and percentage of reach (lower figure) occupied by Russian knapweed.

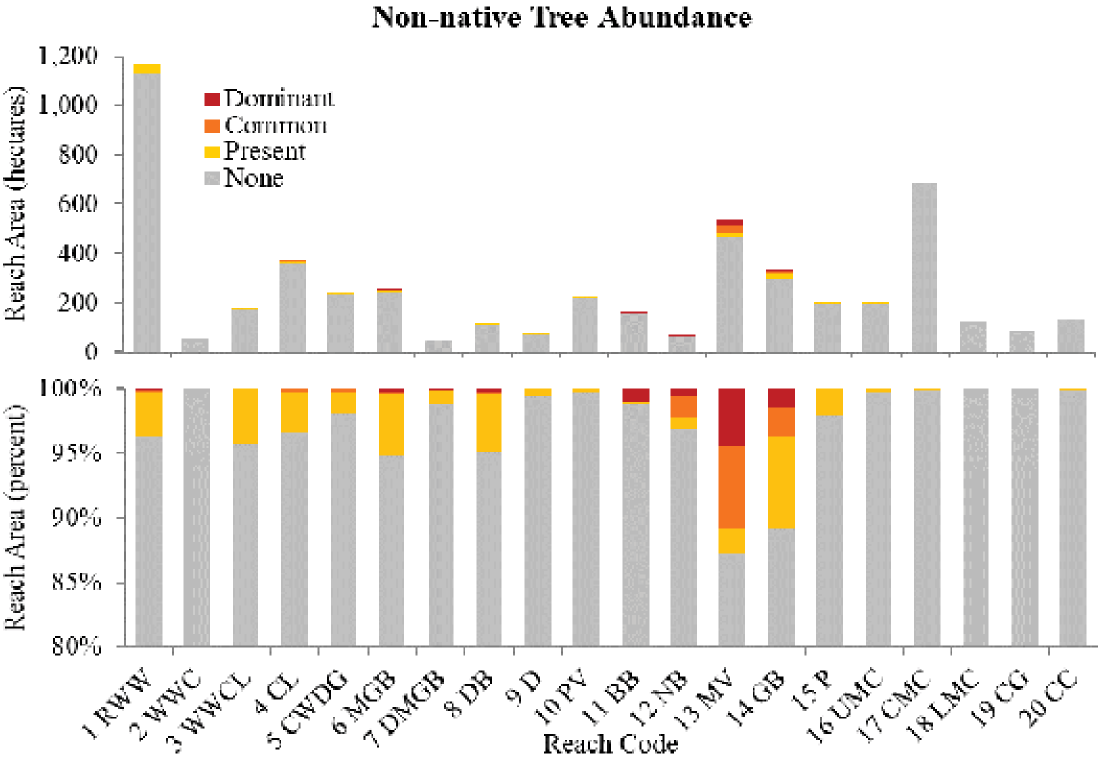

Figure 18 — Area (upper figure), and percentage of reach (lower figure) occupied by non-native trees.

Summary of Channel Types

In this section, we present the proportion of various channel types for each reach during high (886 m³/s [31,300 ft³/s], Cisco gage, 2011) and low flow (96.5 m³/s [3,410 ft³/s], Cisco gage, 2010). We show the presence of different channel types in a series of graphs for both years: 1) off-channel to primary channel types, highlighting the relative proportion of complex channel areas; 2) off-channel habitats subdivided into moving water and still-water types; and 3) types of still-water habitats, as they have distinct habitat values and potential hazards. We define off-channel habitat as any of the channel types listed in Table 7, other than "primary channel". Values at both high and low flow offer snapshot perspectives of changes in habitat types across the project reaches. Short lengths of channel of the Dolores and Green Rivers are mapped for channel types. While they are both tributaries, their channel areas are considered as 'Main' rather than tributary types due to their relatively high velocity flow and volume.

2010 Low Flow

Off-channel areas are quite limited at our mapped extent at low flow, totaling less than 20 ha in 17 reaches and less than 40 ha in any reach (Figure 19). Off-channel habitat comprises less than 10 percent of the bottomland study area--229 ha out of 2602 total ha. Central Meander Canyon (17 CMC) is the longest reach of the project area and has the highest value for off-channel habitats (39 ha), followed by Gold Bar (14 GB) with 29 ha, and Ruby-Westwater (1 RWW) with 23 ha. Cisco Landing (4 CL) has the greatest percentage of off-channel habitats (27%), followed by Dewey-McGraw Bottom (7 DMGB; 19%).

Of the 229 ha of off-channel habitat, most is in the form of secondary or split flow channels (204 ha; Figure 19), where the channel is connected to flowing water at the top and bottom, separated from the primary channel by either a vegetated island (secondary channel) or by an unvegetated bar (split flow). Velocities in these habitats are variable; they may be flowing as fast as the primary channel or may be nearly still.

Still-water features, important to rearing fish and bat watering, are very uncommon with only 25 hectares in the entire project area at low flow (Figures 20 and 21). Of that area, 5.5 ha are in the form of a gravel pit in Ruby-Westwater (1 RWW). Backwaters, connected to flow on one end but not the other, have a total of 13 ha for the project area, and tributary channels only 2.5 ha.

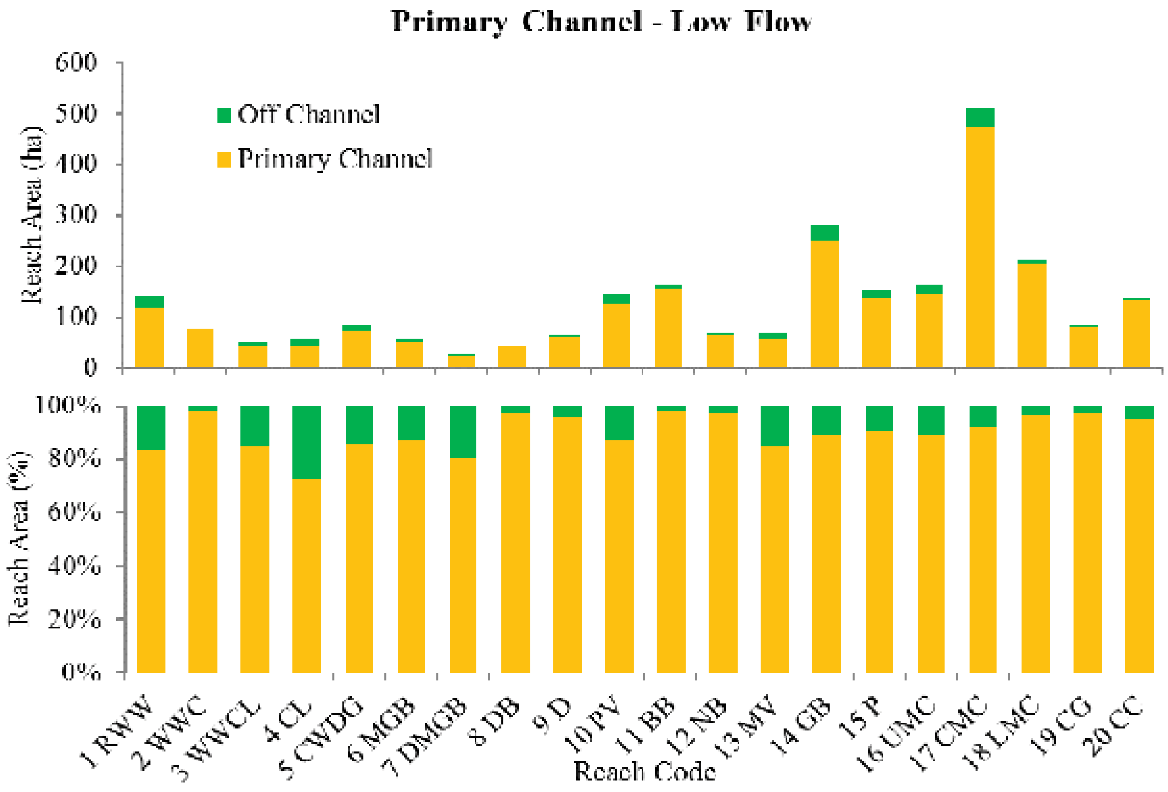

Figure 19 — Area (upper figure), and percent reach (lower figure) occupied by primary and off-channel habitat mapped from 2010 low flow imagery. Note the y-axis scale of 0-600 ha in upper figure.

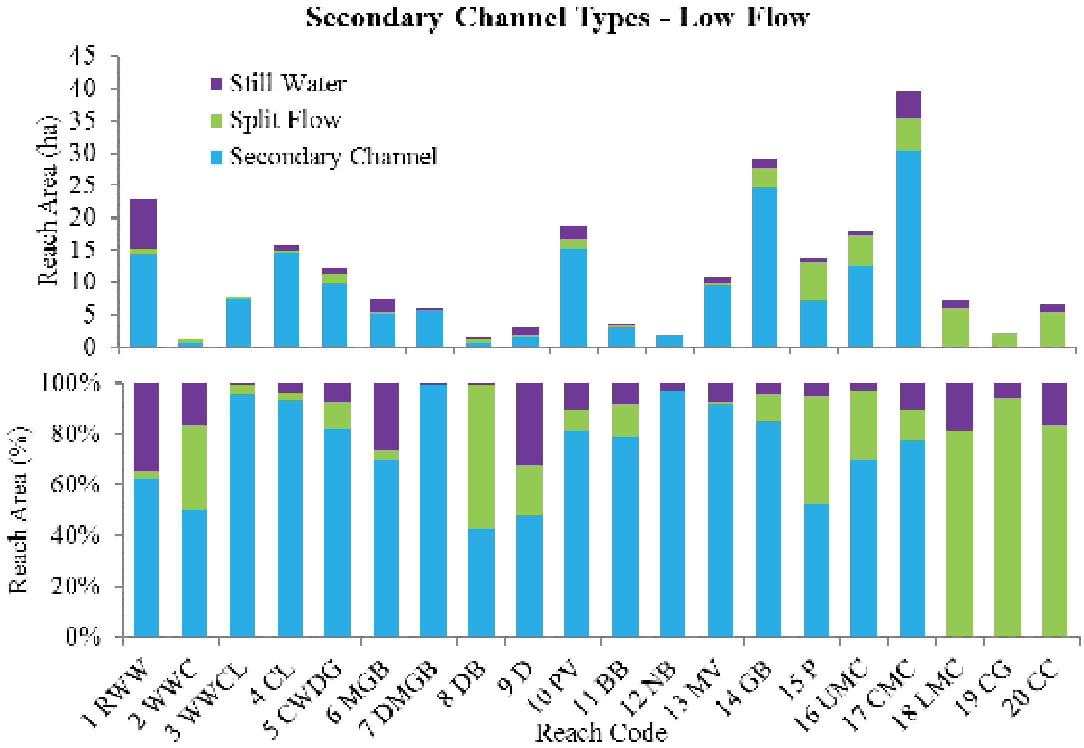

Figure 20 — Figure 20. Area (upper figure), and percentage of reach (lower figure) occupied by off channel (not primary channel) habitat types mapped from 2010 low flow imagery. Still-water areas are: backwaters, isolated pools and tributary mouths. Note the y-axis scale of 0-45 ha.

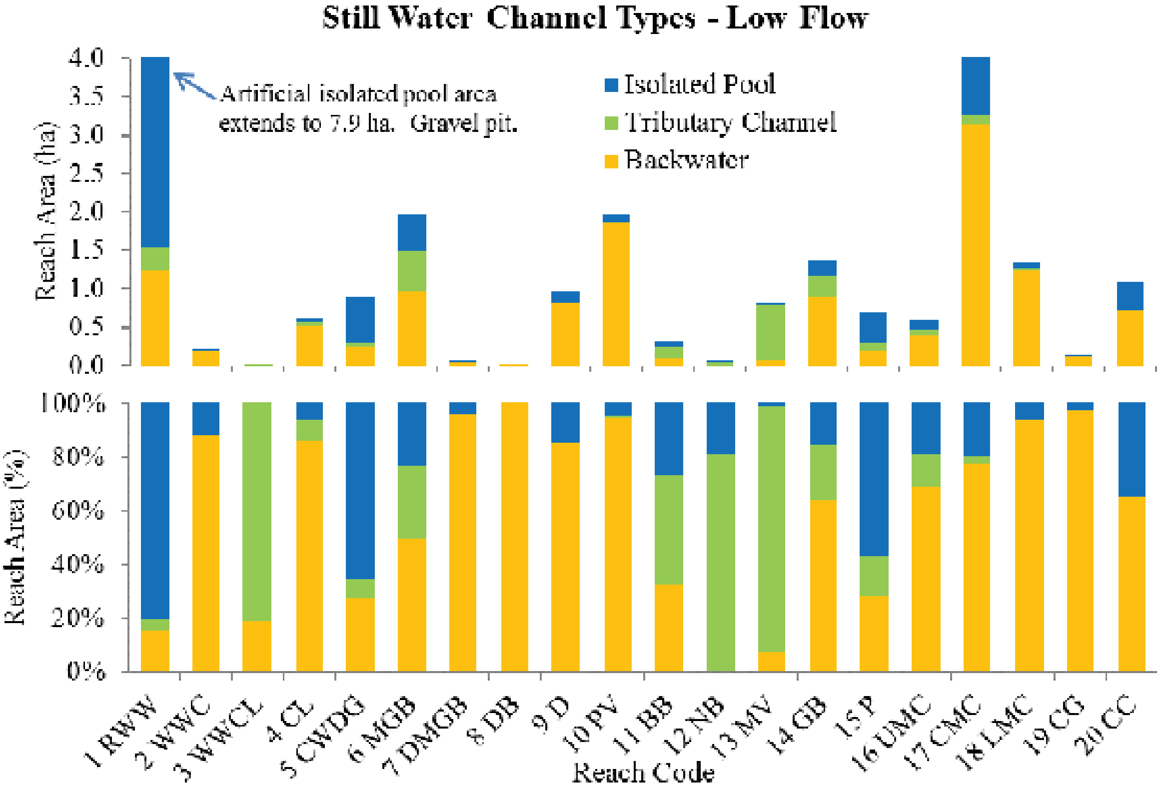

Figure 21 — Area (upper figure), and percentage of reach (lower figure) occupied by still-water habitat types mapped from 2010 low flow imagery. Still-water areas are: backwaters, isolated pools and tributary mouths. Note the y-axis scale of 0-4 ha. Note the very high bar for Reach 1 (1 RWW), extending to 7.9 ha (off scale for y-axis).

2011 High Flow

Channel habitat abundance changes substantially between a low summer flow (2010) and a higher flow (2011), emphasizing the differences in the fluvial geomorphology of individual reaches and lateral connectivity with bottomland surfaces (Table 11). Total channel area expanded significantly in three reaches (Figure 22). Channel area in Ruby-Westwater (1 RWW) and Cisco Landing (4 CL) more than doubled in size (106% expansion) between the two flow conditions, showing significant lateral connectivity of bottomland habitats. Channel area in Moab Valley (13 MV), with the large wetland area on Matheson Preserve, more than tripled, expanding from 71 ha to 304 ha. Reaches with very little expansion of area and lower connectivity with bottomland surfaces are: Lower Meander Canyon (18 LMC) with 22% increase, Big Bend (11 BB) and Negro Bill (12 NB) both with 25% increases, and Dewey Bridge (8 DB) with 27% increase in area.

Off-channel habitats at high flow are predictably scarce in the very narrow Westwater and Cataract Canyons – 2 WW and 20 CC, as well as: Lower Meander Canyon, Colorado-Green, Big Bend, and Dewey (18 LMC, 19 CG, 11 BB and 9 D, respectively).

The largest increases in off-channel habitats between the low and high flow condition were in the reaches below Moab Valley with 229, 73, 43, 45, and 87 ha in reaches 13-17, respectively. Reaches with higher values in the upstream portion of the project area are Ruby-Westwater (1 RWW) with 99 ha, Cisco Landing (4 CL) with 62 ha, and Professor Valley (10 PV) with 37 ha.

As above, off-channel high flow habitats are subdivided into secondary channel (only secondary channel at high flow – no split flow channels) and still-water channel types (Figure 23). The massive pool at Moab Valley (13 MV) of over 200 ha dwarfs any of the other off-channel features in the project area and is truncated in graphs. Still-water habitat types are more limited in upper reaches than in Moab Valley and reaches downstream of Moab. Several reaches (2 WWC, 9 D, 11 BB, 18 LMC, 19 CG and 20 CC) have virtually no secondary channel types, still or otherwise. Secondary channel types in the upper reaches are typically associated with gravel/cobble habitats that could serve as spawning beds for both Colorado pikeminnow and razorback suckers. Still-water habitats, necessary for rearing of newly emerged fry drifting downstream, are more prevalent in reaches downstream of Moab Valley.

Still-water habitats are the least common of the habitat types, with 395 ha total for the project area, over half of which is in the Moab Valley (209 ha; Figure 24). Still-water habitat associated with tributary mouths, important for both fish refuge and wildlife watering, is especially uncommon, with 27 ha for the entire project area. Much of the isolated pool habitat in Ruby Westwater (1 RWW) is a series of ponds associated with an active gravel pit. Access into and out of these ponds is unknown, as is their potential for harboring populations of non-native fish. Still-water habitats of any kind are very limited in middle (Reaches 7-11, less than 9 ha) and lowest reaches (Reaches 18-20, less than 4 ha), suggesting that young fish have few opportunities to hold and are likely swept into downstream reaches.

Table 11 — Summary of total hectares of channel area mapped for the 2010 low flow, the 2011 high flow, and the expansion of channel area between the two mapped extents.

Reach Name	Reach Code	2011 total ha	2010 total ha	Expansion (%)
Ruby-Westwater	*1 RWW*	292.7	142.0	106
Westwater Canyon	*2 WWC*	110.4	77.0	43
WW-CL transition	*3 WWCL*	75.1	50.5	49
Cisco Landing	*4 CL*	119.4	57.9	106
Cisco Wash - Dry Gulch	*5 CWDG*	134.2	86.1	56
McGraw Bottom	*6 MGB*	82.3	57.4	43
Dolores – McGraw Bottom	*7 DMGB*	43.8	29.7	48
Dewey Bridge	*8 DB*	56.9	44.7	27
Dewey	*9 D*	91.7	66.0	39
Professor Valley	*10 PV*	216.2	144.7	49
Big Bend	*11 BB*	202.5	162.2	25
Negro Bill	*12 NB*	85.0	68.2	25
Moab Valley	*13 MV*	304.1	71.1	328
Gold Bar	*14 GB*	374.5	280.7	33
Potash	*15 P*	208.5	150.9	38
Upper Meander Canyon	*16 UMC*	234.0	163.2	43
Central Meander Canyon	*17 CMC*	680.1	512.3	33
Lower Meander Canyon	*18 LMC*	259.6	213.1	22
Colorado - Green	*19 CG*	111.7	84.9	32
Cataract Canyon	*20 CC*	219.7	139.3	58
	Total Area	**3902.3**	**2601.9**	**50**

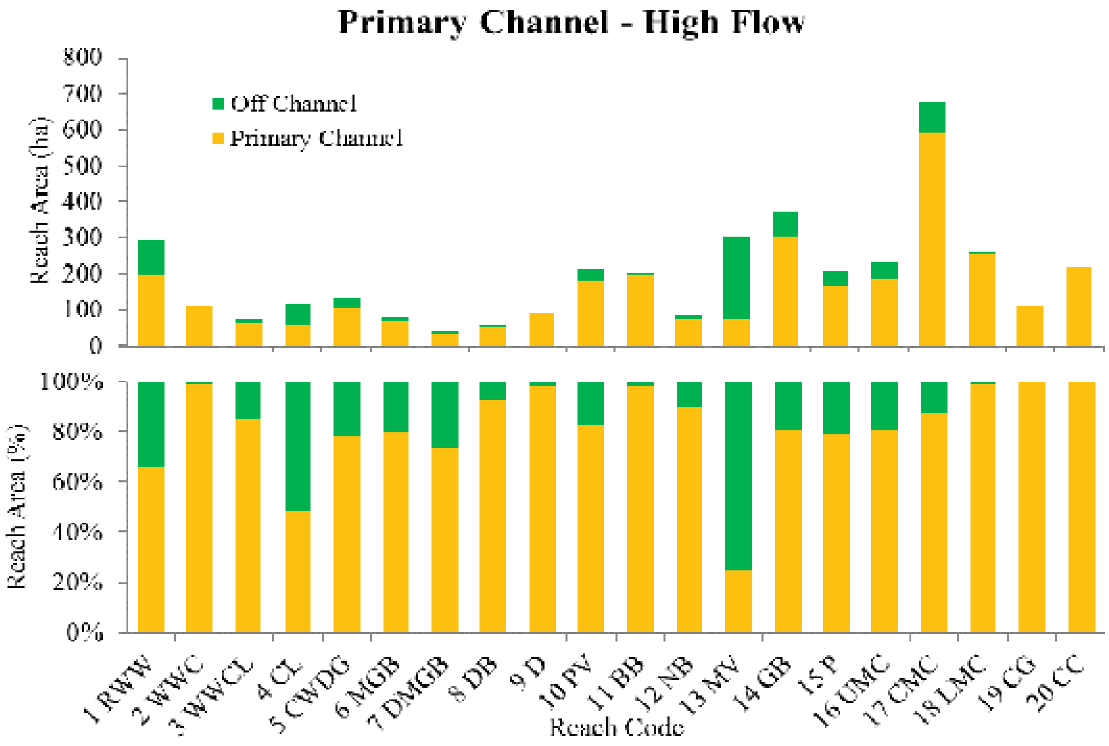

Figure 22 — Area (upper figure), and percentage of reach (lower figure) occupied by primary and off channel habitat types mapped from 2011 high flow imagery. Note the y-axis scale of 0-800 ha.

