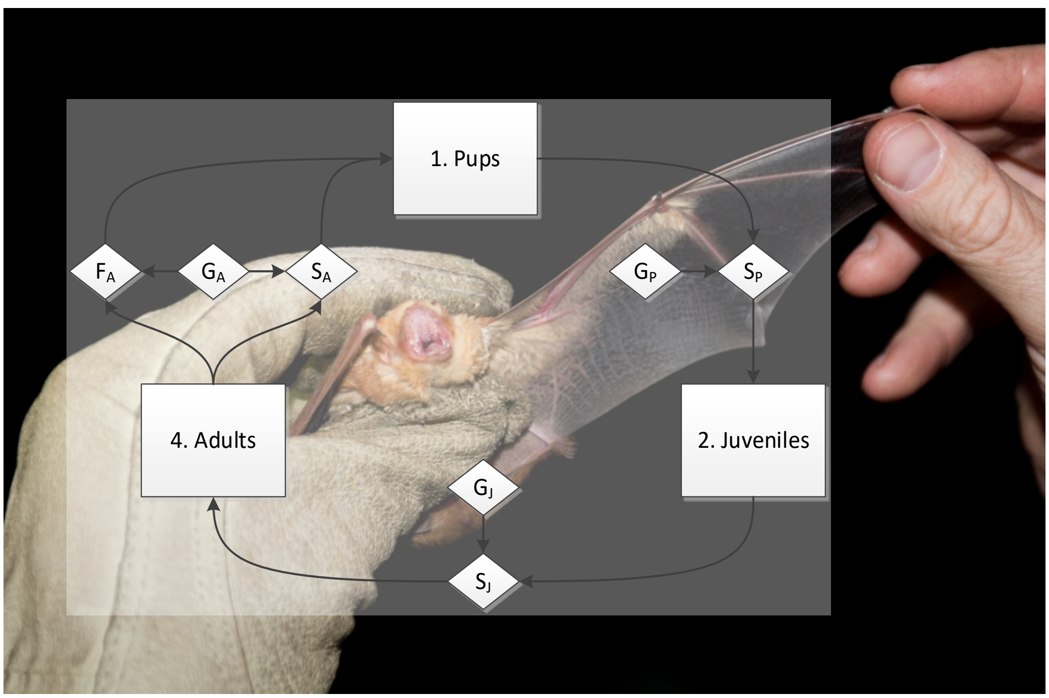
Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

2019 Updates to Western Red Bat (*Lasiurus blossevillii*) (WRBA) Basic Conceptual Ecological Model for the Lower Colorado River



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Work conducted under LCR MSCP Work Task G6

March 2020

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Lower Colorado River
Multi-Species Conservation Program

2019 Updates to Western Red Bat (*Lasiurus blossevillii*) (WRBA) Basic Conceptual Ecological Model for the Lower Colorado River

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ACRONYMS AND ABBREVIATIONS

AZGFD	Arizona Game and Fish Department
CAP	critical activity or process
CEM	conceptual ecological model
CF	controlling factor
cm	centimeter(s)
CVCA	Cibola Valley Conservation Area
DBH	diameter at breast height
HCA	habitat conservation area
HCP	Habitat Conservation Plan
HE	habitat element
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LSO	life-stage outcome
m	meter(s)
PVER	Palo Verde Ecological Reserve
Reclamation	Bureau of Reclamation
WRBA	western red bat (*Lasiurus blossevillii* also known as *Dasypterus blossevillii*)

Symbols

>	greater than
<	less than
%	percent
±	plus or minus

Definitions

For the purposes of this document, vegetation layers are defined as follows:

Canopy – The canopy is the uppermost strata within a plant community. The canopy is exposed to the sun and captures the majority of its radiant energy.

Understory – The understory comprises plant life growing beneath the canopy without penetrating it to any extent. The understory exists in the shade of the canopy and usually has lower light and higher humidity levels. The understory includes subcanopy trees and the shrub and herbaceous layers.

Shrub layer – The shrub layer is comprised of woody plants between 0.5 and 2.0 meters in height.

Herbaceous layer – The herbaceous layer is most commonly defined as the forest stratum composed of all vascular species that are 0.5 meter or less in height.