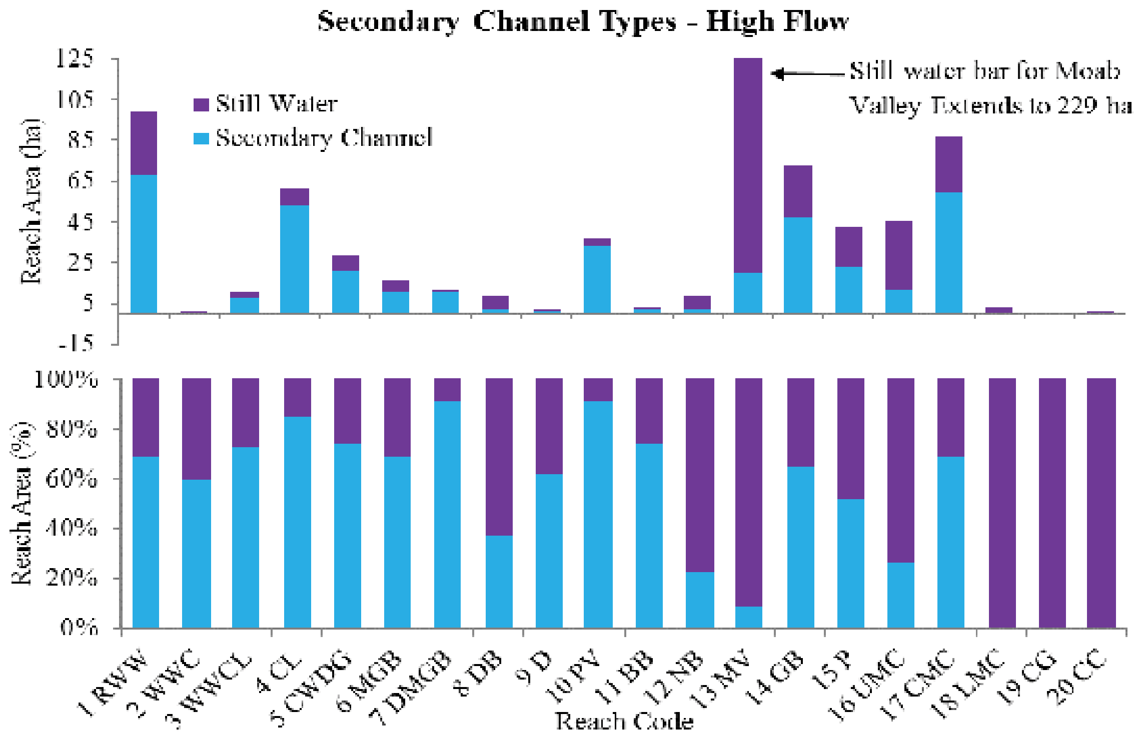

Figure 23 — Area (upper figure), and percentage of reach (lower figure) occupied by off channel habitat areas mapped from 2011 high flow photographs. Still-water areas are: backwaters, isolated pools and tributary mouths. *Note the broken y-axis scale of 0-125 ha where Reach 13, Moab Valley, has a maximum value of 229 ha.

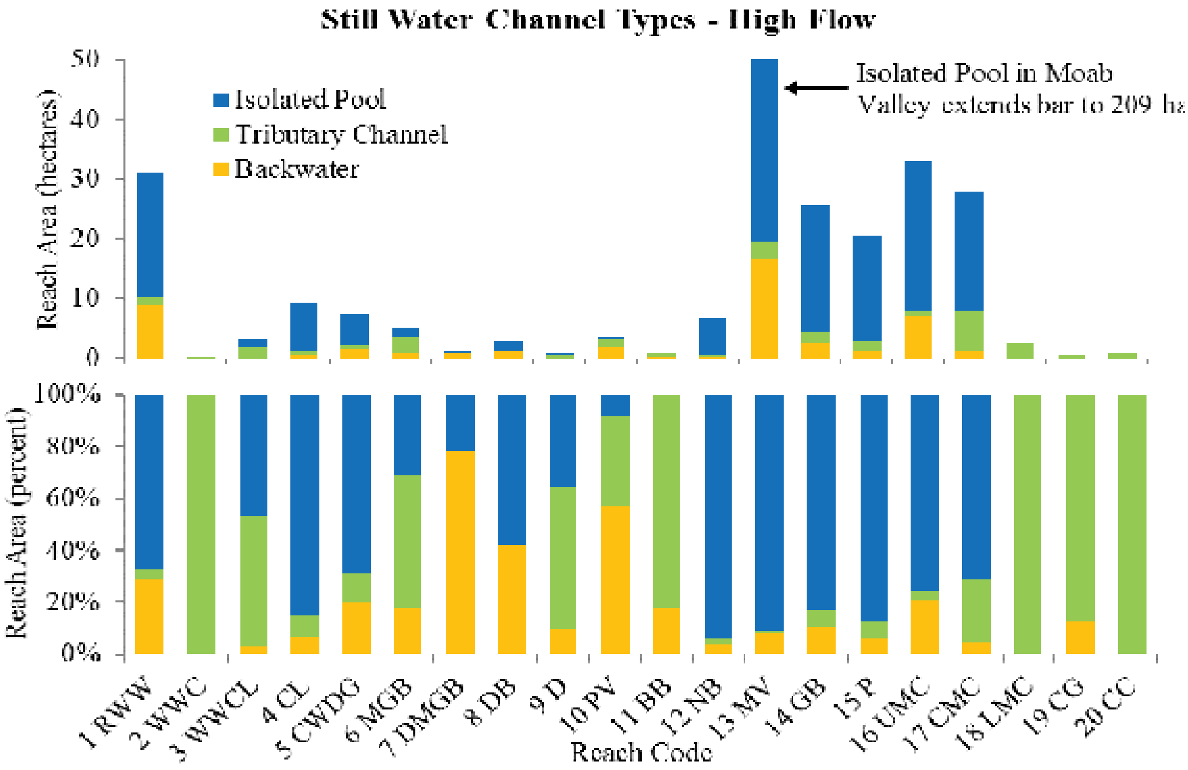

Figure 24 — Area (upper figure), and percentage of reach (lower figure) occupied by still-water habitat types mapped from 2011 high flow photographs. Still-water areas are: backwaters, isolated pools and tributary mouths. *Note the broken y-axis scale of 0-50 ha where values for Moab Valley (13 MV) that has a maximum value of 209 ha.

Results of Habitat Suitability Modeling

In this section, we present the outcomes of each of the habitat suitability models described above. For each model, relative habitat quality is shown as portions of the bottomland (area in hectares) on longitudinal profile of the project area, broken into 1 km subsections. The longitudinal profile is marked with reach breaks, selected reach codes for reference, and confluences with primary tributaries (Dolores and Green Rivers). On all graphs, upstream reaches are on the left side of the x-axis, moving downstream to the right. Reaches are numbered upstream to downstream. Bottomland polygons, however, are numbered consistent with river navigation and fish habitat work and increase in the upstream direction. Bottomland polygon numbering begins at the lower project extent and ends at the boundary between Utah and Colorado. Habitat suitability models include different extents within bottomland boundary depending on the habitat modeled, inclusion or exclusion of channel area in the modeled surface, and geoprocessing of component layers. For the sake of visualizing results in all graphs, only habitat rated as Low, Moderate or High is displayed (Very Low or No Habitat areas are excluded), and scales of y-axes vary with the maximum habitat present in bottomland polygons.

Riparian Overstory Model with and without the Tamarisk Penalty

The Riparian Overstory Model represents habitat for species, (e.g., yellow-billed cuckoo, Bullock's oriole, black-headed grosbeak, blue grosbeak, warbling vireo, Cooper's hawk, screech owl, saw-whet owl, and bald eagle) that depend on tree canopy and prefer large patch sizes with diverse understory structure classes and trees with dense crowns. These habitats are fairly limited in both abundance and quality in the project area as tree cover is intermittent and sparse, and shrub cover is often dominated by now-declining tamarisk (Figure 25). Of the riparian overstory habitat present, most is in the upper reaches (1, 3-8) and in or near Moab Valley. Outside of these two river stretches, overstory habitat is rarely more abundant than 20 hectares per 1 km of bottomland length.

Model results show most habitat rated as Moderate quality; a very limited number of hectares qualify as High quality (4% of the bottomland). After application of the tamarisk penalty (due to defoliation effects of beetle; -1 or -2 depending on tamarisk abundance), the Very Low or No Habitat category increases substantially, at the highest cost to Moderate quality habitats, and the number of High quality hectares drops from 202 to 11 ha.

Riparian Understory with and without Tamarisk Penalty

Riparian understory habitat is defined by the presence of mesic shrubs preferably very near water, with multiple mesic shrub species present and sparse or absent tamarisk. Species dependent on this kind of habitat include southwestern willow flycatcher, common yellowthroat, yellow warbler, yellow-breasted chat, beaver, northern river otter, and black-necked garter snake. These habitats (Low, Moderate and High quality combined) are common in the project area, with the greatest occurrence of calculated high quality habitats in Reaches 13 -17 in the mid-project area of Moab Valley (13 MV) and adjacent downstream reaches (Figure 26). Upper reaches (minus Westwater Canyon – 2 WWC), also show areas of High and Moderate habitat quality. Application of the tamarisk penalty nearly eliminated the High quality habitat areas. Much of the area rated initially as Moderate became Low Quality with the tamarisk penalty. Riparian Understory habitats, with and without the tamarisk penalty, are most limited in Westwater Canyon (2 WWC), Big Bend (11 BB), Dewey (9 D), and the three lowermost reaches of the project area (Reaches 18-20).

Most of the bottomland hectares for the Riparian Understory model are in the Low quality category. Areas with no shrubs are considered No Habitat. With application of the tamarisk penalty, the area with High quality habitat falls from 299 to 43 ha; area with Moderate quality drops from 1,810 to 1,320 ha.

General Diversity Model

The General Diversity Model combines measures of a variety of habitat cover and habitat structural types found within a 1 ha area. Habitats are categorized as Low, Moderate or High quality, with no category for Very Low or No Habitat (Figure 27). Low quality habitats (simplest) are those where patch sizes are large and similar, such as agricultural areas (some upper reaches and the Moab Valley), and areas where a limited number of species and structural types dominate for large areas (shrub dominated Reaches 14-17). High quality habitats occur within reaches 3 and 12, and especially in Big Bend (11 BB). These reaches have high diversity of tree cover types including oak, box elder, and cottonwood, in addition to prevalent sand bars and common mesic shrub and herbaceous cover types. The moderate spike in values in the Colorado-Green Reach (19 CG) reflects the wide valley of Spanish Bottom.

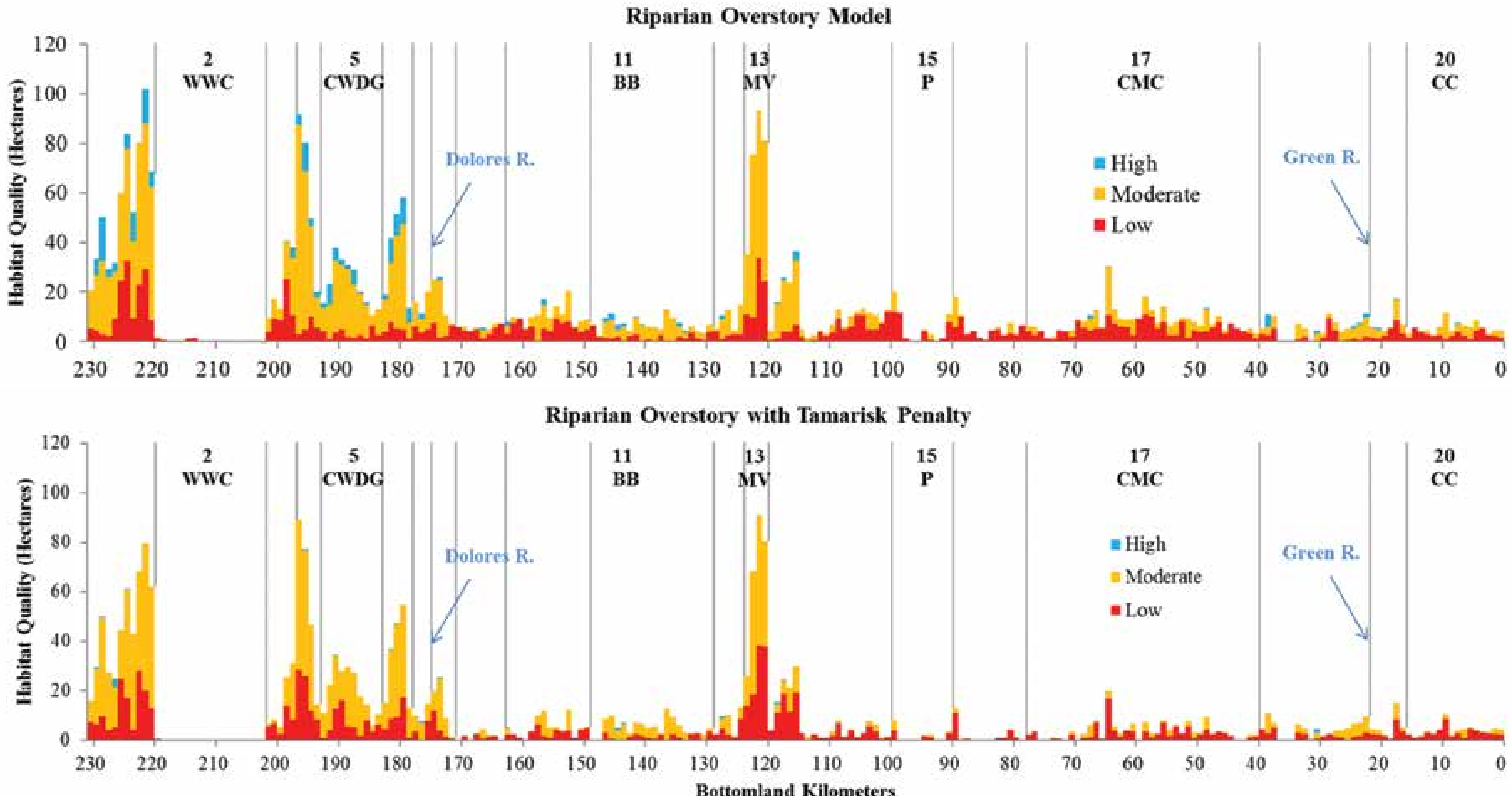

Figure 25 — Riparian Overstory Model (upper figure) and Riparian Overstory Model with Tamarisk Penalty (lower figure) summarizing High, Moderate and Low quality habitats. Very Low or No Habitat values are not shown. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

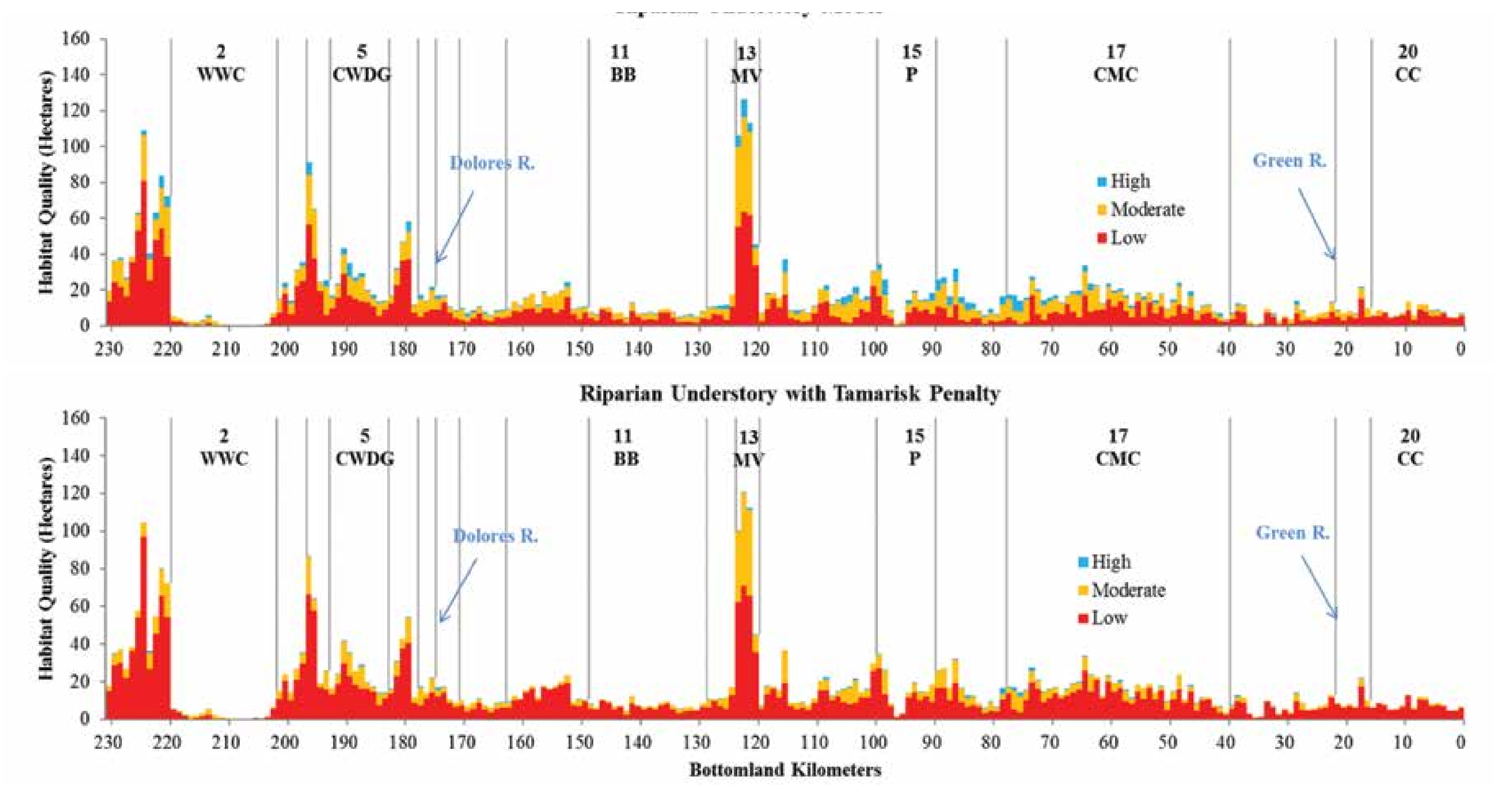

Figure 26 — Riparian Understory Model (upper figure) and the Riparian Understory Model with Tamarisk Penalty (lower figure) summarizing High, Moderate and Low quality habitat values; Very Low or No Habitat values are not shown. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

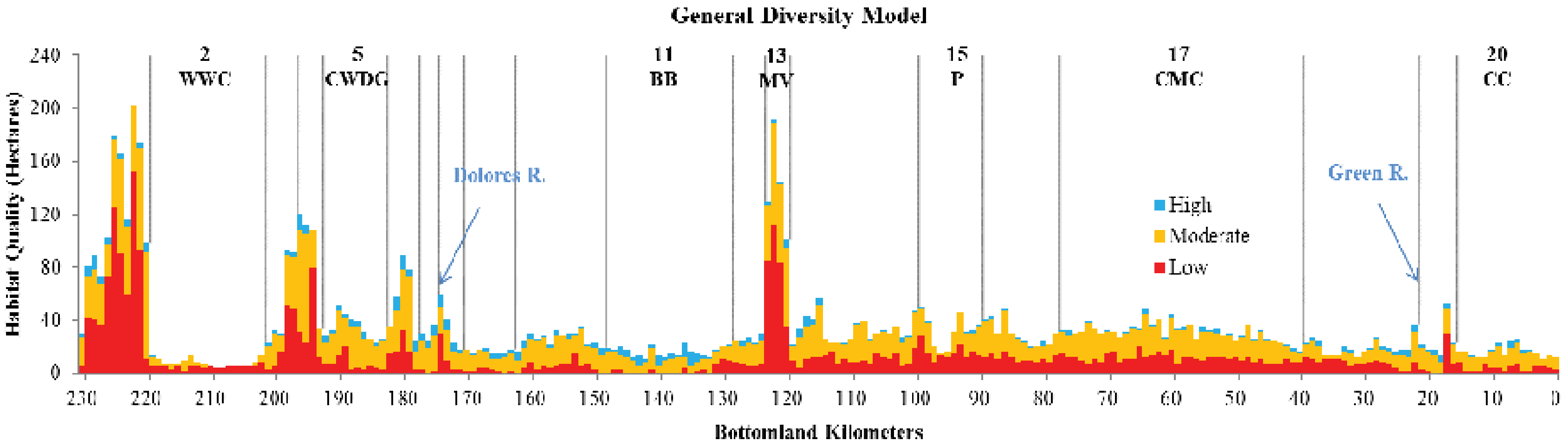

Figure 27 — General Diversity Model summarizing High, Moderate and Low quality habitat values. We display hectares of habitat quality categories on a longitudinal profile of bottomland boundary polygons at 1 km increments. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

Open Land Species Model

The Open Land Species Model values habitats based on their lack of woody plant cover and dryness. Species that depend on this kind of habitat include prairie dogs, gophers, and other burrowing species. These habitats are closely associated with agricultural activities and therefore occur in greatest abundance in the broad valleys in the upper reaches and the Moab Valley (Figure 28). The prevalence of shrub cover greatly reduces the probability of High or even Moderate open land habitat for much of the project area.

This model places the greatest number of hectares in Low quality habitat and over 18 percent of the bottomland area in High quality. Most areas considered High quality are under agricultural production and will be modified by the intensity of activities (e.g., tilling, mowing, or fallow), and by the patch size.

Bat Feeding Model and Bat Watering Model

Habitat required for supporting both agile and non-agile bats requires areas for feeding and accessible areas for watering. Values for bat feeding habitat quality (i.e., insect production) are derived from diversity of cover types, distance to water, and stillness of adjacent water. Moderate and High quality habitats are abundant in the majority of the project area, with the exception of broad, simple and dry areas in upstream reaches (Figure 29). Habitat is especially good in the Moab Valley. Values for bat watering habitat are calculated from stillness of 2011 channel types and absence of woody vegetation near available water surfaces. Open areas with still water are rated as High quality, areas that are vegetated with slow water or open with fast moving channel types are rated as Moderate, and areas with moving water and woody vegetation cover are rated as Low quality. Other than the Moab Valley, High quality watering areas are very limited for much of the project area especially in reaches 2-11, 18-20 (Figure 30). Moderate quality habitat for watering areas is abundant, however.

Rocky Fringe Snakes Model

Habitat for rocky fringe snakes is most dependent on proximity to refuge sites such as those found around rocks, boulders, and fissures often associated with the outer boundary of the project area. Also important is nearness to perennial water and the diversity of woody vegetation. Unlike models described above, this set of habitat criteria highlight narrower reaches with Moderate and High quality habitats fairly uniformly spread throughout the project area, with the exception of Westwater Canyon. Low quality habitat in wider reaches is in part due to simplicity of habitats, but more from the distances from both water and the project boundary (Figure 31).

The Rocky Fringe Snakes model shows a high percentage of hectares as Low quality, but because the best habitat is found in a narrow area near the project boundary and adjacent to surface water, much of the interior bottomland areas will be inherently lesser quality, especially in the broad bottomlands that contribute substantially to total bottomland area.

General Habitat Quality Categories

Most habitat was rated as Low, Very Low or No Habitat, or Moderate. High quality habitat areas are uncommon for any of the Conservation Elements (Table 12 and Appendix G: Habitat Model Results). General Diversity, Bat Feeding and Bat Watering models show the greatest abundance of habitat as Moderate quality. All other models show the greatest abundance in the Low or Very Low/No Habitat quality category.

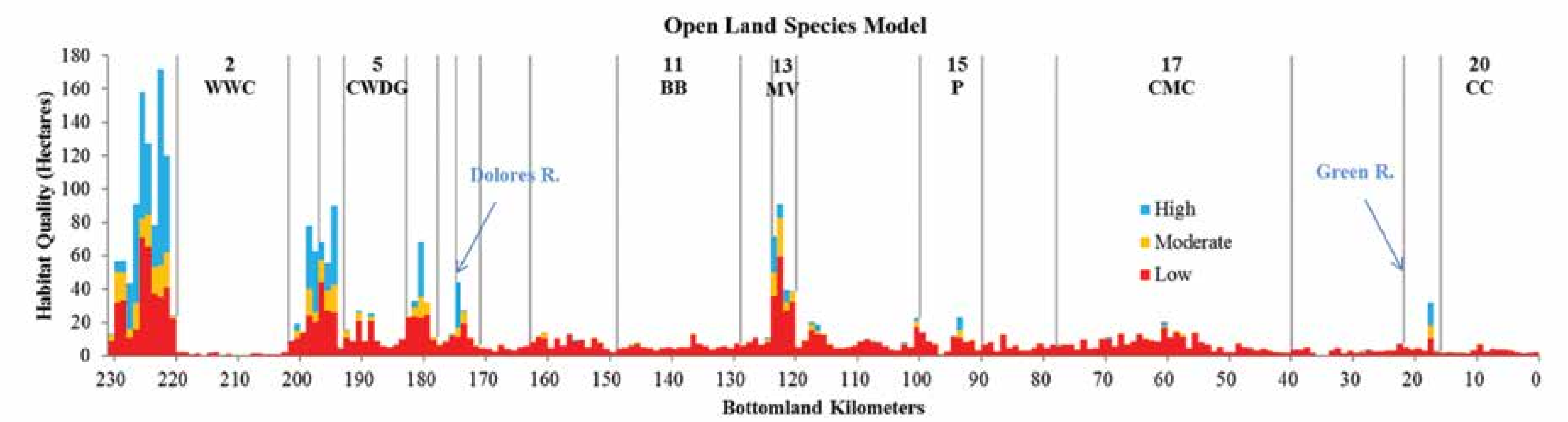

Figure 28 — Open Land Species Model summarizing High, Moderate and Low quality habitat values. We display hectares of habitat quality categories on a longitudinal profile of bottomland boundary polygons at 1 km increments. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

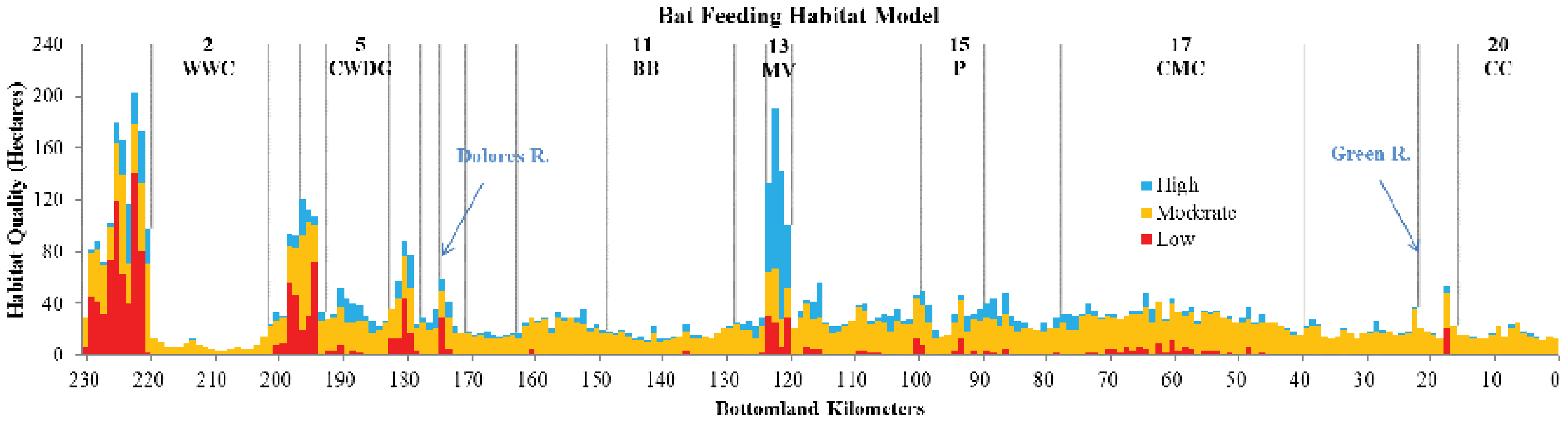

Figure 29 — Bat Feeding Model summarizing High, Moderate and Low quality habitat values. We display hectares of habitat quality categories on a longitudinal profile of bottomland boundary polygons at 1 km increments. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

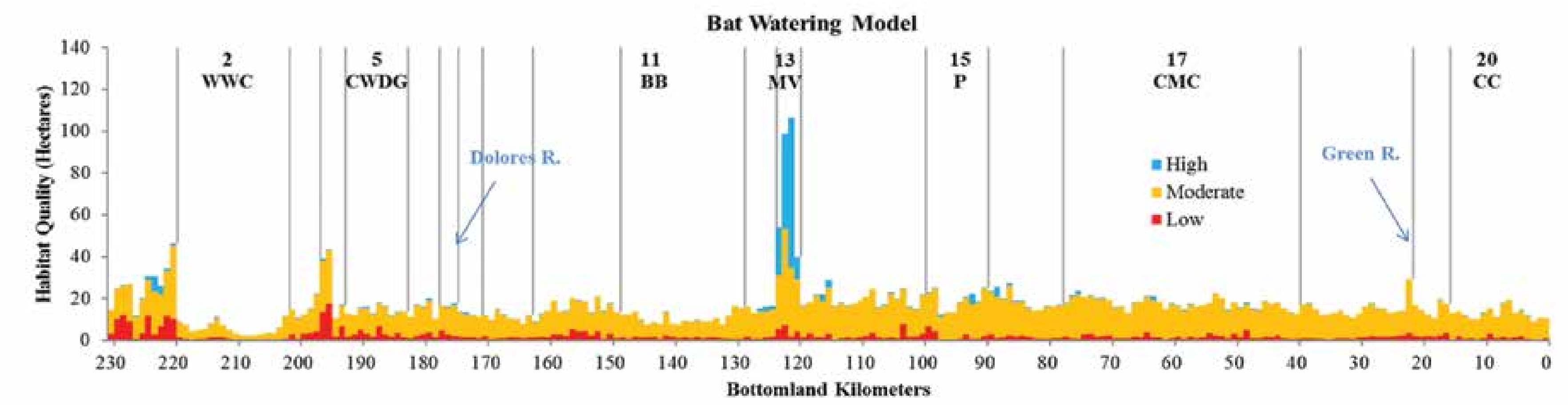

Figure 30 — Bat Watering Model summarizing High, Moderate and Low quality habitat values. We display hectares of habitat quality categories on a longitudinal profile of bottomland boundary polygons at 1 km increments. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

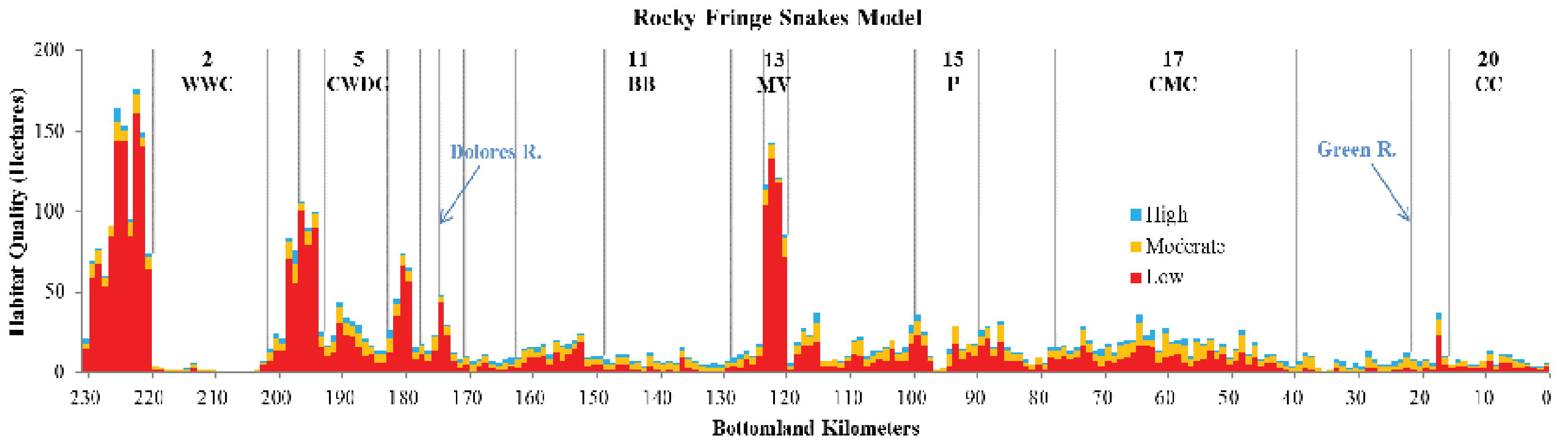

Figure 31 — Rocky Fringe Snakes Model summarizing High, Moderate and Low quality habitats. We display hectares of habitat quality categories on a longitudinal profile of bottomland boundary polygons at 1 km increments. We display hectares of habitat quality categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

Table 12 — A summary of habitat quality calculated with habitat suitability modeling for the seven Conservation Elements.

Model	Very Low or No Habitat	Low	Moderate	High
	Habitat Quality in Number of Hectares (ha)			
Riparian Overstory	**2111**	1074	1810	202
Riparian Overstory w Tamarisk Penalty	**2949**	917	1320	11
Riparian Understory	1174	**2219**	1452	299
Riparian Understory w Tamarisk Penalty	1271	**2909**	922	43
Open Land Species	809	**2018**	363	716
General Diversity		2983	**4240**	551
Bat Feeding		1410	**5006**	1366
Bat Watering		507	**3116**	214
Rocky Fringe Snakes		**3801**	1117	427

Model	Very Low or No Habitat	Low	Moderate	High
	Habitat Quality in Percent of Bottomland (%)			
Riparian Overstory	**40.6**	20.7	34.8	202
Riparian Overstory w Tamarisk Penalty	**56.7**	17.6	25.4	11
Riparian Understory	22.8	**43.1**	28.2	299
Riparian Understory w Tamarisk Penalty	24.7	**56.5**	17.9	43
Open Land Species	20.7	**51.7**	9.3	716
General Diversity		38.4	**54.5**	551
Bat Feeding		18.1	**64.3**	1366
Bat Watering		13.2	**81.2**	214
Rocky Fringe Snakes		**71.1**	20.9	427

[Two additional models estimate the impacts of the current decline in tamarisk cover. Habitat quality is divided into general categories of Very Low or No Habitat, Low, Moderate and High and shown as both hectares of bottomland surface and as a percentage of the total area modeled. Greatest values for each model are in bold.]

Results of Models of Relative Cost, Recovery Potential, and Fire Risk

Supplemental models are intended to assist in reach and site based planning, and will function in combination with habitat suitability models (see Discussion section for an example). Relative cost of restoration, as modeled here (Figure 32), includes ease of access to bottomland areas (e.g., by vehicle, on foot, or raft/camp), and presence and relative abundance of both woody and herbaceous non-native species. Recovery potential (Figure 33) is based on the presence of native species, absence of non-native species, and access to water from high stream flow. Drier sites with abundant non-native species are most common in the Moab Valley. Wetter areas with greater abundance of native species are scattered throughout the project area, with concentrations in wide valleys and much of the bottomland downstream of Potash reach (15 P).

Comparisons of the two fire models (All Fire and Natural Fire; Figures 34 and 35) highlight different aspects of fire risk. The Natural Fire model reflects only the relative density of tamarisk and native trees, with ratings of 'high' showing where both are prevalent. The All Fire model shows greater risk associated with human traffic (roads and campgrounds). Many areas below Potash are rated as low risk in the All Fire model due to the lower density of roads and campgrounds and fewer riparian trees, but are rated as moderate risk in the Natural Fire model because of abundant tamarisk stands. A numeric summary of these models is available in Appendix H.

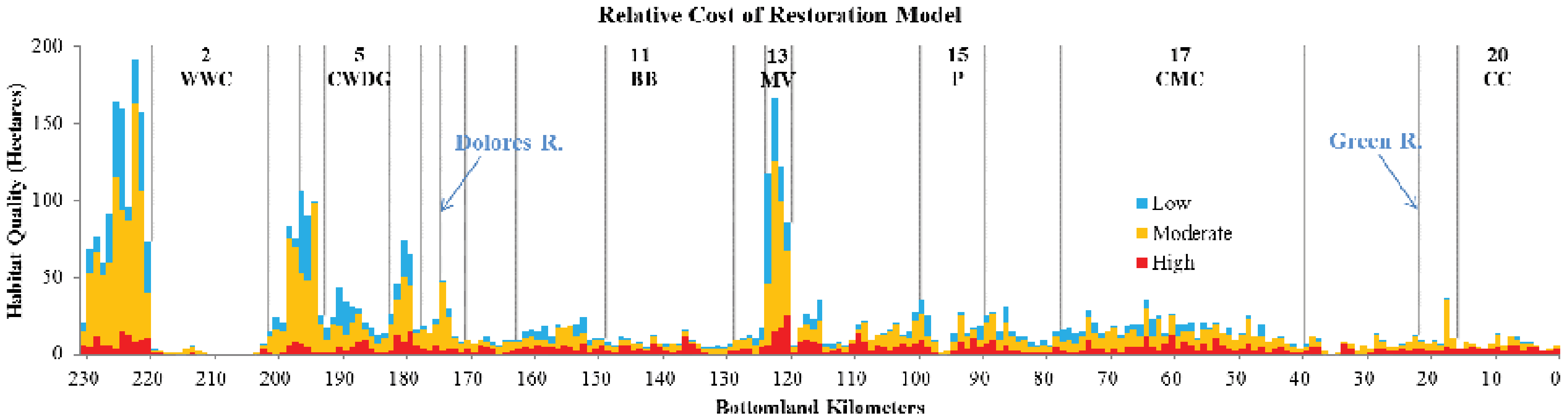

Figure 32 — Relative Cost of Restoration Model, summarizing areas with Low, Moderate and High calculated values. We display relative cost categories on a longitudinal profile of bottomland boundary polygons at 1-km increments. We display hectares of relative cost of restoration categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

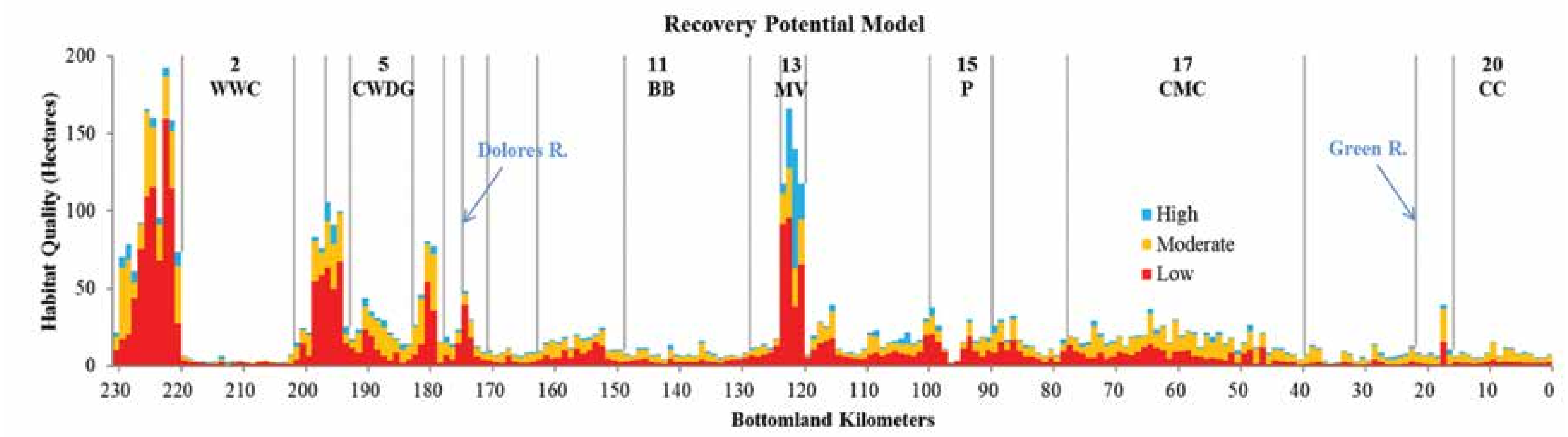

Figure 33 — Recovery Potential Model summary showing habitat areas with High, Moderate and Low calculated values. We display hectares of recovery potential categories along a longitudinal profile of 1km long, bottomland boundary polygons. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

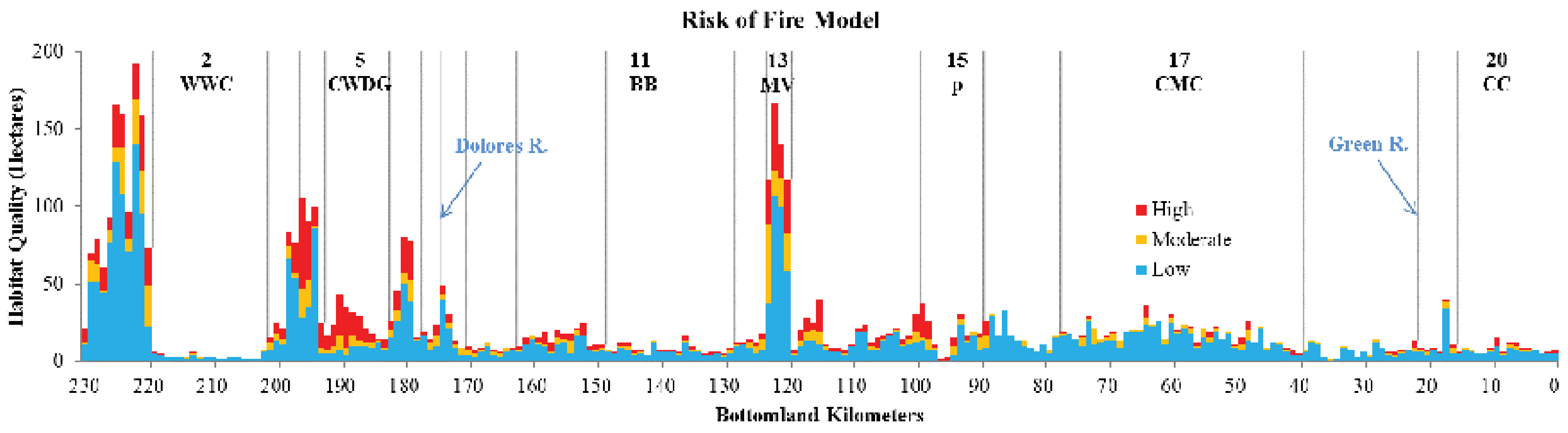

Figure 34 — Risk of All Fire Model summary showing areas with High, Moderate and Low risk of fire due to natural and human ignitions. We display hectares of fire risk from both human and natural sources grouped by coarse categories, on a longitudinal profile of bottomland boundary polygons at 1 km increments. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

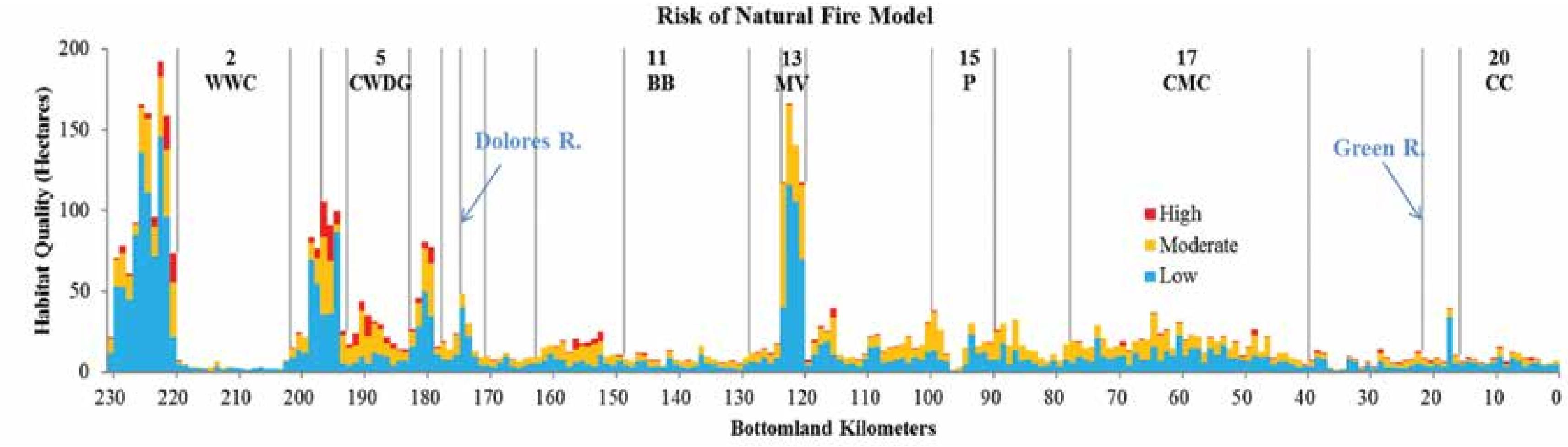

Figure 35 — Risk of Natural Fire Model summary showing areas with High, Moderate and Low risk calculated for natural fire ignitions (lightning). We display hectares of risk natural sources grouped by coarse categories, on a longitudinal profile of bottomland boundary polygons at 1 km increments. The x-axis is ordered from upstream (left) to downstream (right), with reaches numbered from left to right and bottomland kilometers increasing from right to left. Also shown are the confluences of the Green and Dolores rivers and selected reach codes for reference. Refer to Table 2 for full reach names.

Summary, Discussion and Next Steps

In this section, we summarize ecosystem processes and trends, describe how data are being made available to project partners, and recommend approaches and next steps for restoration planning.