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Foreword

This report provides an update to the original conceptual ecological model (CEM) prepared for the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) for the Western red bat (*Lasiurus blossevillii*) (WRBA) (Marty and Unnasch 2015). This update incorporates information reported in publications and presentations at professional meetings since the completion of the original WRBA conceptual ecological model, information from the professional experiences of LCR MSCP staff and other experts, and newer information on western red bat ecology more generally. An updated version of the CEM workbook incorporates the new information. This report constitutes an appendix to the original CEM. The full CEM report, including its life-stage diagrams, has not been updated. The authors of the present report updated the WRBA conceptual ecological model alongside the CEM for the western yellow bat (*Lasiurus xanthinus*) (Braun and Unnasch 2020).

The structure of the present report follows the structure of the original CEM report. Specifically, it presents and documents updates to chapters 1–6. It does not include updates to the original Executive Summary or chapters 7–8 because these were not updated.

The updates reported in the present report change the WRBA conceptual ecological model in several key respects. Six sets of changes are particularly noteworthy: (1) This update adds pup growth, juvenile growth, and adult growth as life-stage outcomes. (2) This update adds breeding, competition, and inter-site movement as new critical biological activities and processes. (3) This update eliminates genetic diversity and infectious agents as a habitat element, replacing it with simply infectious agents. (4) This update combines three habitat elements—canopy cover, patch size, and riparian tree species composition—into a more inclusive habitat element, tree community. (5) This update adds three other new habitat elements—chemical contaminants, fire regime, and monitoring, capture, handling. (6) This update adds two new controlling factors—conservation monitoring and research programs, and surrounding land use—and incorporates information on the original factors, grazing, pesticide application, and tree thinning, into the latter. These major sets of changes had cascading effects on the entire CEM.

The present report also provides a list of all literature cited in the updates to chapters 1–6 and in the updated CEM workbook. In addition, the present report provides a list of all changes made to the names of the CEM components in order to standardize terminology across all CEMs.

The report both explicitly and implicitly identifies possible new research and monitoring questions concerning gaps in knowledge that may bear on adaptive management of WRBA. These questions may or may not reflect the current or future goals of the LCR MCSP decision making and are in no way meant as a call for the Bureau of Reclamation to undertake research to fill the identified knowledge gaps.

Updates to Chapter 1 – Introduction

The information in the initial section of chapter 1 is updated as follows:

This update incorporates information on western red bat (*Lasiurus blossevillii* also known as *Dasypterus blossevillii*)[1] (WRBA) ecology and its status specifically along the Lower Colorado River Valley largely from reports that have appeared since completion of the original WRBA conceptual ecological model in 2015 (Marty and Unnasch 2015), including Berry et al. (2017), Broderick (2016), Calvert (2016a, 2016b), Hill (2018), LCR MSCP (2016), Maturango Museum and Brown-Berry Biological Consulting (2018), Mixan and Diamond (2016, 2017a, 2017b, 2018a, 2018b, 2019a, 2019b), Mixan et al. (2015), and Parametrix, Inc., and GeoSystems Analysis, Inc. (2015). This update also addresses work by Vizcarra (2011) (also see Vizcarra and Chambers 2011), not addressed in the original CEM, and incorporates information from presentations at the annual Colorado River Terrestrial and Riparian meetings in 2015–17,[2] including Broderick (2015), Brown (2015), Calvert (2015, 2016c, 2017), and Mixan (2015, 2016, 2017). Calvert (2017) summarizes the history bat research and monitoring along the Lower Colorado River Valley for the LCR MSCP.

This update also incorporates information from reports since 2015 on WRBA more generally in Arizona and adjacent portions of California and New Mexico, including Andersen and Geluso (2018), Arizona Game and Fish Department [AZGFD] (2019), Bazelman (2016), Fratanduono (2017), NatureServe (2019), Steel et al. (unpublished), and Tietje et al. (2015). Bunkley et al. (2015), Mikula (2015), Mikula et al. (2016), and Rodhouse et al. (2016) provide useful information on bat ecology in general; Faria et al. (2013), Kuzmin et al. (2012), and Stuchin et al. (2018) provide information on rabies transmission and effects in WRBA; Wonkka et al. (2018) provide useful new information on the effects of wildfire on cottonwood (*Populus* spp.) riparian forests.

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[1] Baird et al. (2015, 2017) proposed reclassifying all yellow bat species from the genus Lasiurus to Dasypterus. The American Society of Mammalogists (2019) now recognizes the species as *Dasypterus blossevillii*; however, species accounts (AZGFD 2011; LCR MSCP 2016; Morgan et al. 2019; NatureServe 2019) and LCR MSCP authorizing documents (Bureau of Reclamation 2004) use the original designation, and the present document follows their practice.