Ecosystem Trends and Restoration Planning

Seasonal high flows and sediment transport are much reduced by upstream impoundments and trans-basin diversions (Pitlick and Van Steeter, 1998). Current sediment and water supplies may be in reasonable balance with each other in the reach of the Colorado River just upstream of the project area, as evidenced by the lack of incision or braided channels (Pitlick and Van Steeter, 1998), but estimates of sediment transport also indicate that larger time scales may be needed to reach sediment equilibrium conditions in the project area (Williams et al., 2013). Vegetation growth in the bottomland, especially adjacent to the channel, is encouraged by the truncation of scouring high flows, and also by the artificially elevated low flows (Johnson, 1994; Shafroth et al., 2002). Seed deposition, germination, and successful establishment are less likely at distal points of the bottomland due to reductions in high flow extent (Camporeale et al., 2013; Stromberg et al., 2007; Corenblit et al., 2009). Predictions of future flows suggest that current trends will continue and possibly intensify (Kim et al., 2006; Deems, 2013; Gangopadhyay and McCabe, 2010; Seager et al., 2012).

Encroachment of vegetation has mixed effects on fish and terrestrial wildlife habitats. Loss of off-channel and still-water areas to ongoing vertical sediment accretion (Pitlick and Van Steeter, 1998; LaGory et al., 2003) poses an immediate and persistent threat to native fish habitats both for refuge from spring high flows and access to foraging areas. In addition, loss of diversity in channel habitat types through channel narrowing (e.g., via expansion and stabilization of bars) diminishes the complex habitats favored by the Colorado pikeminnow (Osmundson and Kaeding, 1991; Valdez and Nelson, 2006; LaGory et al., 2003). These threats to fish habitat, however, are compounded by threats from non-native fishes competing with most life stages of native fish species (Valdez and Nelson, 2006).

In the near term, habitat for terrestrial wildlife species that use dense shrubs (riparian understory species) will likely have an increase in habitat availability and quality as tamarisk cover declines and density of understory shrubs increases.

For species that depend on trees (i.e., birds needing overstory cover), trends and possibilities are mixed. In the short term, overbank flows, though more limited than in the past, are allowing some seedling and sapling patches to establish near the channel, potentially also adding to channel narrowing and loss of fish habitat complexity. The recent lack of very high flows protects established trees from scour, and higher-than-natural base flows help sustain patches that are connected to hyporheic flows and shallow alluvial groundwater. On the downside, with reduced flood flows, seeds are deposited and seedlings establish nearer to the channel, where threats due to scour, prolonged inundation and beaver predation are higher, all decreasing probabilities that individual trees will persist over the long term. Trees may become more prevalent near channels in the short term, but as stands in the higher and drier portions of the bottomland die off, they are not likely to be replaced without large flows to promote seedling recruitment and establishment (Lytle and Merritt 2004).

Vegetation is difficult to dislodge once it is well-established (Pitlick and Van Steeter, 1998). Flows needed to entrain and transport sediments are much higher in vegetated stands due to both surface roughness and root strength. Pitlick and Van Steeter (1998) suggest that high flows like those that occurred in 1983/1984 (1,753 and 1,991 m^3/s; 61,900 and 70,300 m^3/s) would be necessary to remove existing shrub stands in the reach of the Colorado River just upstream of the project area. This suggestion is supported by the lack of channel mobility observed during field checks of vegetation mapping after the high flow of 2011 (1,388 m^3/s; 49,000 ft^3/s, considerably lower than the 61,900 and 70,300 ft^3/s peak flows in 1983/1984). That said, however, if the mainstem in the project area experiences a very large flow soon, before native shrubs are able to occupy declining tamarisk stands, sediment mobility and turnover rates could be high (Pollen-Bankhead et al., 2009; Vincent et al., 2009).

Vegetation processes are highly dynamic at present, with widespread defoliation of tamarisk due to the tamarisk beetle. The nature of the understory below declining tamarisk stands will determine the amount of effort required to restore or recover native vegetation stands. Recolonization by knapweed and other secondary non-native species is the largest concern, as these species often co-occur with tamarisk and can tolerate a broad range of soil moisture conditions. Tamarisk stands also commonly co-occur with native shrubs, especially willow; dominance is already shifting toward native cover in many places. Existing stands of sumac in the reaches above Moab and NM privet downstream of Moab are well-situated to expand into areas where tamarisk is declining. These stands tend to be moderately close to the channel. Standing dead material from heavily impacted tamarisk offers thermal protection (partial shade) to seedlings in the understory (Tamzin McCormick, Pers. Comm. August, 2013).

The effects of the tamarisk beetle complicate restoration planning, both accelerating progress towards ecological goals and releasing competitive pressure on aggressive weeds. Beetle effects are not uniform in space or time, as some stands are hard hit, dominated by standing dead stems, while other stands are green and relatively vigorous. For purposes here, effects of the beetle are considered: 1) of uncertain duration—it is possible that beetle populations will fail in the future, allowing recovery of tamarisk, or populations may settle into dynamic equilibrium with tamarisk and the beetle persisting at lower densities, and 2) of uncertain extent—defoliation effects are spatially variable year-to-year, with some patches in sharp decline and others showing strong vigor (Hultine et al., 2013). To address these uncertainties for short-term planning, we suggest the following: 1) assume that tamarisk stands are intact and vigorous, until the next iteration of vegetation mapping indicates otherwise, or until change is validated by local knowledge, and 2) assume that beetle biological control is one of many treatment options, and should it be ineffective in high priority sites, another treatment option should be selected, thus incorporating variation in tamarisk populations in revegetation planning. Results of new research in genotype adaptation of tamarisk and genetic analysis will help refine restoration planning.

Xeric habitats, those at least partly occupied by xeric-riparian shrubs and trees, can pose significant challenges for restoration (Shafroth et al., 2008). These habitats are typically in positions some distance above or away from the channel, with little connection to high flows and are often co-occupied by non-native herbaceous species. Xeric communities are slower to recover after surface disturbance, with lower growth rates than mesic species and less capacity to out-compete fast growing non-native species. While xeric communities are typically more difficult to restore than mesic areas, they also often occur on sites where populations or potential expansion of understory weeds may warrant the additional effort required for restoration of native communities (Shafroth et al., 2008).

Near-channel stands of riparian vegetation that are frequently inundated by floods are often dominated by native shrubs that can readily expand as tamarisk declines. In some sites, with the actions of the tamarisk beetle, new stands of tamarisk on sandbars and secondary channels are less likely to become dominant; seedling tamarisk are often attacked by the beetle, decreasing the vigor needed for quick establishment in a challenging environment (Kara Dohrenwend, Pers. Comm. 2012). The exception to this trend with near-channel stands, however, is the presence and possible expansion of Russian olive and other invasive trees. Russian olive appears to prefer wetter habitats in the project area, as shown by its occurrence in near-channel and wetland locations. Expansion of Russian olive will be an ongoing concern; given that it is abundant in reaches upstream of the project area. However, with the dominance of riparian shrubs, it could be a minor concern in most reaches.

Project Data and Decision Support

At the project area scale, information presented here provides insights into which habitat types are more or less common, the relative quality and abundance of habitats for the suite of CEs, and how conditions are likely to change with basin-wide ecosystem trends. This broad perspective allows selection of reaches best suited for protection or restoration of different habitat types, and development of strategies that maximize benefits while minimizing conflicts between habitat needs of diverse CEs. Some of the broader findings from this effort include:

1. Off-channel, and especially still-water habitats, are very limited throughout the project area and are increasingly threatened. These habitats are needed for refuge, rearing, and foraging needs of endangered fish species; watering areas for bats; and for high quality habitat favored by riparian understory species. Current basin trends of decreased peak flows and elevated low flows promote growth of erosion-resistant native and non-native vegetation, narrowing of main channels and in-filling of secondary and off-channel habitats. These trends are ongoing and likely to increase with predicted climate change and human demands. Information from biologists participating in the project can guide prioritization of efforts relative to historical and current fish and wildlife use and greatest restoration needs.

2. Riparian overstory habitat is abundant only in a subset of reaches (1, 3-8, and 13) and is very often compromised by tamarisk due to the defoliating actions of the tamarisk beetle and the increased threat of losing riparian trees to fire. Short-term trends suggest that riparian overstory habitat quality may increase with the decline in tamarisk, but only in areas where tamarisk is replaced by native shrub species. Long-term impacts of altered basin hydrology on riparian overstory riparian habitats are uncertain, but will likely include declining tree cover due to less frequent overbank floods.

3. Riparian understory habitats are scattered throughout the project area in wide and moderately wide reaches, and are similarly threatened by fire where tamarisk is abundant.

4. Not captured in our analysis, but identified as a threat by project fish biologists, is the possibility of endangered fish being stranded behind dense stands of shrubs in slough habitats.

At the reach scale, project data on relative habitat quality can be evaluated to identify the most promising areas for protection, areas where restoration is warranted and feasible, or areas of lower priority due to basin trends, prohibitive costs, or other factors. Data indicating relative costs, risk of fire, and recovery potential are intended to inform decisions at the reach scale (Figure 36). For areas that our models indicate have moderate habitat quality, managers can use additional data layers to understand the factors that limit habitat quality. For example, in the Riparian Understory model, scores showing moderate habitat quality may be impacted by several factors such as proximity or speed of water, density of shrubs, or presence of tamarisk. Examination of component layers will allow discerning which factors contribute to lower scores.

Refining Habitat Models

Habitat suitability models are typically built from occurrence data of species of interest, and then linked to habitat features (Bayliss et al., 2005; Bellamy et al., 2013; Rittenhouse et al., 2010). Such occurrence and field data exist for birds in the project area (Pope et al., 2015). Efforts could be made in the future to link existing occurrence data sets at least for the Riparian Overstory and Understory models, and possibly Rocky Fringe Snakes and Open Land Species models (similar to efforts by Mathieu et al., 2006.) For other CEs, validating with field data will be challenging. Bats can be difficult to sample without damaging them, especially the larger, high- and fast-flying bats most in need of obstruction-free flight lines to slow moving water. Acoustic monitoring techniques

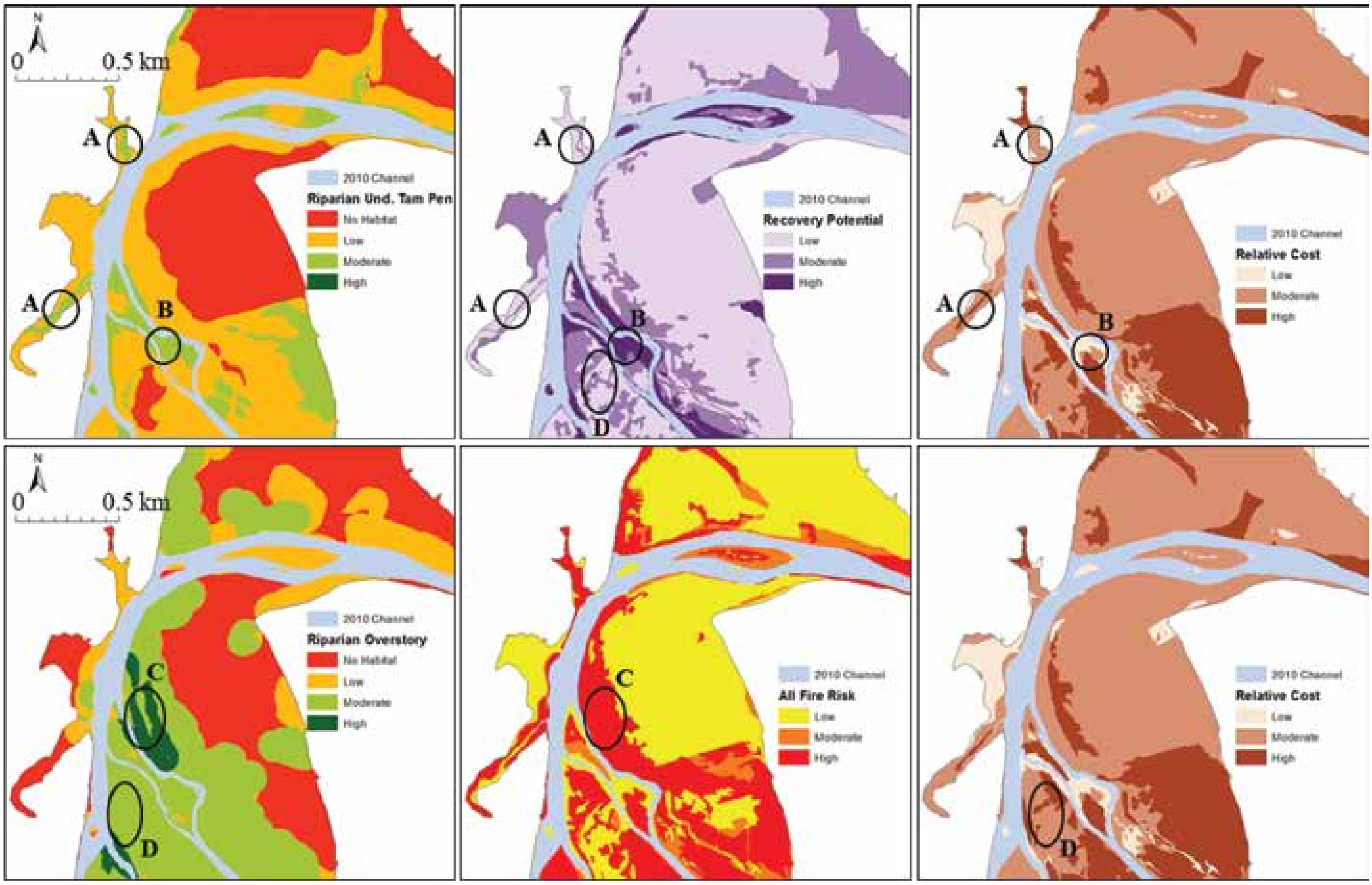

Figure 36 — Examples of combinations of habitat and supplemental models. Areas marked with 'A' indicate where habitats of moderate value for riparian understory species could be improved, where habitats are unlikely to recover without intervention, and costs are moderate. Areas marked with 'B' show habitat of moderate quality where work may be unnecessary, because recovery potential is high, even without intervention. Areas marked 'C' indicate where protection of existing higher quality habitat requires mitigation of high fire risk; areas marked 'D', where habitat may be improved for moderate cost.

can be a big help, especially when coupled with spotlighting and limited, focused use of standard netting techniques. Preferences in bat feeding, however, may be documentable (Bellamy et al., 2013).

Construction of the habitat models introduced many types of uncertainties (Table 13). Habitat modeling required identifying thresholds for habitat values and assumptions regarding habitat needs. Each of these assumptions and decisions are sources of uncertainty that have potential to affect the results of the models and eventual outcomes of restoration plans (Beale and Lennon, 2012; Burgman et al., 2001). Many uncertainties were addressed during model construction (e.g., trials with combinations of model components, review and editing with field biologists, experimentation with different geoprocessing protocols); other uncertainties warrant further investigation. Data exist for some of the species addressed within Conservation Elements (primarily overstory and understory birds and fish). These data could be used in the future to validate, correct or refine habitat suitability models to be used in planning. Significant data gaps include actual measurements of vegetation heights and density, and detailed ground topography. Project partners have funded and flown LiDAR imagery for this project area, to be made publically available in 2016-17. Sensitivity analysis on some of the items in bold text in Table 13 will be possible in future project efforts.

Our aim here is to provide a transparent context for decision making, with stated assumptions, habitat quality thresholds, and caveats. Also, we recognize that resource conditions change over time, and have constructed habitat models in a modular fashion, allowing for updated layers (e.g., revised vegetation maps) that can be assimilated into habitat suitability models. Division of habitat models into categories of High, Moderate and Low and No Habitat are for convenience of reporting, only.

Restoration Approaches

Restoration planning on the Colorado River poses substantial challenges. In the broader sense, 'restoration' implies moving ecosystem conditions and dynamics toward forms and functions that existed prior to human perturbations. In this setting, however, with the millions of households and industries that depend on Colorado River water, both upstream and downstream of the project area, full restoration of flows and functions may be implausible, if not politically impossible, especially in light of predictions of population growth and climate change (BOR, 2012). Incremental, strategic improvements in habitat conditions are possible, however, especially if project goals and objectives, site conditions, and priorities are well-defined (Shafroth et al., 2008).

Table 13 — Primary sources of uncertainty in the construction of habitat models for the Colorado River Conservation Planning project. Assessment of bolded items could be possible in future project efforts.

Category of Uncertainty	Source of Uncertainty	Ways to Reduce/Refine Uncertainty
Identification of CEs	• Grouping CEs by habitat needs	• More models with greater specificity
Construction of models	• Merging/grouping species • Use of available data (e.g., average tree heights, not actual heights) • Choice of model components • Alternative models for tamarisk • Use of Focal Statistics (size/shape of analysis window)	• **Better data on species occurrence and/or habitat needs** • **Better quality data on habitat metrics (e.g., measured tree heights, not averages)** • Sensitivity analysis on component choices (including tamarisk scores) • Sensitivity analysis on use of Focal Stats
Construction of components	• Thresholds for component values • Average, Max, Min, Variety functions • Size of analysis window	• **Sensitivity analysis of component values** • **Sensitivity analysis of with and without focal statistics functions** • **Sensitivity analysis of size of analysis window**
Combination of components	• Relative weights of components	• **Sensitivity analysis of relative weights of components**
Classification of model results	• Relative weights of components	• **Sensitivity analysis of defining thresholds**

Three fundamental needs for restoration planning are: 1) knowledge of conditions and trends of resources in question at catchment, project, and local scales; 2) knowledge of desired future conditions or ultimate goals of restoration actions, and 3) explicit recognition of constraints on restoration efforts (Beechie et al., 2010; Wohl et al., 2005; Shafroth et al., 2008; Groves et al., 2012). The first and third conditions are nearer completion through the CRCP, in general terms, and would benefit from additional flow and sediment studies. The second condition has been partially addressed with resource goals for vegetation management stated by the Southeast Utah Riparian Partnership. Some of the habitat needs presented here are related to fish habitat and to the river's flow regime, calling for a fuller discussion by project partners and stakeholders regarding the inclusion of these actions and priorities.

The concept of 'reconciliation ecology' (Rosenzweig, 2003; Arthington et al., 2014) is applied to habitats that are dominated by human activities, where natural processes that create habitat characteristics are minimal or absent. Ecosystems of highly developed California rivers (Moyle, 2014) and bird habitat in urbanized areas are examples of ecosystems where localized, strategic actions can be taken to improve habitat quality and diversity artificially, using natural history knowledge and ecological relationships to improve habitat for select species. This approach acknowledges the intense, ongoing and likely increasing human domination of natural processes, such as those on the Colorado mainstem in the project area. This approach does not preclude investigation into and restoration of ecologically relevant stream flow conditions, but rather 'buys time' for such studies and directs strategic actions for maximizing benefits.

Armed with this information from this effort, next steps in restoration planning include triage of habitats, prioritizing threats and treatments, and possibly, optimizing efforts. Similar to work by Hobbs and Kristjanson (2003), triage of habitats for restoration is based on factors such as:

1. greater or lesser value to Conservation Elements (habitat models), relative to conditions on-site and position in the project area;

2. likelihood of recovery without intervention (dependent on intact natural processes, proximity to the channel, status of weeds, abundance of native species);

3. intensity of impacts by human activities (roads, disturbance, fires); and

4. limitations of restoration possibilities due to land ownership, access or management.

During the Expert Workshop (March 2012), resource specialists identified a wide variety of threats to floodplain habitats, and located opportunities for restoration and protection. Each threat could be graded in terms of intensity and time frame (e.g., long-term, low intensity such as cheatgrass invasion or short-term, high intensity, such as a wildfire). Opportunities could be graded by the level of effort involved and duration of effects, with the goal of determining and grouping types of actions and determining best possible types of locations and possible priorities. Optimization of planning, an option available to project partners, involves prioritizing combined actions against an external constraint such as a maximum dollar amount or minimum area requirement (Lethbridge et al., 2010; Wintle, 2008). This approach requires examining multiple scenarios of possible treatments with specified desired outcomes, and would be possible within or between land management entities. Optimization can also take into account disparities of treatments available in different management settings such as those available within Canyonlands National Park, or logistically limited, such as areas accessible only by boat. A prioritized list of areas well-suited for restoration, or deemed critical for one or more CE, can then be used to solicit funds for project work, with project-specific goals and objectives stipulated by participating partners.

While the majority of the project was focused on identifying ecosystem trends and conservation actions for terrestrial species, there may be some immediate opportunities to improve fish habitat. Possible activities include clearing or deepening off-channel habitats, promoting access to floodplain habitats during high flows, and identifying stranding hazards. As it stands, data presented here are best suited to identifying where such projects may be most beneficial to fish, but considerably more planning, and detailed elevation data, would be needed.

We had three primary goals for the Colorado River Conservation Planning project: 1) to collect, consolidate and organize information for the project area; 2) to identify ecosystem trends that have the potential to impact restoration planning; and 3) to offer suggestions for restoration approaches and next steps for the project. With existing datasets, resource mapping, habitat modeling, and our review of existing literature, we have created a foundation for devising strategies and priorities that balance the variety of needs for bottomland resources. Next steps may include refinement of habitat models with soon-to-be-available topographic and vegetation height data (LiDAR), and working with project partners and local practitioners to use data presented here to generate a working list of prioritized protection and restoration projects.

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Appendix A. Land Area and Human Uses

Summary of human activities and attributes present or applicable to the project area.

	Roads		Fires 1980 – 2011	Rec Sites - Campgrounds *	Vegetation Treatments^		Boat Ramps*	Ownership			Agricultural Use (of Terrestrial Area)	
Reaches	(km)	(km/ ha)	Number of Fires	Number of Public Sites	Area (ha)	Area %	#	% Federal	% Private	% State	In Hectares	In Percent
Ruby Westwater	50.9	0.038	10	1	7.8	0.6	1	15.2	53.4	31.4	502.9	42.6
Westwater Canyon	0.0	0.000	0	0	3.4	2.5	0	16.9	0.0	83.1	0.0	0.0
WW-CL Transition	9.3	0.042	2	0	35.7	16.0	0	24.6	47.4	28.1	93.4	54.2
Cisco Landing	8.1	0.019	2	1	0.0	0.0	1	15.5	64.6	20.0	152.8	41.4
Cisco Wash - Dry Gulch	12.2	0.033	1	1	0.0	0.0	1	26.2	5.1	68.7	0.0	0.0
McGraw Bottom	8.1	0.030	1	0	0.0	0.0	1	28.3	44.2	27.6	30.0	14.6
Dolores-McGraw Bottom	1.8	0.018	0	0	10.8	11.0	0	9.0	19.8	71.2	5.8	9.5
Dewey Bridge	10.0	0.068	4	1	11.8	8.0	1	8.7	49.0	42.3	57.4	55.0
Dewey	2.5	0.017	3	1	10.5	7.0	0	32.9	0.0	67.1	0.0	0.0
Professor Valley	10.7	0.022	7	3	30.7	6.5	3	14.8	15.0	70.2	18.8	6.6
Big Bend	8.7	0.031	10	9	22.5	8.1	3	33.2	0.0	66.8	0.0	0.0
Negro Bill	8.2	0.066	4	2	23.8	19.0	1	15.0	2.0	83.0	0.0	0.0
Moab Valley	34.8	0.053	4	1	234.4	35.7	0	2.1	51.8	46.1	345.8	67.3
Gold Bar	40.6	0.065	8	10	29.0	4.6	1	30.5	7.0	62.6	15.5	5.2
Potash	14.2	0.038	1	0	9.6	2.5	1	13.5	25.5	61.0	9.4	5.2
Upper Meander Canyon	0.8	0.002	1	0	0.0	0.0	0	36.0	0.0	64.0	0.0	0.0
Central Meander Canyon	2.0	0.002	3	8	10.6	0.9	0	89.1	0.0	10.9	0.0	0.0
Lower Meander Canyon	0.0	0.000	0	2	0.0	0.0	0	100.0	0.0	0.0	0.0	0.0
Colorado - Green	0.0	0.000	3	7	0.0	0.0	0	100.0	0.0	0.0	0.0	0.0
Cataract Canyon	0.0	0.000	0	15	0.0	0.0	0	100.0	0.0	0.0	0.0	0.0

^Footprint of treatment areas. Most areas with multiple treatments. Inventory of areas as of early 2013. Does not include all work by NPS.

*Does not include undeveloped campgrounds or boat ramps.

Appendix B. Reach Narratives

Reach breaks and geological descriptions were provided by John Dohrenwend (Dohrenwend, 2012), retired Research Geologist with the USGS, from previous fluvial geomorphic work in the area. Valley width and depth dimensions were converted from original English units to metric. Cover type percentages are drawn from Appendix G as a percent of total bottomland area, including water surfaces. State of Utah ownership is managed by the Utah Forestry, Fire and State Lands, and includes Colorado River Utah Sovereign Lands, designated as the river channel and near channel areas up to the typical high water extent. Land use percentages have been calculated from the landownership GIS layer found on the Utah Automated Geographic Reference Center (gis.utah.gov; accessed 2013).

Ruby-Westwater, Reach 1

The Ruby-Westwater reach begins near the downstream end of Ruby Canyon at the Colorado-Utah border (Bottomland Kilometer 230 [Bkm 230]) and extends for 10 km along the bottomland to Westwater Canyon (Bkm 220) just upstream of Whitehorse Rapid. This reach trends southwestward within a relatively broad strike valley that cuts across the northwest-plunging nose of the Uncompahgre Uplift. This valley is bounded on its northwest side by sandstone outcrops to the Salt Wash member of the Morrison Formation (Fm) and Entrada Fm and on its southeast side by outcrops of the Entrada and Kayenta Fms. The valley is shallow (generally less than 75 m deep) and variable in width (mostly 1100 to 1500 m wide but narrowing to less than 160 m at the downstream end of Ruby Canyon). The average river slope is 0.1%.

Vegetation is a mix of xeric shrub species at the drier bottomland margins and associated tributary alluvial fans, and several species and types of woody vegetation nearer the channel. Much of the reach is privately owned and actively farmed (503 ha); pivot irrigation, grazing, and mowing occupy large portions of the bottomland area. Native tree cover is common, especially in the lower end of the reach, ranging from single species patches to complex, layered canopies of trees, shrubs and herbaceous species. Tamarisk dominates broad expanses of the bottomland surface and has been heavily impacted by the tamarisk beetle. Native mesic shrubs, especially willow and sumac, dominate much of the near channel areas. Russian olive is found on many of the near channel and secondary channel areas, typically as single small trees or low density patches. Knapweed is prevalent in the upper half of the reach.

Compared to other reaches in the project area, fluvial geomorphology and channel complexity are very high in the lower end of this reach, with multiple secondary channels, extensive overbank flooding and active sediment processes. Land ownership is mostly private (53%) with additional State (31%) and Bureau of Land Management (BLM - 15%) holdings.

Westwater Canyon, Reach 2

The Westwater Canyon reach begins at the downstream end of the Ruby-Westwater reach (Bkm 220) and extends for 18 km to the Westwater Canyon - Cisco Landing transitional reach at RM 202 (approximately 1.6 river km upstream from the mouth of Cottonwood Wash). This bedrock dominated canyon also trends southwestward across the northwest plunging nose of the Uncompahgre Uplift. Overall, the canyon ranges from 760 to 1220 m wide and 180 to 240 m deep. The canyon's narrow inner gorge (approximately 150 m wide and 75 to 90 m deep) is cut into highly resistant Precambrian granitic gneiss. Consequently, this reach is primarily erosional. It is characterized by an average slope of 0.2% and numerous rapids.

Due to the very narrow character of this reach, cover is limited to shrubs, mostly tamarisk and willow, and bare ground. Fluvial complexity is also limited, with essentially only primary channel features. Near channel areas are owned and managed by the State of Utah (83%); the remainder of the bottomland area is managed by the Bureau of Land Management (17%).

Westwater Canyon – Cisco Landing Transition, Reach 3

This short reach (5 km) forms the transition between Westwater Canyon (Bkm 202) and the broad strike valley of Cisco Landing (Bkm 197). It expands from the narrow (about 150 m wide) gorge of Westwater Canyon to the relatively broad (as much as 1500 m wide) valley of Cisco Landing. The cliffs flanking the river along this reach are, for the most part, composed of sandstones of the Wingate, Kayenta, Dakota and Entrada Formations. This reach is short (about 5 km) and has an average slope of approximately 0.05%.

Vegetation is mostly non-native herbaceous cover, typically associated with current or inactive agricultural activities (54% of vegetative cover). Xeric shrub cover is common (15%) in distal areas of the bottomland, with tamarisk, largely defoliated, as the dominant shrub cover (13%). Riparian forest is present but limited (2%). Fluvial habitat types include main channel area with some secondary channels. Project partners have been active in clearing tamarisk and treating for aggressive non-native species on the north bank, downstream portion of the bottomland. Areas near the channel are managed by the State (Sovereign Lands, 28%), with the largest percentage area privately held (47%) and a lesser portion managed by the BLM (25%).

Cisco Landing, Reach 4

Cisco Landing Reach is another short reach (4 km), beginning at Bkm 197 and extending downstream to Bkm193. The Cisco Landing reach extends around a single, large river bend to the mouth of Dry Gulch (Bkm 193) and contains the federally managed Cisco Landing boat ramp. This reach is characterized by a shallow (45 to 100 m deep), broad strike valley that trends SSE along the WSW flank of the Uncompahgre Uplift. Alluvial bottomlands are continuous and up to 1500 m wide. This valley is bounded on its west side by the Summerville and Morrison Fms and on its east side by the Kayenta Fms. The average river slope is 0.05%.

Vegetation is mostly non-native herbaceous cover (30%), reflecting the dominance of agriculture on the bottomland surface (153 ha). Cottonwood patches are common, with the greatest percentage of tree cover of any reach within the project length (15% of total bottomland area). Tamarisk cover is high (19% of bottomland area), and has been heavily impacted by the tamarisk beetle. Xeric shrubs are common on the distal portions of the bottomland (8%) and knapweed is also common (4%).

Cisco Landing reach is geomorphically active with a variety of channel habitat types available at both high and low water, including less common backwater features. This reach is mostly privately owned (65%), with smaller portions under State (20%) and BLM (15%) management.

Cisco Wash - Dry Gulch, Reach 5

The Cisco Wash to Dry Gulch reach begins near the mouth of Dry Gulch (at the downstream end of Cisco Landing reach – Bkm193) and extends 10 km to the upstream limits of McGraw Bottom at the point where Cisco Wash becomes a yazoo stream (running parallel to the Colorado channel - about 1.6 river km upstream of the mouth of Cisco Wash). This reach flows within a transverse valley that cuts across the axis of the northwest plunging syncline that bounds the southwest flank of the Uncompahgre Uplift. This valley cuts across gently dipping strata of the Morrison, Dakota, Cedar Mountain and Mancos formations, and its character is largely controlled by the lithology and structure of these geologic formations. The valley is shallow (60 to 110 m deep), and variable in width (370 to 760 m wide). The average river slope of this reach is very similar to the Cisco Landing reach - 0.05%.

Vegetation is a mix of tamarisk (27%) and cottonwood (14%) with smaller portions of willow (9%) and sumac (5%) in nearer channel areas and xeric shrubs (8%) at the distal portions of the bottomland. Geomorphology is relatively active, with secondary channels available for fish use. Ownership is primarily State (69%) with some BLM (26%) and very little private (5%).

McGraw Bottom, Reach 6

This short, alluvial reach (5 km) flows between McGraw Bottom (to the northwest, Bkm 183) and Hotel Bottom (to the SE). Hotel Bottom (Bkm 178) is a low fluvial terrace veneered by gently sloping alluvial fan deposits. McGraw Bottom is, for the most part, an active floodplain formed by deposition of fine-grained sediments at the mouths of Cisco Wash and Sager's Wash. These two southeast-flowing washes drain an extensive area to the north and east that is underlain primarily by mudstones and claystones, and to a lesser extent, by fine grained sandstones of the Mancos Shale. Along this reach, the valley of the Colorado is straight, broad and shallow. The valley is underlain by the Mancos Shale (to the northwest) and the Brushy Basin member of the Morrison Fm (to the southeast). The average river slope is about 0.04%.

Vegetation is dominated by xeric species (21%), tamarisk (17%), and cottonwood (10%). Non-native herbaceous covers 9% of the vegetated surface of which knapweed is common (5%). Agriculture, either currently active or historic, occupies 30 ha of the reach.

The confluence of Sager's Wash, with multiple channels and off-channel habitats is an important holding and refuge site for fish. Ownership is a mix of private (44%), BLM (28%) and State (28%) management.

Dolores to McGraw Bottom, Reach 7

This short reach (3 km) extends from the downstream limit of McGraw Bottom (Bkm 178) to the mouth of the Dolores River (Bkm 175). This reach has a relatively gentle slope (0.08%). It flows through a shallow, north-south trending valley that cuts across northeast dipping sandstones and shales of the Cedar Mountain, Dakota and Morrison formations.

This reach is dominated by shrub species: tamarisk (14%), willow (12%), xeric shrubs (7%) and sumac (2%). Cottonwoods comprise 6 percent of the bottomland cover, with only 4% in non-native herbaceous cover, mostly associated with agricultural activities (6 ha). Ownership is mostly State (71%), with some private (20%) and a small portion of BLM (9%).

Dewey Bridge, Reach 8

This short (4 km) reach flows westward from the downstream the mouth of the Dolores River (Bkm 175) to Bkm 171 (near the mouth of Buck Spring Wash). Within this reach, the river flows along the south side of a broad, asymmetric valley underlain by very gently dipping Navajo Sandstone and flanked by very gently dipping sandstones of the Carmel, Entrada, Curtis and Morrison (Salt Wash Member) formations. Average slope is approximately 0.08%.

Over half of the vegetated area within the Dewey Bridge reach is occupied by agriculture and non-native herbaceous cover. Knapweed is common (6%). Cover of woody vegetation is a nearly equal mix of willow, tamarisk, xeric shrub species and cottonwood trees (5-6%). Ownership is mostly private (49%) and State (42%), with a small portion of BLM (9%).

Dewey, Reach 9

The Dewey reach begins just downstream of Dewey Bridge at Bkm 171 and extends for 8 km around two large river bends to the upstream end of Professor Valley, about 0.8 river km upstream from Hittle Bottom (Bkm163). This reach flows within a progressively widening transverse canyon that ranges from 150 to 400 m deep and 460 to 1500 m wide. This canyon cuts through gently northeast dipping strata of the Glen Canyon Group (Navajo, Kayenta and Wingate formations) underlain by strata of the Chinle and Moenkopi formations and the Cutler Group. The canyon is narrowest and shallowest where it cuts through the resistant sandstones of the Wingate Formation (at its upstream end) and progressively wider and deeper where it cuts through the siltstones, mudstones and shale of the Chinle, Moenkopi and Cutler formations (at its downstream end). The average river slope is approximately 0.14%.

Dewey reach is narrower than reaches immediately upstream and downstream, has no agricultural development or trees, and has prevalent sand bars (bare areas). Tamarisk and willow dominate vegetation cover types. Cottonwood trees are absent, but just less than 1% of the bottomland area is occupied by box elder trees. Ownership is mostly State (67%) and BLM (33%), with no private holdings.

Professor Valley, Reach 10

The Professor Valley reach extends for 14 km from Bkm 163 (about 0.8 km upstream of Hittle Bottom) to Bkm 149 (approximately 0.8 km downstream of White's Rapid at the mouth of Castle Creek. This reach flows along the northwest margin of the Richardson Amphitheater – Professor Valley, a structurally complex composite of two breached, northwest-trending, salt-cored anticlines near the northeastern margin of the Paradox Basin. The present valley is broad (up to 7600 m wide) and highly asymmetric. The northwest side of the valley is bounded by steep talus-covered slopes, approximately 300 m high, capped by tall sandstone cliffs of the Wingate Formation as much as 210 to 240 m high. In contrast, much of the southeast side of the valley consists of a broad, relatively gently sloping piedmont sculpted by drainage from the La Sal Mountains. The alluvial fans of the five largest streams draining across this piedmont (Onion Creek, Professor Creek, Stearns Creek, Ida Gulch and Castle Creek) have formed rapids on the Colorado River. The northeast part of the Richardson Amphitheater – Professor Valley is underlain by strata of the Cutler Fm; the southwest part by strata of the Moenkopi Formation. The average river slope is approximately 0.1%, although Pitlick and Cress (2000) report an average slope of 0.149% for this reach.

Most of the bottomland cover in Professor Valley is tamarisk (27%) and xeric shrubs (8%), with some willow (6%) and considerable bare ground (9%). Cottonwood trees are present but very limited (2%). Ownership in Professor Valley is mostly State (70%) with smaller portions of private (15%) and BLM (15%).

Big Bend, Reach 11

The Big Bend reach extends for 20 km from approximately 1 km downstream of the mouth of Castle Creek (Bkm 149) to just upstream of the mouth of Negro Bill Canyon (Bkm 129). This reach occupies a deep (275 to 370 m), narrow (610 to 820 m wide), generally symmetric canyon that cuts across gently folded strata of the Navajo Sandstone, Kayenta Formation, Wingate Formation, Chinle and Moenkopi Formations. The average slope of this reach is approximately 0.05%. (Note: Pitlick and Cress (2000) report an average slope of 0.1% for this reach, about 33% higher than estimates based on available US Geological Survey topographic data for this reach.)

Big Bend reach vegetation cover is mostly shrubby: tamarisk (11%), willow (9%) and xeric species near the outer margins of the bottomland. Cottonwoods are present but uncommon (1%), but Gambel oak makes up 5% of the bottomland cover; the highest of any reach in the project area. There is not agricultural development in this reach, though there are numerous campgrounds (nine public campgrounds) and boating access points (three public ramps). Ownership in the Big Bend reach is State (67%) and BLM (33%) with no private holdings.

Negro Bill, Reach 12

The Negro Bill reach extends for 5 km from just upstream of the mouth of Negro Bill Canyon (Bkm 124) to the US 191 highway bridge on the northeast edge of Moab Valley (Bkm 129). This reach flows within a deep (90 to 275 m deep), narrow (245 to 460 m wide) asymmetric canyon that cuts across very gently dipping strata (mostly sandstones) of the Kayenta and Navajo Formations. This reach marks the upstream limit of a continuous series of very low gradient reaches that extends downstream for almost 116 river kilometers to the upstream limit of Cataract Canyon. The average slope is about 0.03%.

Shrubs are the most prevalent cover type in this reach with tamarisk (9%), willow (8%) and native xeric (4%). Non-native herbaceous species are common here (9%), though they are not associated with agricultural activities. Riparian trees are present but not abundant (cottonwood 1%, Gambel oak 3%). Ownership in the Negro Bill reach is mostly State (83%) with some BLM (15%) and a small amount of private (2%).

Moab Valley, Reach 13

The Moab Valley reach consists of one large river bend that extends 4 km from Bkm 124 (at the US 191 highway bridge) to Bkm 120 (at The Portal). A broad floodplain (up to 1830 m wide) bounds the south and east side of the river channel. This floodplain contains the Matheson Wetlands, the largest riparian wetland complex along the Colorado River between the Utah-Colorado border and Lake Powell. The Moab Valley is a breached, salt-cored anticline within the Paradox Basin. This fault-bounded structural valley is actively subsiding as the groundwater circulation associated with the Colorado River continues to dissolve salts within the Paradox Formation that underlies the alluvial fill of the valley floor. In part because of the continuing subsidence of the valley floor, the average slope of this broad, alluvial reach is 0.03% slope.

Much of the Moab Valley has been, or is, used for agricultural activities (346 ha). Ditches and plow lines are visible even within the boundaries of the current Matheson Preserve, shown by the often coincident non-native herbaceous cover (24%). Goodding's willow, cottonwood and Russian olive cover are common (2, 8 and 4% respectively). Much of the interior of the Matheson Preserve is covered by mesic herbaceous vegetation, comprised of a mix of sedges and rushes, including patches of large bulrush.

Ownership in the Moab Valley is split between State (46%) and private (52%), and a small portion of BLM (2%).

Gold Bar, Reach 14

The Gold Bar reach extends for 20 km from The Portal (Bkm 120) to approximately 1 km upstream of Potash (Bkm 100). This reach consists of two large river bends that flow through a canyon of somewhat variable depth and width -- 120 to 245 m deep and 760 to 1070 m wide -- and cut across gently east-dipping strata of the Glen Canyon Group. This reach has a slope of approximately 0.03%.

Vegetation cover in the Gold Bar reach is mostly shrubs: tamarisk (15%), willow (9%), NM privet (3%), and native xeric species (3%). Cottonwood are present but not abundant (3%); many other tall woody cover types are present but rare (Goodding's willow, hackberry, non-native trees and Gambel oak – each less than 1% of the bottomland). Bare ground is prevalent as exposed sand bars (5%); non-native herbaceous species (5%) are present and typically associated with agricultural development (16 ha). Ownership of the Gold Bar reach is mostly State (63%) with BLM (31%) and a small portion of private (7%).

Potash, Reach 15

The Potash reach is generally south-trending and extends for 10 km; from Bkm 100 just upstream of Potash to Bkm 90 near the south end of Pyramid Butte. This reach flows within a transverse valley that is cut within sub-horizontal strata of the lower Cutler Formation and, for about one 1.6 km, within the Honaker Trail Fm. This valley of the Potash reach is highly variable in shape, ranging from 825 to more than 1525 m wide and 60 to 275 m deep. The average slope of this reach is approximately 0.03%.

This reach has a long history of industrial activity (potash mining and processing, railroad development) both in the river bottom and in the adjacent uplands. Vegetation is dominated by shrubs: tamarisk (24%), willow (7%), native xeric species (7%), and NM privet (1%). Riparian trees are very uncommon, with less than one percent cover combined. Bare ground is relatively high (7%), both due to sand bars within the active channel area and disturbance on the floodplain surface. Ownership of the Potash reach is mostly State (61%) and private (25%) with some BLM management.

Upper Meander Canyon, Reach 16

The upper Meander Canyon reach extends for 12 km from Bkm 78 near the south end of Pyramid Butte to Bkm 90 at the mouth of Shafer Canyon. This canyon trends generally east-west across broadly-folded, sub-horizontal strata of the Honaker Trail Fm and Cutler Fm (locally capped by the arkosic facies of the Cutler Fm). The canyon is generally symmetric in cross-profile, 520 to 915 m wide and 75 to 150 m deep. The average slope along this reach and throughout Meander Canyon from Pyramid Butte to Cataract Canyon is approximately 0.02%.

Shrubs dominate the vegetative cover in this reach: tamarisk (22%), willow (10%), native xeric shrubs (7%), and NM privet (3%). Native riparian trees are very rare, making up less than a half percent of the bottomland area, combined. Ownership is State (64%) and BLM (36%) with no private holdings.

Central Meander Canyon, Reach 17

The central Meander Canyon reach extends for 38 km from Bkm 78 at the mouth of Shafer Canyon to Bkm 40 at the upstream end of The Loop. This canyon trends generally north-south across broadly-folded, sub-horizontal strata of the lower Cutler Fm, locally capped by the arkosic facies of the Cutler Fm. The canyon is generally symmetric in cross-profile, 460 to 760 m wide and 90 to 200 m deep. The average slope along this reach and throughout Meander Canyon is approximately 0.02%.

This long and narrow reach is heavily shrub dominated with tamarisk (19%), native xeric shrubs (9%), willow (8%), and seepweed (2%). Many native riparian tree species are present, though none are common; cottonwood, box elder, Goodding's willow, and hackberry make up just over 1% cover, combined.

The Central Meander reach is nearly entirely federally managed (89%), mostly by the National Park Service (NPS) – Canyonlands National Park, with State ownership of 11 percent, mostly in the upstream portion of the reach.

Lower Meander Canyon, Reach 18

The lower Meander Canyon reach extends for 18 km the upstream end of The Loop (Bkm 40) to the confluence with the Green River (Bkm 22). This deep symmetric canyon trends generally northeast-southwest across broadly folded, sub-horizontal strata of the lower Cutler Formation and Cedar Mesa Sandstone. The canyon is symmetric in cross-profile, 610 to 914 m wide and 245 to 274 m deep. The average slope along this reach and throughout Meander Canyon is approximately 0.02%.

Vegetation cover within this reach is limited by the narrowness of the canyon, and 64% of the bottomland area is occupied by river channel. Of the remaining bottomland area, most is covered in xeric native shrubs (9%), tamarisk (7%), willow (4%), box elder (3%) and NM privet (2%). The Lower Meander reach, in its entirety, is federally owned and managed by Canyonlands National Park.

Colorado-Green River, Reach 19

The Colorado - Green River reach extends for 6 km from the confluence with the Green River (Bkm 22) to the upstream entrance to Cataract Canyon just downstream from Spanish Bottom (Bkm 22). This reach is both geologically and geomorphically similar to the lower Meander Canyon reach. However, it is defined as a separate reach because the combined high flows of the Green and upper Colorado through this reach can be nearly twice the flow of either river upstream from the confluence.

Xeric native shrubs are the most common vegetation type in this reach (15%), with much of the area occurring in the wide and dry Spanish Bottom. Willow is common in near river areas (8%), as is tamarisk (7%). Riparian trees are present, though sparse: box elder (1%), Goodding's willow (1%), and hackberry and cottonwood with less than 0.5% combined. The entire Colorado-Green River reach is federally owned and managed by Canyonlands National Park.