[2] The Colorado River Terrestrial and Riparian annual meetings did not take place in 2018 or 2019 due to temporary closures of the Federal Government.

Western Red Bat Reproductive Ecology

This update expands on the discussion of WRBA reproductive ecology to take note of the generalization summarized by Mikula et al. (2016) that "In general, bats are K-strategists with long life spans and small litter sizes (Kunz and Fenton 2003), and life-history traits directly related to effective avoidance of predation (Speakman 1991a, 1995; Rydell et al. 1996)." As discussed in the updates to chapter 3, "Predation"), the literature on WRBA does not record any activities to drive off, distract, or misdirect predators at roosts or in the air. Anti-predator defenses appear limited to avoidance behaviors and cryptic coloration (Lavender 2014). Reports often note the difficulty of visually distinguishing roosting WRBA from dead leaves (AZGFD 2011; Calvert 2017).

Conceptual Ecological Model Purposes

This update does not include any changes to this section of chapter 1; however, when the CEMs are fully updated, chapter 1 should be revised to indicate that the CEM methodology followed here is a crucial foundation for carrying out effects analyses as described by Murphy and Weiland (2011, 2014) and illustrated by Jacobson et al. (2016).

Conceptual Ecological Model Structure

No change.

Updates to Chapter 2 – WRBA Life-Stage Model

PROPOSED WRBA LIFE STAGES AND LIFE-STAGE OUTCOMES

This update standardizes the names of the WRBA life stages and life-stages outcomes and adds three new outcomes focused on pup, juvenile, and adult growth. Table 1 and figure 1 are updated accordingly. The updated version of figure 1 also appears as the cover illustration for this report.

Table 1.—(Revision of original table 1) WRBA life stages and life-stage outcomes in the LCR ecosystem

Life stage	Life-stage outcome(s)
1. Pups	• Pup survival • Pup growth
2. Juveniles	• Juvenile survival • Juvenile growth
4. Adults	• Adult survival • Adult growth • Adult fertility

Specifically, this update drops the adjective, breeding, from the name of the WRBA adult life stage. The adult life stage begins with the onset of sexual maturity, and no reports suggest that WRBA cease sexual activity at some later stage of life; however, observations of the very closely related eastern red bat (*Lasiurus borealis*) suggest that not all WRBA adults may participate in reproduction in any single year. Reports on WRBA in the Lower Colorado River Valley routinely distinguish reproducing from non-reproducing females caught at the same places and times (Calvert 2009, 2016a, 2016b; Hill 2018; LCR MSCP 2016). Carter and Menzel (2007) found that, among the closely related eastern red bat, reproductive females roost in warmer locations than do non-reproductive females and male eastern red bats. Consequently, it is not appropriate to refer to all adult WRBA as breeding adults. Instead, this update adds a new critical biological activity, breeding, to address the differential year-to-year participation of WRBA adult females in reproduction.

This update also adds the name of the associated life stage to the name of each life-stage outcome, for consistency with the other LCR MSCP conceptual ecological model updates, as shown in table 1 and figure 1. Further, this update changes the name of the life-stage outcome for adult reproduction to adult fertility, again for consistency with the other updates.