Cataract Canyon, Reach 20

The Cataract Canyon Reach extends for 16 km from Bkm 16 (just downstream from Spanish Bottom) to the maximum upstream limit of Lake Powell at Bkm 0. Averaging approximately 900 m wide and 300 to 370 m deep, Cataract Canyon is the deepest canyon within the 20 reaches defined by this project. This moderately sinuous canyon trends generally northeast-southwest through gently-dipping, pervasively-faulted strata of the Honaker Trail and lower Cutler formations. This pervasive normal faulting is yet another manifestation of 'salt tectonics' within the Paradox Basin. Continuing solution of salts within the Paradox Fm (associated with continuing incision of the Canyonlands region by the Colorado River and its larger tributaries) has resulted in widespread collapse of the overlying rock strata and the concomitant northwestward lateral shifting of these fragmented rocks. This normal faulting and lateral shifting is the underlying cause of the numerous large debris flows that have partly damned the Colorado River and significantly slowed canyon incision along this reach. As a result, the river slope within this reach (approximately 0.275%) is the highest average slope for any reach between the Colorado-Utah border and Lake Powell.

Bare ground is the most common cover type (20%) after water surface (51%) in this reach, with hackberry often lining the uppermost extent of the riparian area (3%), and a mix of tamarisk (9%) and willow (4%) near the channel. Native xeric shrubs are common (4%) at the margin of the bottomland area. Cataract Canyon is federally owned and managed by Canyonlands National Park.

Appendix C. Data Layers and Sources

Layer Types	Specific Spatial Layers	Source	Description	Limitations/Considerations/Details
Imagery	2010 Photography	Aero-graphics (2010), NPS contract, SLC, Utah	High resolution, 0.3 m, ortho-rectified true color imagery flown for the bottomland corridor	Color registration less than optimal (Russian Olive not obvious), some spatial errors due to sharp topographic breaks. Derived DEM not useful for analysis. Derived color IR available.
	2010 Photography	Aero-graphics, NPS contract	Color Infrared imagery, derived from true color images, combined into mosaics	Resolution lost with conversion to mosaics, but adequate for visualization. Some irregularity due to color registration of original photos.
	2011 aerial photographs	NAIP Imagery, (USGS Earth Explorer, 2012)	Regularly flown ortho-rectified, publicly available imagery. 1.0-meter resolution.	Lower resolution than 2010 photos. Coverage of entire watershed rather than the corridor alone. Some problems with extreme topographic shifts and shadow, and wind on water surfaces, especially in the Potash reach. Color registration is better than 2010 photos. 2011 used extensively for cross-checking vegetation mapping (e.g., Russian olive).
	Digital elevation models	USGS Earth Explorer (2012), public source	10m digital elevation models for Grand and San Juan counties in Utah	Very coarse resolution. Good for visualization of bottomland corridor and adjacent tributaries.
	Flood extent 1984 (Imagery)	Acquired by John Dohrenwend	Satellite imagery of 1984 high flow, 30m pixels. Public imagery acquired by J. Dohrenwend.	Very large pixel size. Used for cross-checking bottomland boundary

Layer Types	Specific Spatial Layer	Origin of Layer	Description	Limitations/Considerations/ Details
Vegetation	Vegetation mapping from NPS, 2010	Mapped by National Park Service, Amy Tendick. Ground-truthing and edits by Chris Rasmussen	Mapped from 0.3 m resolution color aerial imagery (2010, above). Ground-truthed and edited by Chris Rasmussen, 2012. Average scale of mapping likely 1:2000, at best. Four categories of declining patch dominance, 25 cover types. Only the dominant category was field checked. All categories for most polygons were validated or edited using available aerial photography, especially polygons with trees or bare ground.	Trimmed to the bottomland boundary. Added 'bare ground' to non-dominant cover class designation. Reviewed and added polygons with Russian olive due to color registration errors in 2010 imagery. Roads are inconsistently mapped, as is rural/residential or industrial use. Xeric shrub types were field checked the least as they were often far from the river and shorter than streamside vegetation. Very large patches were reviewed for consistency with other patch designations.
Fluvial Geomorphology	Channel mapping 2010	Mapped by John Dohrenwend, edited by Chris Rasmussen	Mapped from 2010 high resolution photos. Heavily edited from J. Dohrenwend's initial mapping. Channel subdivided into flow types.	Mapped at moderate low flow (3,410 cfs at Cisco gage)
	Bare area mapping 2010	Mapped by Chris Rasmussen	Mapped from 2010 high resolution photos. Heavily edited from J. Dohrenwend's initial mapping. Mapped at approximately 1:1000	Includes some areas of bare soil not fluvially generated. Impossible to tell if bareness is due to scour, inundation or burial of vegetation.
	High flow 2011	Mapped by Chris Rasmussen	Mapped from 2011 NAIP imagery at 2 weeks post-peak flow. Mapped at 1:2,500 max. Channel attributed with flow types.	Poorer quality photos in Potash, sometimes difficult to tell wet soil from water surface.
Bottomland Boundary	Geomorphic boundary/ project boundary	Mapped by Chris Rasmussen	Mapped from USGS topo maps, 1984 flood extent, vegetation boundary and 2010/2011 channel extents. Alluvial fans associated with moderate and large tributaries are included, but separated, from CO River bottomland. Typically mapped at 1:2,000 larger if necessary for wide valley sections.	Not field checked. Some sources conflicted (Topographic maps from one side of bottomland to other). Used as a rough bounding envelope for the project area.
Human Influences	Ownership	Acquired from Utah AGRC (2012). Edited by C. Rasmussen	Ownership of bottomland boundary, clipped from layer acquired from the Utah AGRC website.	Quality unknown. State level source.
	Roads	Acquired from Utah AGRC (2012)	A subset of roads layer available on Utah AGRC website. Layer cut to bottomland boundary and updated.	Original quality unknown, better after updating within the bottomland boundary.
	Campgrounds, boat ramps and trails	From NPS, BLM, Moab, Utah	BLM and NPS camping areas	Update status unknown.

Layer Types	Specific Spatial Layer	Origin of Layer	Description	Limitations/Considerations/Details
Terrestrial habitat features	All Cover Layer	Created by Chris Rasmussen	Dominant vegetation, channel, bar and bottomland data combined into one layer	Vegetation, bars, and channel features from 2010 mapping
Riparian Understory Species Model	Riparian Understory Species Model	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Riparian Understory Species Model with Tamarisk penalty	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Presence of still water (plus 20m)	Created by Chris Rasmussen	From 2011 data	--
	Prevalence of mesic shrubs	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Number of shrub species	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Tamarisk penalty	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
Riparian Overstory Species Model	Riparian Overstory Species Model	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Riparian Overstory Species Model with Tamarisk Penalty	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Prevalence of trees	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Size of tree patch	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Diversity of woody structure	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Quality of canopy for nesting	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Tamarisk penalty	Created by Chris Rasmussen	From vegetation data; see model descriptions	--

Layer Types	Specific Spatial Layer	Origin of Layer	Description	Limitations/Considerations/Details
General Diversity Model	General Diversity Model	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Diversity of all structural types	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Diversity of all cover types	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
Rocky Fringe Snakes Model	Rocky Fringe Snakes Model	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Distance to permanent water	Created by Chris Rasmussen	From 2010 channel mapping	--
	Distance to bottomland boundary	Created by Chris Rasmussen	From bottomland boundary	--
	Diversity of woody structure	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Diversity of vegetation	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
Bat Watering Model	Bat Watering Model (at high flow)	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Stillness of water	Created by Chris Rasmussen	From 2011 channel mapping	--
	Areas open for flight	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
Bat Feeding Model	Bat Feeding Model	Created by Chris Rasmussen	Derived from mapping, using criteria set by experts at workshop	Would benefit from comparison with species occurrence data and sensitivity analysis.
	Distance to water	Created by Chris Rasmussen	From 2011 channel mapping	--
	Diversity of cover types	Created by Chris Rasmussen	From vegetation data; see model descriptions	--
	Stillness of adjacent water	Created by Chris Rasmussen	From 2011 channel mapping	--

Layer Types	Specific Spatial Layer	Origin of Layer	Description	Considerations/Limitations/Details
Expert Workshop Data	Landmarks	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review
	Fish Use	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review
	Fish Comments	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review
	Fish Restoration potential	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review
	Threats to habitat or wildlife	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review
	Wildlife Restoration Potential	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review
	Wildlife Use	Created by Chris Rasmussen	Layer created from Expert Workshop data	Would benefit from peer review. Data cannot be published because some locations are sensitive.
Analysis	Channel centerline	Created by Chris Rasmussen	Center of low flow channel (2010). Used for deriving sinuosity.	--
	Channel Kms	Created by Chris Rasmussen	1 km points on channel centerline	--
	Bottomland centerline	Created by Chris Rasmussen	Center of bottomland boundary, derived from bisecting distances perpendicular to bottomland orientation. Converted to a route for marking stops for bottomland polygons.	--
	Bottomland polygons (1 km)	Created by Chris Rasmussen	Bottomland boundary partitioned into sections based on 1 km lengths of the bottomland centerline. Partitions cut perpendicular to centerline.	--

Appendix D. List of Expert Workshop Participants

Participants in the Expert Workshop, March 19-20, 2013, in Moab, Utah.

Jason Johnson: Area Manager for the Southeast Area of Forestry, Fire and State Lands
Cheryl Decker: NPS Botanist, vegetation manager
Mike Scott: Retired USGS, riparian ecologist
Bill Sloan: Sensitive Species Biologist for NPS
Tony Wright: Sensitive Terrestrial Species Biologist for the Southeast Area Division of Wildlife Resources
Pam Riddle: BLM Wildlife Biologist in Moab
Ann Marie Aubry: BLM Hydrologist/Riparian Coordinator,
Jeremy Jarnecke: BLM Hydrologist
Kara Dohrenwend: Wildland Scapes and Rim to Rim Restoration
Brian Laub: USU Post Doc, aquatic ecologist
Casey Mills: UWDR Salt Lake City, Sensitive Aquatic Species
Steve Young: Canyonlands NP River District Ranger
Doug Osmundson: USFWS Grand Junction, Fisheries, now retired
Katie Creighton: UDWR Moab, Colorado River and San Juan River Recovery Program
Alison Lerch: Former Sovereign Lands Coordinator for Utah Forestry, Fire and State Lands
Mark Miller: NPS Ecologist and Chief of Resource Science and Stewardship for Southeast Utah Group (SEUG)
John Dohrenwend: Retired USGS, geomorphologist, now deceased
Shannon Hatch: Restoration Coordinator for Tamarisk Coalition
Mary Moran: NPS-SEUG, Vegetation and Water Quality Technician
Laura Martin: NPS Canyonlands, Archaeologist
Robert Wigington: TNC, water supply management
Sue Bellagamba: TNC, restoration coordination and planning
Chris Rasmussen: CSG/USGS Riparian Restoration Ecologist. now with EcoMainstream Contracting

Appendix E. Detailed Model Descriptions

Riparian Overstory Model

Characteristic species: Western yellow-billed cuckoo, Bullock's oriole, black-headed grosbeak, blue grosbeak, warbling vireos, Cooper's hawk, screech owl, saw-whet owl.

We designed this model to identify habitats that are generally suitable for species that use deciduous riparian forest habitat, preferably a large patch with an understory of diverse shrubs, for nesting and feeding. Tree canopy with a dense, multi-layered, shrub understory provides excellent habitat, as do large patches of trees. Because it is difficult to see under a tree canopy using aerial imagery, we used a measure of the variety of woody patches (including trees) available within a 1.5-hectare area, as birds also use understory that is adjacent to trees. The quality of canopy (combination of broad-leaved and dense) is important for nesting habitat and supporting insect biomass; thin canopy or small-leaved trees such as Russian olive and hackberry are less desirable (Oliver and Tuhy, 2010; and from Expert Workshop). The tamarisk leaf-beetle has caused widespread defoliation and mortality of tamarisk in the study area. Because dead or defoliated tamarisk has lower habitat value as understory, (not because of inherent habitat value; Stromberg et al., 2009; Van Riper et al., 2008) experts advised creating a second version of the Riparian Overstory Model that applied a penalty to patches where tamarisk is common or dominant. Factors such as proximity to roads, human activity, and non-native species were not accounted for here, but may be addressed as threats to habitat in later efforts. At the time of model construction, we did not have data on two important factors for habitat assessment: actual tree height and patch density. For tree heights, we substituted an average height encountered within the project area for each tree cover type. We approximate patch density by using the abundance class assigned to species within each patch: category A, or Dominant, is assumed to be dense; category B, or Common is less dense; categories C or D is Present and sparse.

Of the target species listed, the threatened western distinct population segment of the yellow-billed cuckoo has the greatest amount of literature describing habitat needs (Oliver and Tuhy, 2010). We assume that habitat requirements for the western yellow-billed cuckoo are transferable, at least in general, to other species sharing similar habitats. Parameters for construction of the model came from literature on the cuckoo assembled in Ecological Integrity Tables in a cooperative effort between the Utah Division of Wildlife Resources and The Nature Conservancy (Oliver and Tuhy, 2010). Within the project area, even the best available habitat is marginally desirable for cuckoos, relative to habitats available in other drainages, especially with regard to tree density and patch sizes (A. Wright, UDWR, personal communication, April, 2013).

For the woodland raptors represented in the model, Cooper's hawks primarily eat other birds and prefer woodland areas and riparian zones; northern saw-whet owls often pounce on prey from a perched position; and western screech owls are often found in riparian woodlands and along streamsides (UCDC for respective species, accessed 11-2-2013).

Model Description Details

Habitat values in the Riparian Overstory model depend primarily on: 1) prevalence of trees, 2) diversity of woody structure present, 3) tree patch size, 4) the canopy quality for nesting, and 5) an optional tamarisk penalty. We used a large analysis window size of 1.5 hectares for this model; results should be interpreted as presence of general habitat features within a fairly large area. Potential for project implementation should be verified with inspection of detailed aerial photographs and field checks.

1. <u>Prevalence of trees:</u> We estimated the prevalence of trees using the listing order of tree cover types: if Dominant, value of 3; if Common, value of 2; if Present, value of 1. We used a maximum function in Focal Statistics (ESRI ArcGIS, version 9 to 10.2, Focal Statistics use a 'moving window' of a user defined size to analyze adjacent pixels) to show the highest tree prevalence available within the 1.5 ha analysis window.

2. <u>Diversity of woody structure:</u> This measure shows the number of woody structural groups available within a 1.5 ha area. Woody cover types are grouped as follows: Tall Trees (cottonwood and Goodding's willow); Short Trees (box elder, Gambel oak, hackberry, non-native trees); Tall Shrubs (tamarisk, willow, NM privet); Short Shrubs (skunkbush, xeric native shrubs, seepweed). We used the variety function within Focal Statistics to count the number of woody structural types present (values 0-4) as dominant cover types.

3. <u>Tree Patch size:</u> We derived a measure of patch size by creating polygons containing contiguous patches within which trees were Common or Dominant. We grouped polygons into four patch size classes: greater than 20 ha, value of 3; greater than 10 ha but less than 20 ha, value of 2; greater than 1 ha but less than 10 ha, value of 1.

4. <u>Canopy Quality:</u> Low quality nesting trees are those with small leaves or sparse canopy (Russian olive and hackberry), versus dense, broad-leaved

canopy (cottonwood, Goodding's willow, box elder, Gambel oak). Mulberry and elm fit in the broad-leaved category, but are not common (especially mulberry), and were mapped in a combined cover type of non-native tree with much more prevalent Russian olive. We penalized polygons with sparse-canopied Dominant species by assigning a value of -2; polygons with sparse-canopied Common species were penalized by assigning a value of -1. We did not penalize patches where sparse canopies were Present only. We assigned the minimum value present within a 1.5 ha circular area using the minimum function within Focal Statistics.

5. Tamarisk penalty (optional): Due to defoliation by the tamarisk beetle, where tamarisk is Dominant within a patch, we assigned a penalty of -2. Where tamarisk is Common, we assigned a penalty of -1. We did not penalize patches where tamarisk is Present only. We assigned minimum values present within a 1.5 ha area using Focal Statistics, minimum function.

For this model, we weighted diversity of woody structure, canopy quality and prevalence of trees at 1.0. In the standard model, we weighted patch size by a factor of 0.5 and tamarisk prevalence by a factor of 0. In the alternate model with the tamarisk penalty, we weighted tamarisk prevalence by a factor of 1.

*Riparian Overstory Model score = (diversity of woody structure * 1.0) + (prevalence of trees * 1.0) + (patch size * 0.5) – (canopy quality * 1.0) – (tamarisk penalty * 0.0)*

*Riparian Overstory Model, with tamarisk penalty, score = (diversity of woody structure * 1.0) + (prevalence of trees * 1.0) + (patch size * 0.5) – (canopy quality * 1.0) – (tamarisk penalty * 1.0)*

Final model results are represented in four categories: No Habitat (values 1 - 2.9), Low quality habitat (values 3 - 4.9), Moderate quality habitat (values 5 - 7.9), and High quality habitat (values 8 - 9.9). This model would be greatly improved with the acquisition of actual tree heights and tree density. Model limitations include the generalization that broad leaved trees are better, which may or may not apply to all species preferring tree cover.

Riparian Understory Model

Characteristic species: Willow flycatcher, common yellowthroat, yellow warbler, beaver, northern river otter and black-necked garter snake.

This model is designed to represent species that need dense riparian shrubs in close proximity to the channel, and proximity to still water or saturated soils; shorter distances are better (<10 m excellent, >25 m poor, per Ecological Integrity Tables for the southwestern willow flycatcher [UDWR, 2010]). Slow water supports higher insect biomass for birds, higher quality habitat for prey species of otters, and ease of mobility for beaver. Dense shrubs provide nesting cover, support prey species (insects), and comprise a food base for beavers. Otters do not depend on shrub cover, but other habitat needs were consistent with Riparian Understory representations. Greater numbers of mesic shrub species add relative stability of the resource, as disease or predators may disproportionately impact one species over another, and provide a more diverse prey/food base for birds and beavers.

We used the well-documented habitat needs of the southwestern willow flycatcher as the basis for the Riparian Understory Model (Sogge and Marshall, 2000; Finch et al., 2000; UDWR 2010) and assume that species sharing these habitats will have generally similar, and possibly less demanding needs. The Ecological Integrity Tables (UDWR, 2010) used for developing component layers focused on breeding habitats for these birds, which may or may not occur within the project area.

The Riparian Understory Model also represents habitat for non-bird species that occur in the project area and have local, statewide or regional significance. The State of Utah has designated Northern otters as a rare species and is managing the population in order to expand current distributions to historic ranges (UDWR, 2010b). State wildlife managers are promoting increases in beaver populations where compatible with human uses (UDWR, 2010a). The black-necked garter snake, almost always found near water and having a diet of amphibians and crustaceans, is the least common of Utah's three garter snake species; key habitat lies adjacent to, but outside of, the project area (UDWR, 2013).

As in the Riparian Overstory Model, we offer an alternate version of the habitat model that includes a penalty for poor condition tamarisk cover due to the defoliation and mortality effects of the tamarisk beetle. Incorporation of patch size as a modifier of habitat quality, after factoring in threats from exotic species and disturbance, would likely improve this model.

Model Description Details

The fundamental components of this model are: 1) stillness of water as shown by channel types in the high water 2011 channel extent, 2) shrub density, 3) the number of mesic shrub species present, and 4) an optional tamarisk penalty. We used an analysis window of 1.0 hectare.

1. Stillness of water: The 2011 channel extent at high water shows the area of potential flooding and the spatial range of potential riparian understory

species habitats. We categorized areas within the 2011 channel boundary as still water (value of 2), or moving water (value of 1). We used Focal Statistics, maximum function, to assign water stillness values to floodplain surfaces within 25 m of the channel.

2. Shrub density (shrub prevalence): We used the prevalence of shrubs in individual polygons to show relative shrub density: polygons with shrubs in Category A, or Dominant, value of 3; polygons with shrubs in Category B, or Common, value of 2; shrubs in categories C or D, or Present, value of 1. We averaged shrub prevalence values with Focal Statistics, mean function.

3. Number of mesic shrub species: This component shows the number of mesic species present in each polygon. Mesic shrubs in the project area included: tamarisk, sandbar willow, skunkbush sumac and NM privet. We assigned the maximum number of shrubs present (range 0-4) in a 1 ha area using Focal Statistics, maximum function.

4. Tamarisk penalty (optional): Where tamarisk is Dominant in a polygon, we applied a penalty of -2; where Common, a penalty of -1; where Present only, no penalty. We assigned values for the tamarisk penalty within 1 ha using Focal Statistics, minimum function.

We present two versions of the Riparian Understory Model, one with, and one without a penalty for tamarisk cover. Component weights are: water stillness, 1.5 and shrub density, 1.0. The number of mesic shrub species present is de-emphasized with a weight of 0.5, as suggested by advising wildlife biologists. For the model with no tamarisk penalty, we weight the tamarisk component at 0. For the alternate model we weight the tamarisk penalty component at 1.0.

*Riparian Understory Model score = (water stillness * 1.5) + (shrub prevalence * 1.0) + (number of mesic shrubs * 0.5) – (tamarisk penalty * 0.0)*

*Riparian Understory with tamarisk penalty model score = (water stillness * 1.5) + (shrub prevalence * 1.0) + (number of mesic shrubs * 0.5) – (tamarisk penalty * 1.0)*

Final model results are represented in four categories: No Habitat (values -0.5 to 0.9), Low quality habitat (values 1 - 3.9), Moderate quality habitat (values 4 - 5.9), and High quality habitat (values 6 - 7.9). This model would be improved by having habitat values adjusted by patch sizes and possibly by a human disturbance factor. Actual values of patch density and stand heights would improve estimation of habitat quality.

General Diversity Model

We created the General Diversity Model to document the diversity of habitats potentially available for prey species of bottomland raptors, assuming that greater habitat diversity supports a greater variety of prey species. The model accounts for both cover and structural diversity, recognizing the value of both, simultaneously. Model construction reflects the assumption that greater habitat complexity (cover and structural types) supports greater biodiversity, and it includes all cover types except those reflecting human development (transportation corridors, residential/recreational development).

Model Description Details

The General Diversity Model includes: 1) the diversity of cover types and 2) the diversity of structural types for the project area. We designated the analysis window to be 1 ha, but not based on the needs of any particular species. See the discussion of sensitivity analysis in a later section.

1. Diversity of cover types: We calculated the diversity of cover types from the dominant category only, and considered vegetated and non-vegetated cover types. We generated values for each cell with Focal Statistics (variety function) which counts the number of unique cover types encountered within the analysis window.

Diversity of structural types: We based structural categories on plant heights typically encountered in the project area (see main document, Table 6). Both categories and height ranges were validated by reviewers and local resource specialists. Structural diversity reflects the variation in dominant cover type only. Cover types are grouped as follows: Tall Trees (cottonwood and Goodding's willow); Short Trees (box elder, Gambel oak, hackberry, Russian olive, Siberian elm, mulberry); Tall Shrubs (tamarisk, sandbar willow, NM privet); Short Shrubs (xeric native shrubs, seepweed); Herbaceous (mesic herbaceous, weedy herbaceous, knapweed, xeric native grasses, bulrush); Bare (sand bar or bare); and Water (ponds and channel areas). Mulberry and elm are capable of reaching tall tree heights, but are mapped in the same non-native tree cover type as the much more prevalent Russian olive. Values for each cell are generated using Focal Statistics which counts the number of unique cover types within a 1 ha circular area.

We weighted the structure of cover types by 1.0 and the diversity of cover types by 0.7 to make components equivalent within the model.

*General Diversity Model score = (diversity of cover types * 0.7) + (diversity of structural types * 1.0)*

Final model results are represented in three categories: Low quality habitat (values 1.7 - 3.9), Moderate quality habitat (values 4 - 7.9), and High quality habitat (values 8 - 14). Measurements of actual patch heights would improve this model.

Bat Feeding Model

Characteristic species: Agile species - Alan's big-eared bat, Townsend's big-eared bat, fringed myotis, Yuma myotis. Also non-agile species: big free-tailed bat, spotted bat.

The Bat Feeding Model aims to represent potential feeding habitats for bats in the project area. While biology and life histories of most Utah bats are poorly and incompletely known, the Utah Bat Conservation Plan (Oliver et al., no pub. date), states that conservation of roosting habitats and foraging habitats are obvious needs for conservation. Six species of bats are on the Utah Sensitive Species List (UDWR, 2011), and there is concern for the conservation of nearly all bats (Oliver et al., no pub. date). The Bat Feeding Model attempts to identify areas with greater or lesser potential production of insects that make up the diet of the vast majority of Utah bat species (Oliver et al., no pub. date). We assumed that areas such as the boundaries of cover types, especially those between vegetation and water, and areas near slow water are likely to support greater insect biomass.

The bat feeding model highlights habitat features that (are assumed) to support insect biodiversity including: diversity of locally available cover types, proximity to water, and the relative velocity of adjacent water (slow preferred). We also assumed that greater variety of cover types available within a half hectare area will support greater insect biodiversity. The model applies to both agile and non-agile bat species.

Model Description Details

Feeding habitat values shown by the model reflect: 1) distance to water, 2) diversity of cover types, and 3) stillness of adjacent water. The model uses an analysis window of 0.5 ha.

1. Distance to water: In the absence of supporting literature for insect production, we applied general thresholds for varying proximity to the 2011 high flow channel boundary. We assigned a value of 3 to distances closer than 50m, value of 2 for distances between 50 and 100m, and a value of 1 for distances greater than 100 m from the channel.

2. Diversity of cover types: We calculated the diversity of vegetation cover types from the dominant category only, and considered all cover types (except transportation corridors and residential/recreation development). We used Focal Statistics (variety function) to assign values to a cell by counting the number of unique cover types encountered within a 0.5 ha area.

3. Stillness of adjacent water: Channel habitats (2011 high flow boundary) were categorized as: still water, value of 2 (isolated pools, backwaters, tributary channels); moving water, value of 1 (main and secondary channels).

Stillness of adjacent water is weighted by a factor of 1.5 and diversity of cover types by a factor of 0.3 to help equalize the range of values with distance to water (1.0).

*Bat Feeding Model score = (distance to the channel * 1.0) + (stillness of adjacent water * 1.5) + (diversity of cover types * 0.3)*

Final model results are represented in three categories: Low quality habitat (values 1 - 7.9), Moderate quality habitat (values 8 - 19.9), and High quality habitat (values 20 - 28).

Bat Watering Model

Target species: non-agile big free-tailed bat and spotted bat.

Bats most often drink by skimming the water surface with an open jaw during flight (UBCP, 2013), requiring clean, open water, with a flight line un-occluded by tall surrounding vegetation and free of surface turbulence. Availability of still, open water is seasonally variable, and is typically less available during periods of high flow when the main and secondary channels are turbulent and overbank flow is often covered in emergent, woody riparian vegetation. Flooded tributary canyon mouths and off-channel backwaters can be important watering habitats during high flows, though they are of lower quality where covered by riparian vegetation. During periods of low flow, backwaters and tributary mouths are often dry, but the main channel offers more slow water areas suitable for drinking. Water surfaces available for drinking are irregularly distributed in the project area; considering the watering and feeding models together will help prioritize restoration actions for bats.

Model Description Details

The quality of bat watering habitats, as modeled, are dependent on: 1) water stillness (2011), and 2) the flight openness of areas near water, or the absence of vegetation that would inhibit flight near the water surface. We used an analysis window size of 0.5 ha.

1. Water stillness: Channel habitats at high flow (2011) were categorized as: still water, value of 2 (isolated pools, backwaters, tributary channels), and moving water, value of 1 (main and secondary channels).

2. Flight openness: We identify 'flight open' areas as those with cover types that are short or absent: all herbaceous cover types, seepweed, bare ground, and water. Flight open areas were assigned value of 2, not open a value of 1. We calculated mean values for the bottomland surface using Focal Statistics, mean function.

No weighting was necessary for this model.

Bat Watering Model score = (water stillness * 1.0) + (flight openness * 1.0)

Final model results are represented in three categories: Low quality habitat (value 2), Moderate quality habitat (3), and High quality habitat (value 4). Measurements of patch densities and heights would improve estimates of habitat quality presented here.

Open Land Species Model

Target species: prairie falcon, rough-legged hawk (winter), short-eared owl (winter), burrowing owl, milksnake

Open land species in the project area depend on areas free of woody species and saturated soils. This model shows areas that support burrowing animals directly (e.g., burrowing owls) or indirectly by supporting burrowing prey. The focus on burrowing habitat requires that the ground be free from inundation from stream flow or ground water, and clear of strong root systems of woody species. Bottomlands dominated by native vegetation in the project area are often unsuitable for burrowing animals, as most surfaces in the project area are either actively managed for agriculture or other uses or are occupied by shrubs or trees. Disturbance from agriculture (tilling especially) is disruptive, though irrigated but untilled pastures are excellent habitat. The best patch sizes are over 10 ha; areas dominated by knapweed are considered poor habitat. We will address agricultural intensity in later models of threats, as well as proximity to roads and dominance by knapweed. The model is based on the two primary factors described below, and is modified by subtracting areas covered by the 2011 flood extent. We will evaluate patch sizes using model outputs and will address threats from non-native species in a later phase of the project.

Model Description Details

The Open Land Species Model depends primarily on: 1) open areas not covered with woody species, and 2) distance to water (channel map of high flow 2011). The analysis window size was 2.0 ha.

1. Open areas: We identify open areas as non-woody cover types including all herbaceous cover types and open or sand bar. Non-woody cover types in the Dominant category are valued as 2; in the Common category, valued as 1. Areas with little or no open area are valued as 0. Values for each polygon were processed with Focal Statistics calculating mean cell values.

2. Distance to water: In the absence of detailed bottomland elevation data, we use distance to the channel as a surrogate measure for the dryness of soils. We classified distances near the 2011 high flow channel (0-50 m) as value of 1; 50-100 m, value of 2; and greater than 100 m, value of 3.

Open areas were weighted by a factor of 2.0 to emphasize the importance of no woody vegetation.

*Open Land Species Model score = (open areas * 2.0) + (distance to water * 1.0)*

Areas covered by the 2011 high flow channel were removed from the final model output with an erase function. Final model results are represented in four categories: No Habitat (values -0.5 to 0.9), Low quality habitat (values 1 - 3.9), Moderate quality habitat (values 4 - 5.9), and High quality habitat (values 6 - 7). Detailed ground elevation information would greatly improve the quality of this model, as would measurements of patch densities.

Rocky Fringe Snakes Model

Target species: cornsnake, Smith's black-headed snake

The model for Rocky Fringe Snakes combines several different habitat needs including: refuge habitat (logs, boulders, debris, fissures) for retreat and hibernation; diverse vegetation; complex woody structural cover and proximity to perennial water. Ideal habitat includes ground surface complexity, healthy riparian vegetation that supports a robust prey base, and close proximity to both water and rocky talus from adjacent cliffs or hillslopes. This model accentuates habitats in narrow to moderately narrow bottomland areas where three habitat elements are in close proximity: water, riparian vegetation and the bottomland boundary. Diversity of vegetation cover types within a small area (50 m2) serves as a surrogate for possible prey species diversity and habitat quality.

Of the two snake species represented by the Rocky Fringe Snakes Model, one, the cornsnake, is on the Utah Sensitive Species List (UDWR, 2011), and the other, Smith's black-headed snake is so secretive that distribution and life history data are sparse (UDWR, 2013). Smith's black-headed snakes are very small, have very small home ranges, typically prey on insects and other invertebrates, and seldom emerge above ground (Dr. Stephen Spears, pers. comm., July 29, 2013). Cornsnakes are a larger species that eat a broad range of prey types including rodents, birds, insects, lizards and other snakes (UDWR, 2013).

The model could be improved significantly by using a digital elevation model to show steepness at the bottomland boundary; steeper slopes are more likely to provide necessary refuge habitats. We will account for roads, fire risk, and dominance by non-native vegetation as threats in future models.

Model Description Details

Habitat values estimated by this model depend primarily on: 1) distance to water [low flow 2010], 2) distance to the bottomland boundary, 3) diversity of woody structure, and 4) diversity of vegetation cover types. We used an analysis window of 50 m^2 to evaluate habitats.

1. Distance to water: We use the distance to the 2010 channel as it best represents availability of perennial water. Distances are classified as: between 0-100 m, value of 4; 100-200 m, value of 3; 200-400 m, value of 2; 400-800 m value of 1, and 800-2000 m, value of 0.

2. Distance to bottomland boundary: Distance to the bottomland boundary best represents the outside margin of riparian habitat, with or without substantial rocky features. We classified distances to: 0-25 m, value of 3; 25-50 m, value of 2; 50-100 m, value of 1; and 100-800 m, value of 0. This component could be greatly improved with use of a digital elevation model to estimate boundary slope and potential for snake refuge habitat.

3. Diversity of woody structure: This measure of woody structure is based on heights of cover types as they typically occur in the project area (see main document, Table 6). Woody cover types are grouped as follows: Tall Trees (cottonwood and Goodding's willow); Short Trees (box elder, Gambel oak, hackberry, non-native trees); Tall Shrubs (tamarisk, willow, NM privet); Short Shrubs (skunkbush, xeric native shrubs, seepweed). We counted the number of height classes present within each polygon, as home ranges for snakes are too small for measures using only dominant cover types. The average count value was assigned using Focal Statistics for a 50 m^2 circular area.

4. Diversity of vegetation cover types: Diversity of vegetation is estimated using the number of vegetation classes identified for each polygon. Each polygon has the potential for four separate vegetation types (e.g., willow Dominant, with tamarisk Common, sand bar and sumac Present). Diversity of riparian vegetation is represented very generally as the number of cover type categories listed (e.g., dominant only=1, dominant and common=2) with a maximum of 4. The cover count was averaged over the 50 m2 analysis window using Focal Statistics.

We ran the model with the bottomland boundary weighted by a factor of 2.5, and the nearness of water de-emphasized by a factor of 0.5.

*Rocky Fringe Snakes model score = (distance to bottomland boundary * 2.5) + (distance to water * 0.5) + (diversity of woody structure *1.0) + (diversity of vegetation cover types * 1.0)*

Final model results are represented in three categories: Low quality habitat (values 1 - 8.9), Moderate quality habitat (values 9 - 11.9), and High quality habitat (values 12 - 18). Better representation of steep or cliff dominated habitats could be accomplished using a digital elevation model rather than the bottomland boundary, if warranted. The model was reviewed by Dr. Stephen Spears, herpetologist for the Orianne Society.

Relative Cost of Restoration Model

Effective planning for restoration includes weighing the relative costs involved in restoring vegetation community characteristics against the possible gains to habitat quality. Fundamental costs include: site access for crews and materials, time and equipment needed for treatment of non-native species, and the effort required to manage biomass (Evangelista et al., 2007). Planning costs are also substantial (Martin, 2012), such as choosing and managing crews, navigating land use permits where needed, and coordinating the specific interests of landowners and managers. While we acknowledge the importance of planning costs, the model presented here is restricted to fundamental site costs, and uses only information readily available. Also, vegetation mapping from aerial images represents only stands dense enough to be recognized from afar. On-site visits are a critical follow-up to broad-scale mapping and site selection.

Ease of access to sites is a large factor in fundamental costs as both distance and topography can magnify expenses of moving works crews, equipment and materials. Sites with access for vehicles are least expensive, with the greatest costs required for sites where crews have access only by boat or must camp on site. Another fundamental cost involves the volume of biomass of non-native woody vegetation, a factor that involves both density of stands and height of vegetation (Drus et al., 2012). For this effort, we have relative densities of non-native species, only, and no information on stand heights. Detailed topographic information on both ground surface and vegetation heights, anticipated in the near future through LiDAR, would greatly refine and improve this model. In addition, the mix of structural types of non-native species (woody and herbaceous) requires equipment specified for treatment of each, including different herbicides and means of spraying (e.g., cut stump vs. broad area spray).

Land use permitting is the most involved on land managed by the BLM and access and equipment restrictions are greatest on land managed by the NPS. Restrictions and flexibility of practices on private lands are highly variable. Areas managed by the Sovereign Lands Program (State of Utah) have few land use permitting requirements and equipment restrictions. Ownership (State, NPS, BLM and private) is not directly incorporated into the cost model, but is available for consideration at later steps in the planning process.

Model Description Details

Dominant physical factors relating to cost of restoration implementation for the project area include: 1) access to the site, 2) types of non-native species present, 3) density of non-native herbaceous species present, and 4) density of non-native woody species present. The Colorado River mainstem is considered an impassable barrier for all types of access, and access was calculated for each side of the river separately.

1. <u>Access to the site:</u> This first and most complex model component shows the means of access available for each portion of the bottomland surface. Possibilities are: 1) road access, buffered by 200 feet (61 m), or the distance of hose available on a truck mounted herbicide unit; 2) 4-wheel-drive access, or herbaceous-dominated vegetation adjacent to a road (not accounting for topography, i.e. impassable ditches; buffered by 10 m); 3) day-hiking access, or a distance less than 3.2 km from a reasonably-sized road near the bottomland, that is not separated from the bottomland by cliffs; and 4) rafting/camping access, where none of the above are available. For hiking distance, according to Mike Wight, Restoration Coordinator of the Southwestern Conservation Corps (pers. comm., March 25, 2013), crews can be expected to hike ~2 miles per hour, on even and clear terrain carrying light loads. Hiking conditions in the Colorado bottomland are typically not 'clear', and for a day-hiking scenario, all gear would have to be hauled in. Due to the difficulty of hiking and gear, the model reflects a maximum distance of 3.2 km (2 miles) as a maximum distance to be hiked, round trip, while allowing 7-8 hours of work time. Road, 4-wheel drive and hiking access are calculated for each side of the river separately. Road access is assigned a value of 1, 4-wheel access, value of 2, day hiking, value of 3, and raft or camp, value of 4.

2. <u>Structural types of non-native species:</u> The second layer accounts for the combined presence of woody and herbaceous non-native vegetation, as treatments for each require different herbicides and planning. This layer shows where each type of non-native patch is mapped, with a value of 2 with only one type present, or 4, where both woody and herbaceous non-native species are present.

3. <u>Density of non-native herbaceous species:</u> Relative density of herbaceous, non-native cover is shown with a separate layer, assigning each cover polygon with a score of 2 for Present, 3 for Common, and 4 for Dominant.

4. <u>Density of non-native woody species:</u> Relative density of woody, non-native cover is shown with a separate layer, assigning each cover polygon a score of 2 for Present, 3 for Common, and 4 for Dominant.

All layers were weighted equally for this model.

*Relative Cost Model score = (site access * 1.0) + (non-native structural types * 1.0) + (density of non-native herbaceous cover * 1.0) + (density of non-native woody cover * 1.0)*

Individual layers are classified such that the 'worst' conditions are scored highest, and all have a maximum value of 4. The highest possible score is 15 (not 16) as patches have only one dominant cover type. For reporting results, final ratings of 1-5 were considered 'low', ratings of 6-10 'moderate', and 11-15 'high'.

Fire Risk Model

Dominance of tamarisk and general increase of vegetation density within riparian zones has altered the role of fire in Southwestern riparian systems. Where riparian zones once acted as fire breaks for surrounding uplands, fires in the bottomlands are now common, with great capacity to damage human structures and native plant communities (Busch, 1995; Brooks et al., 2008; Drus, 2010). An abundance of fine fuels and high stem densities often associated with tamarisk allows carriage of fire (note: cheatgrass is a known fire risk, but could not be mapped consistently from aerial imagery). When combined with the ability of tamarisk to re-sprout quickly after fire, infested riparian zones often trend towards tamarisk monoculture (Shafroth, et al., 2005) at the expense of fire-intolerant native riparian species such as cottonwood and some willow (Brooks et al., 2008). Estimating fire risk across the bottomland allows placement of fire breaks or clearing tamarisk in order to protect valuable sites.

For our purposes here, we define 'fire risk' as the potential to lose ecological assets on the floodplain (i.e. stands of riparian trees). Native shrub species are common to dominant throughout the project area, and with the action of the tamarisk leaf beetle, abundance of these native shrubs is increasing. Riparian trees, however, are less common than native shrubs, are less likely to recolonize due to decreased peak flows, and take substantial time to regrow to heights valued for habitat. The density of native riparian trees is included in the model, as habitat values for species that prefer overstory habitat are often density dependent.

Campgrounds and roads are assumed to be possible ignition sources, with higher probability of sparks from campfires, cigarettes and vehicle operation (e.g., exhaust systems). To address fires from lightning, an alternate model excludes proximity to human ignition sources.

Model Description Details

The Fire Risk Model consists of three layers: the density of tamarisk, presence of native trees, and proximity to human ignition sources; the higher the value, the greater the risk of fire.

1. Density of tamarisk: The density of tamarisk layer assigns values to densities of tamarisk based on vegetation mapping. In patches where tamarisk is Dominant, we assigned a value of 3; Common, a value of 2, and for all other patches, a value of 0. Patches where tamarisk is present (categories 3 and 4 in vegetation mapping) are judged to pose little fire risk.

2. Density of native riparian trees: This map shows risk of fire to ecological resources as a function of the density of native riparian trees. Patches where those trees are: Dominant are assigned a value of 3; Common, a value of 2; Present a value of 1; and Not Mapped, a value of 0.

3. Proximity to human ignition sources: Proximity to ignition sources includes places where open flames are more likely to occur: campgrounds and roads. We did not have consistent and reliable data on trail locations for all areas (some available for NPS and BLM, but not private lands). Distances were calculated for each side of the river separately, assuming that the river channel serves as an effective fire break. We assigned values for degree of risk as: <500 m, 500-1000 m, 1000-1500 m, and 1500 m+ with values of 3, 2, 1, 0, respectively.

All factors were weighted equally for this model.

*All Fire Risk Model score = (density of tamarisk * 1.0) + (density of native trees * 1.0) + (proximity of human ignition sources * 1.0)*

Natural Fire Risk Model score (optional) = (density of tamarisk * 1.0) + (density of native trees * 1.0)

For reporting purposes, total scores for the All Fire Risk Model were rated: 0-3 is low risk of fire, 4-5 moderate risk, and 6-8 high risk of fire. The Natural Fire Risk Model results were rated: 0-1 low risk, 2-3 moderate risk and 4-5 high risk of fire.

Potential for Natural Recovery Model

When prioritizing restoration actions on the bottomland, it is very helpful to know where little or no work is needed. Access to water and existing plant communities are combined here to show areas that are likely to recover or be maintained without intervention. Sites already dominated by native species, for instance, are in less need of active restoration, as are those frequently flooded during high flows. The presence of non-native species can interfere with colonization by native species, and is treated as a penalty that varies with density. For our purposes we assume that areas that have access to high flows: 1) are better watered, with greater potential to support riparian vegetation, 2) have better access to seed sources carried by flood water, and 3) have higher potential for being scoured by flood flow. Areas within the extent of the high flow boundary are also exposed to the seeds of non-native species (e.g., Russian olive), and should be monitored periodically for new populations.

Model Description Details

Factors included in this model are: the relative density of native cover, the presence of overbank flows, and a penalty for the relative density of non-native species. The higher the value, the more likely a site is to recover or maintain without active restoration.

1. Overbank flow (2011): Overbank flows are shown using the 2011 high flow extent. Floodplain areas covered with water are assigned a value of 3; non-flooded areas are valued at 0.

2. Density of native species: Density of native species is valued as: 3 for Dominant, 2 for Common, 1 for Present, and 0 for Not Mapped.

3. Density of non-native species: A penalty is applied for relative density of non-native species: Dominant stands valued at -3, Common at -2, Present at -1, and Not Mapped at 0.

All factors were weighted equally for this model.

*Potential for Natural Recovery Model score = (overbank flow * 1.0) + (density of native species * 1.0) + (density of non-native species * 1.0)*

For reporting purposes, ratings for the Potential for Natural Recovery models were designated: -3 to 0 low potential, 1 to 3 moderate potential, and 4 to 6 as high potential for natural recovery.

Appendix F: Bottomland Cover Types by Percent of Reach and Hectares

Summary of cover types by reach (1-10), shown in percent of total reach cover. Refer to Tables 1 and 2 in main document for reach codes and detailed cover type descriptions. RWW=Ruby Westwater, WWC=Westwater Canyon, WWCL=Westwater-Cisco Landing, CL=Cisco Landing, CWDG= Cisco Wash-Dry Gulch, MGB=McGraw Bottom, DMGB=Dolores-McGraw Bottom, DB=Dewey Bridge, D=Dewey, PV=Professor Valley

Cover Type	Reach Code and Values in Percent of Reach Area									
	1 RWW	**2 WWC**	**3 WWCL**	**4 CL**	**5 CWDG**	**6 MGB**	**7 DMGB**	**8 DB**	**9 D**	**10 PV**
Tamarisk	13.5	4.1	12.8	18.7	27.2	17.1	14.1	6.5	13.3	27.3
Coyote Willow	3.4	6.0	4.2	5.0	8.6	5.6	12.4	6.2	11.6	5.6
NM Privet (Desert Olive)	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Sumac	0.5	0.0	6.0	0.7	4.5	2.2	4.6	2.5	2.8	1.9
Seepweed	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Native Xeric Shrub	13.0	0.0	14.5	8.0	7.1	21.2	6.9	6.1	5.7	7.9
Cottonwood	8.3	0.0	2.0	14.7	14.0	10.3	5.5	4.6	0.0	2.4
Box Elder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Gambel Oak	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Goodding's Willow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hackberry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-native Trees	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0
Knapweed	5.5	0.0	5.7	4.4	1.3	5.2	4.9	5.7	1.4	1.3
Non-native Herbaceous	39.1	0.2	24.7	29.9	3.1	9.4	3.8	31.7	3.6	1.4
Wetland Herbaceous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xeric Native Grass	0.0	0.0	1.3	0.0	3.8	1.4	1.1	1.0	0.3	0.5
Mesic Herbaceous	0.2	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.1	0.2
Bare	4.5	5.2	5.4	4.3	2.5	2.2	5.5	3.8	10.7	9.0
Water	10.8	59.1	22.1	13.6	26.5	18.5	39.5	28.3	48.2	40.0
Transportation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Recreational/Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.5
Bottomland	1.1	25.3	1.3	0.5	1.3	6.5	1.9	2.3	1.6	2.0
Total Percent	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Summary of cover types by reach (11-20), shown in percent of total reach cover. Refer to Tables 1 and 2 in main document for reach codes and detailed cover type descriptions. BB=Big Bend, NB=Negro Bill, MV=Moab Valley, GB=Gold Bar, P=Potash, UMC=Upper Meander Canyon, CMC=Central Meander Canyon, LMC=Lower Meander Canyon, CG=Colorado-Green River, CC=Cataract Canyon

Cover Type	**Reach Codes and Percent of Reach Area**									
	11 BB	**12 NB**	**13 MV**	**14 GB**	**15 P**	**16 UMC**	**17 CMC**	**18 LMC**	**19 CG**	**20 CC**
Tamarisk	11.4	9.3	10.6	14.8	23.8	22.3	19.1	6.5	6.9	8.5
Coyote Willow	8.8	8.3	3.5	9.0	7.2	10.0	8.1	4.4	8.2	3.5
NM Privet (Desert Olive)	0.1	0.3	0.0	3.2	1.2	3.4	5.8	2.2	1.0	0.8
Sumac	1.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.2
Seepweed	0.0	0.0	0.0	0.5	0.4	0.1	1.9	0.7	0.0	0.0
Native Xeric Shrub	8.0	3.9	1.2	3.1	7.0	6.6	9.2	9.1	14.9	3.6
Cottonwood	1.2	1.3	7.7	3.1	0.1	0.3	0.4	0.0	0.2	0.5
Box Elder	0.0	0.0	0.0	0.0	0.0	0.1	0.3	3.1	1.0	0.0
Gambel Oak	5.0	3.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Goodding's Willow	0.0	0.4	2.4	0.3	0.3	0.0	0.3	0.0	1.3	0.0
Hackberry	0.1	0.0	0.0	0.3	0.0	0.0	0.1	0.4	0.4	3.3
Non-native Trees	0.5	0.3	3.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Knapweed	1.9	2.1	2.4	0.4	0.9	2.0	0.6	0.2	0.1	0.1
Non-native Herbaceous	1.6	8.7	24.4	4.5	3.9	0.5	0.3	0.0	7.0	0.4
Wetland Herbaceous	0.0	0.0	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xeric Native Grass	0.1	0.0	1.5	0.2	0.2	0.2	0.1	0.2	0.0	0.0
Mesic Herbaceous	0.0	0.0	0.8	0.1	0.2	0.0	0.0	0.0	0.0	0.0
Bare	5.1	2.5	4.5	4.8	6.6	4.2	6.7	4.7	7.1	19.8
Water	50.3	50.8	13.2	45.8	43.1	45.2	42.8	63.5	48.9	51.1
Transportation	0.2	0.6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Recreational/Residential	0.8	1.4	0.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Bottomland	3.9	7.3	8.3	7.7	4.9	4.9	4.1	5.0	2.9	8.1
Total Percent	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Summary of cover types for project study area reaches 1-10, shown in number of hectares. See Table 2 in main document for reach codes and detailed cover type descriptions. RWW=Ruby Westwater, WWC=Westwater Canyon, WWCL=Westwater-Cisco Landing, CL=Cisco Landing, CWDG=Cisco Wash-Dry Gulch, MGB=McGraw Bottom, DMGB=Dolores-McGraw Bottom, DB=Dewey Bridge, D=Dewey, PV=Professor Valley

Cover Type	**Reach Codes and Hectares of Each Cover Type**									
	1 RWW	**2 WWC**	**3 WWCL**	**4 CL**	**5 CWDG**	**6 MGB**	**7 DMGB**	**8 DB**	**9 D**	**10 PV**
Tamarisk	176.7	5.4	29.2	79.8	88.7	53.1	10.6	10.3	18.3	98.6
Coyote Willow	45.1	7.8	9.5	21.4	28.0	17.4	9.4	9.9	15.8	20.2
NM Privet (Desert Olive)	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0
Sumac	7.1	0.0	13.6	2.8	14.7	6.8	3.5	3.9	3.8	6.9
Seepweed	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Native Xeric Shrub	171.0	0.1	33.2	34.2	23.1	65.8	5.2	9.7	7.8	28.7
Cottonwood	108.4	0.0	4.6	62.5	45.6	32.1	4.1	7.3	0.0	8.8
Box Elder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0
Gambel Oak	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Goodding's Willow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hackberry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Non-native Trees	0.7	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.0	0.0
Knapweed	72.4	0.0	12.9	18.9	4.1	16.0	3.7	9.0	1.9	4.6
Non Native Herbaceous	513.5	0.2	56.4	127.6	10.0	29.0	2.8	50.3	4.9	4.9
Wetland Herbaceous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xeric Native Grass	0.0	0.0	2.9	0.0	12.2	4.2	0.8	1.6	0.4	1.8
Mesic Herbaceous	2.1	0.0	0.0	1.1	0.3	0.0	0.0	0.0	0.1	0.9
Bare	59.5	6.8	12.4	18.4	8.2	6.9	4.1	6.0	14.6	32.6
Water	142.2	77.0	50.5	57.9	86.1	57.4	29.7	44.9	66.0	144.7
Transportation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Recreational/ Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	1.9
Bottomland	14.2	33.0	3.0	2.0	4.1	20.1	1.4	3.7	2.2	7.3
Grand Total	**1312.9**	**130.4**	**228.1**	**426.6**	**325.6**	**310.4**	**75.2**	**158.8**	**136.8**	**362.0**

Summary of cover types for project study area reaches 11-20, shown in number of hectares. See Tables 1 and 2 for reach codes and detailed cover type descriptions. BB=Big Bend, NB=Negro Bill, MV=Moab Valley, GB=Gold Bar, P=Potash, UMC=Upper Meander Canyon, CMC=Central Meander Canyon, LMC=Lower Meander Canyon, CG=Colorado-Green River, CC=Cataract Canyon

Cover Type	Reach Codes and Hectares of Each Cover Type										
	11 BB	12 NB	13 MV	14 GB	15 P	16 UMC	17 CMC	18 LMC	19 CG	20 CC	Reach Total
Tamarisk	36.9	12.5	66.2	90.4	83.9	80.5	227.9	21.7	12.0	23.2	1225.8
Coyote Willow	28.5	11.1	21.7	55.1	25.5	36.0	96.8	14.8	14.3	9.6	497.8
NM Privet (Desert Olive)	0.3	0.4	0.1	19.6	4.4	12.3	69.6	7.4	1.8	2.2	118.2
Sumac	3.2	0.0	0.0	0.0	0.2	0.0	0.1	0.1	0.3	0.5	67.5
Seepweed	0.0	0.0	0.0	2.9	1.2	0.5	23.1	2.2	0.0	0.0	31.0
Native Xeric Shrub	25.8	5.2	7.7	19.1	24.6	24.0	110.2	30.5	25.8	9.7	661.2
Cottonwood	3.9	1.7	47.9	19.0	0.3	1.0	5.4		0.3	1.4	354.4
Box Elder	0.0	0.0	0.0	0.2	0.0	0.2	3.4	10.5	1.8	0.0	17.1
Gambel Oak	16.1	4.0	0.0	4.1	0.0	0.0	0.2	0.0	0.0	0.0	24.4
Goodding's Willow	0.0	0.6	15.1	1.6	1.2	0.2	3.5	0.0	2.3	0.1	24.5
Hackberry	0.3	0.0	0.0	1.9	0.0	0.0	1.4	1.4	0.7	9.0	14.8
Non-native Trees	1.5	0.4	23.9	4.6	0.0	0.0	0.0	0.0	0.0	0.0	32.1
Knapweed	6.3	2.8	14.8	2.3	3.3	7.3	6.7	0.7	0.1	0.3	188.1
Non-Native Herbaceous	5.0	11.6	152.0	27.9	13.7	1.8	4.1	0.0	12.1	1.2	1029.3
Wetland Herbaceous	0.0	0.0	91.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	91.5
Xeric Native Grass	0.2	0.1	9.1	1.2	0.7	0.7	1.7	0.8	0.0	0.0	38.5
Mesic Herbaceous	0.0	0.0	4.9	0.4	0.8	0.0	0.3	0.0	0.0	0.0	11.0
Bare	16.4	3.3	28.2	29.4	23.2	15.3	79.8	15.8	12.2	54.1	447.3
Water	162.2	68.2	81.9	280.7	152.1	163.2	512.4	213.1	84.9	139.3	2614.4
Transportation	0.5	0.8	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	2.7
Recreational/ Residential	2.5	1.8	4.4	4.6	0.1	0.0	0.0	0.0	0.0	0.0	16.8
Bottomland	12.6	9.8	51.8	47.0	17.3	17.8	49.5	16.8	5.1	22.1	340.9
Grand Total	**322.4**	**134.4**	**621.8**	**612.3**	**352.7**	**360.9**	**1196.0**	**335.8**	**173.6**	**272.7**	**7849.3**

Appendix G: Habitat Model Results

Habitat quality for each reach and model shown in hectares. RWW=Ruby Westwater, WWC=Westwater Canyon, WWCL=Westwater-Cisco Landing, CL=Cisco Landing, CWDG= Cisco Wash-Dry Gulch, MGB=McGraw Bottom, DMGB=Dolores-McGraw Bottom, DB=Dewey Bridge, D=Dewey, PV=Professor Valley

		Habitat Suitability Results for Reaches (in hectares)									
Habitat Model	Quality	1 RWW	2 WWC	3 WWCL	4 CL	5 CWDG	6 MGB	7 DMGB	8 DB	9 D	10 PV
Riparian Overstory	No Hab	559.4	47.2	81.1	107.1	18.1	53.5	9.4	31.6	22.3	72.7
	Low	152.2	5.6	52.2	28.8	29.4	25.4	14.6	17.0	38.7	81.5
	Mod	390.5	0.5	43.8	207.8	164.4	127.4	18.7	63.6	9.1	58.7
	High	68.9	0.0	0.5	24.9	27.5	37.6	2.7	1.9	0.8	4.5
Riparian Overstory Tamarisk Penalty	No Hab	665.7	52.9	119.6	124.1	44.6	72.5	23.5	44.2	57.6	149.7
	Low	139.8	0.5	31.6	80.0	58.1	46.7	4.0	25.4	8.5	36.0
	Mod	361.0	0.0	26.5	164.0	136.7	124.7	17.2	44.1	4.7	31.3
	High	4.4	0.0	0.0	0.5	0.0	0.1	0.8	0.4	0.0	0.3
Riparian Understory	No Hab	578.9	0.3	73.0	141.8	6.4	67.1	4.2	48.7	1.1	11.6
	Low	412.5	12.3	68.6	133.6	134.1	122.3	16.6	40.6	32.3	116.6
	Mod	153.3	19.5	29.7	79.3	77.0	44.8	20.2	20.5	30.3	81.8
	High	25.8	1.7	5.8	13.6	22.0	8.1	4.6	3.7	7.1	6.3
Riparian Understory Tamarisk Penalty	No Hab	610.3	0.4	77.9	153.8	11.8	78.7	4.3	48.7	1.2	17.2
	Low	475.0	19.4	78.8	172.7	162.3	131.0	24.2	49.3	48.7	174.5
	Mod	83.9	14.0	20.4	41.4	63.4	32.2	16.1	13.8	20.4	24.3
	High	1.1	0.0	0.0	0.4	2.0	0.4	0.9	1.5	0.6	0.3
Open Land Species	No Hab	79.5	0.2	9.0	50.0	75.2	51.9	5.8	7.2	7.1	28.1
	Low	373.2	19.7	66.8	111.5	100.6	108.4	22.6	52.6	37.2	111.6
	Mod	146.7	0.0	25.5	44.3	13.4	25.5	3.0	14.3	0.9	5.1
	High	420.6	0.0	51.9	101.3	2.3	36.3	0.0	27.8	0.0	0.9
General Diversity	Low	727.3	83.6	99.0	178.1	68.1	84.8	4.9	46.9	16.8	74.5
	Mod	526.7	42.1	113.4	227.1	224.4	178.0	57.0	79.5	102.5	247.0
	High	58.7	0.2	15.6	21.4	33.0	36.8	13.2	32.4	17.5	40.3
Bat Feeding	Low	645.3	0.3	86.2	159.7	31.3	92.4	2.1	35.3	0.2	14.2
	Mod	467.0	127.8	121.3	209.9	214.6	152.2	57.5	87.7	122.5	308.4
	High	200.3	2.2	20.7	57.0	79.6	52.8	15.5	35.8	14.1	39.4
Bat Watering	Low	82.2	8.4	12.8	41.9	30.3	12.8	9.1	6.0	10.2	37.9
	Mod	193.5	82.7	60.4	75.3	101.6	68.2	34.3	48.3	81.0	176.6
	High	16.1	0.0	0.7	1.8	1.9	1.2	0.3	1.8	0.3	0.4
Rocky Fringe Snakes	Low	1394.9	15.9	130.1	320.5	147.1	180.5	26.5	84.6	26.6	119.7
	Mod	84.6	14.2	33.3	35.4	62.3	38.3	13.1	21.9	26.7	66.5
	High	31.5	1.8	13.0	12.0	28.0	15.3	5.4	5.7	17.0	27.3

Habitat quality for each reach and model shown in hectares. BB=Big Bend, NB=Negro Bill, MV=Moab Valley, GB=Gold Bar, P=Potash, UMC=Upper Meander Canyon, CMC=Central Meander Canyon, LMC=Lower Meander Canyon, CG=Colorado-Green River, CC=Cataract Canyon

		Habitat Suitability Results for Reaches (in hectares)										
Habitat Model	**Quality**	**11 BB**	**12 NB**	**13 MV**	**14 GB**	**15 P**	**16 UMC**	**17 CMC**	**18 LMC**	**19 CG**	**20 CC**	**Row Total**
Riparian Overstory	**No Hab**	24.7	17.7	224.1	111.6	139.7	127.9	359.1	26.7	33.4	43.1	2110.6
	Low	35.6	15.5	81.2	92.3	49.3	49.1	198.1	35.1	24.6	47.8	1074.0
	Mod	89.5	31.0	210.0	121.8	12.5	19.9	119.9	51.6	27.6	41.8	1810.1
	High	10.3	2.1	0.0	5.8	0.0	0.0	2.4	9.0	2.7	0.5	201.9
Riparian Overstory Tamarisk Penalty	**No Hab**	55.8	29.4	243.7	190.1	187.6	174.5	542.5	50.2	49.3	71.2	2948.8
	Low	27.7	17.3	113.9	100.7	8.9	19.4	97.2	32.3	20.4	48.7	917.1
	Mod	75.4	18.4	157.5	39.8	5.1	3.0	40.0	38.4	18.6	13.2	1319.7
	High	1.1	1.1	0.0	0.8	0.0	0.0	0.0	1.4	0.0	0.0	11.0
Riparian Understory	**No Hab**	10.4	4.8	112.3	25.5	22.2	3.0	40.8	0.8	17.6	3.8	1174.0
	Low	87.3	27.2	222.7	140.7	86.6	62.9	293.0	67.6	43.8	97.7	2219.3
	Mod	57.9	26.9	154.4	130.9	68.3	85.7	272.5	43.9	26.0	29.7	1452.4
	High	4.2	5.3	23.7	31.9	22.7	41.1	64.2	6.1	0.8	0.4	299.0
Riparian Understory Tamarisk Penalty	**No Hab**	12.4	4.9	125.1	28.2	24.4	3.1	45.6	0.8	17.8	4.4	1270.9
	Low	118.2	38.9	243.0	204.3	127.5	113.5	458.9	93.4	59.1	116.0	2908.8
	Mod	29.0	19.7	142.6	90.1	47.0	68.8	150.9	21.7	11.1	11.2	922.1
	High	0.1	0.6	2.5	6.3	0.9	7.3	15.2	2.4	0.2	0.0	42.8
Open Land Species	**No Hab**	9.6	8.4	37.3	78.5	34.4	56.5	233.2	25.2	5.4	6.3	808.8
	Low	108.5	40.5	160.0	145.7	89.6	70.2	269.4	49.5	35.0	46.0	2018.4
	Mod	1.6	0.6	49.3	7.3	9.8	0.1	6.1	1.2	7.7	0.6	362.9
	High	0.2	0.0	40.1	6.3	10.3		4.2	0.0	13.8	0.0	716.1
General Diversity	**Low**	39.2	37.1	319.2	202.0	172.3	133.9	441.5	142.1	47.3	64.6	2983.1
	Mod	196.7	81.6	248.2	373.3	173.9	212.6	702.2	161.5	100.1	192.7	4240.5
	High	86.4	15.7	10.2	35.8	5.6	10.9	45.8	31.0	25.8	14.3	550.6
Bat Feeding	**Low**	6.9	3.4	94.8	37.0	42.9	14.9	114.6	5.1	21.0	2.4	1409.9
	Mod	282.0	103.6	127.2	469.2	237.3	258.2	950.2	308.4	142.7	258.7	5006.4
	High	33.5	27.4	357.2	104.8	71.7	86.0	125.4	21.7	9.3	11.2	1365.7
Bat Watering	**Low**	25.4	6.7	19.2	37.9	22.1	19.2	66.1	23.1	15.9	19.3	506.7
	Mod	175.6	72.5	133.2	325.9	175.7	200.8	593.6	230.0	95.4	191.6	3116.3
	High	0.2	5.2	150.6	8.6	7.7	7.9	8.8	0.0	0.1	0.1	213.7
Rocky Fringe Snakes	**Low**	44.9	26.6	431.8	166.8	117.1	110.3	332.1	26.0	37.9	60.9	3800.8
	Mod	74.8	21.4	35.6	102.2	59.2	59.6	239.6	56.3	32.3	39.4	1116.8
	High	34.0	11.8	8.0	34.4	15.0	16.6	82.7	32.0	15.4	20.0	426.9

Appendix H: Supplemental Model Results

Results of all habitat models for study reaches 1-10. Habitat quality for each reach shown in hectares. RWW=Ruby Westwater, WWC=Westwater Canyon, WWCL=Westwater-Cisco Landing, CL=Cisco Landing, CWDG= Cisco Wash-Dry Gulch, MGB=McGraw Bottom, DMGB=Dolores-McGraw Bottom, DB=Dewey Bridge, D=Dewey, PV=Professor Valley

		Supplemental Model Results for Reaches (in hectares)									
Model Results (Ha)	Quality	1 RWW	2 WWC	3 WWCL	4 CL	5 CWDG	6 MGB	7 DMGB	8 DB	9 D	10 PV
Recovery Potential	Low	762.6	36.7	102.2	229.5	97.6	116.4	17.0	76.2	24.7	104.7
	Moderate	345.2	9.2	65.2	106.2	114.7	123.5	21.6	32.3	38.1	95.5
	High	63.2	7.4	10.2	32.9	27.1	13.2	6.9	5.6	8.0	17.1
Relative Cost of Restoration	Low	93.0	6.2	15.2	20.0	36.0	42.5	8.9	15.5	22.5	56.7
	Moderate	755.5	14.2	132.9	241.2	108.5	125.2	30.5	83.9	36.6	96.3
	High	308.0	0.4	26.4	105.4	90.7	65.1	4.7	10.9	9.4	56.8
Natural Fire Risk	Low	828.0	43.1	128.6	199.0	71.0	140.7	21.4	83.5	38.9	89.0
	Moderate	271.2	10.0	40.8	112.6	127.5	90.1	23.6	30.2	31.6	107.2
	High	71.8	0.3	8.2	57.1	40.9	22.3	0.5	0.3	0.3	21.1
All Fire Risk	Low	798.9	47.0	122.9	191.0	74.3	144.9	31.6	81.2	43.3	138.8
	Moderate	167.6	2.9	22.6	39.4	39.1	35.6	8.4	15.2	18.4	25.6
	High	204.5	3.5	32.1	138.3	126.1	72.5	5.6	17.6	9.1	52.9

Results of all habitat models for study reaches 11-20. Habitat quality for each reach shown in hectares. BB=Big Bend, NB=Negro Bill, MV=Moab Valley, GB=Gold Bar, P=Potash, UMC=Upper Meander Canyon, CMC=Central Meander Canyon, LMC=Lower Meander Canyon, CG=Colorado-Green River, CC=Cataract Canyon

		Supplemental Model Results for Reaches (in hectares)										
Model Results (Ha)	Quality	11 BB	12 NB	13 MV	14 GB	15 P	16 UMC	17 CMC	18 LMC	19 CG	20 CC	Total
Recovery Potential	Low	62.5	38.0	300.1	164.9	123.3	94.6	269.7	31.9	24.3	39.9	2717
	Moderate	76.7	22.2	105.6	130.0	60.3	83.3	356.8	74.7	53.8	83.9	1999
	High	20.9	6.0	145.3	36.8	18.2	19.8	57.3	16.1	10.6	9.5	532
Relative Cost of Restoration	Low	65.4	15.5	65.1	98.9	45.8	42.5	159.2	41.0	20.2	59.4	930
	Moderate	63.6	29.5	275.6	140.6	89.9	91.8	348.9	58.7	61.0	45.0	2830
	High	18.2	11.3	158.4	45.0	48.6	45.6	125.9	6.3	2.4	6.8	1146
Natural Fire Risk	Low	86.9	35.0	335.6	175.3	96.0	90.6	361.5	73.8	59.8	89.9	3048
	Moderate	69.1	28.9	212.3	142.3	104.0	106.1	311.3	40.1	24.2	36.2	1919
	High	4.2	2.3	3.2	14.2	1.8	1.0	10.9	8.8	4.8	7.2	281
All Fire Risk	Low	117.3	43.6	305.9	210.6	102.1	171.6	564.3	105.9	66.5	99.0	3461
	Moderate	14.4	11.8	113.9	39.4	35.5	15.2	80.0	12.6	14.1	15.3	727
	High	28.4	10.9	131.2	81.7	64.2	10.9	39.5	4.3	8.1	19.0	1060

COLORADO MESA UNIVERSITY
WATER CENTER

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