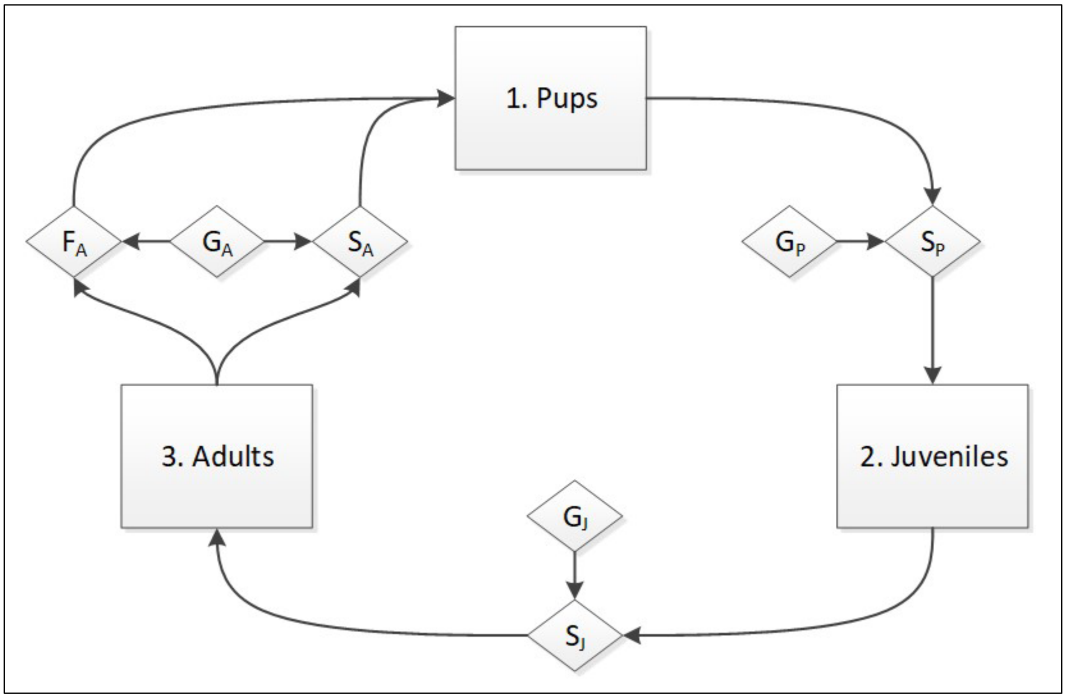

Figure 1.—(Revision of original figure 1) Proposed WRBA life history model. Squares indicate life stages, and diamonds indicate life-stage outcomes. Life-stage outcomes are rates, as follows: S_P = survival of pups; G_P = growth of pups; S_J = survival of juveniles; G_J = growth of juveniles; S_A = annual survival of adults; F_A = fertility of adults; G_A = growth of adults.

Finally, this update adds life-stage outcomes for growth in all three life stages. Growth here includes both (a) morphological and physiological development and (b) the maintenance of body mass and condition (health) in the face of the stresses of daily life and fluctuations in food intake. Pup growth includes morphological and physiological maintenance and development to fledging; juvenile growth includes morphological and physiological maintenance and development to sexual maturity; and adult growth includes the maintenance and continued development of body mass as well as support of gestation and subsequent lactation in females. This update adds these outcomes to the CEM to capture the ways in which (a) various types of stress potentially can affect condition and growth in all three life stages; (b) competition with siblings and the quality of maternal care potentially can affect pup growth; (c) competition and foraging success potentially can affect juvenile growth; (d) competition, foraging success, and gestating and caring for pups potentially can affect adult growth; and (e) growth, in turn, can affect survival in all three WRBA life stages.

The authors of this update also considered including an additional life-stage outcome for WRBA adults to represent the possible dynamics of WRBA migration; however, as discussed in detail below (see updates to chapter 3, "Inter-Site Movement," and "Roosting"), the WRBA detected along the Lower Colorado

River Valley since 2010 do not appear to engage in large-scale seasonal movements (mass migration) in or out of the valley. The LCR MSCP conceptual ecological model for WRBA therefore does not need to include a life-stage outcome for adult migration.[3] However, WRBA do exhibit within-season, season-to-season, and year-to-year shifts in where they occur within the Lower Colorado River Valley (Calvert 2017; Mixan and Diamond 2019b), indicating a need for the CEM to include a critical biological activity category for inter-site movement.

This update also expands on the discussion of the individual WRBA life stages as follows:

Pups

This update integrates information on the importance of thermal regulation in WRBA pups that the original WRBA conceptual ecological model (Marty and Unnasch 2015) presented separately. Chapter 2 in the original CEM noted that lasiurines are thought to develop more slowly than the young of crevice-roosting bat species because their foliage roosts do not offer as much thermal protection as bark or tree hollows, leading to a greater use of torpor (Carter and Menzel 2007). Further, in chapter 3 under the topic of thermal stress, the original WRBA conceptual ecological model noted that bat pups in general are particularly susceptible to temperature extremes. Jones et al. (2009) document the effects of extreme cold and heat on various bat species, including a massive die-off of bat pups in Australia in 2006. Among the closely related eastern red bat, reproductive females have been found to roost in warmer locations than do non-reproductive females and males presumably to lower their thermoregulatory costs while pregnant and caring for their pups (Carter and Menzel 2007). Finally, the spreadsheet for the original WRBA conceptual ecological model (Marty and Unnasch 2015) takes note of reports that red bat pups (eastern and western species not distinguished) initially completely rely on the mother to maintain their body temperature. The pups hang from the mother's fur with their teeth, thumb claws, and hind feet (Shump and Shump 1982).

As noted above, this update explicitly recognizes the importance of morphological and physiological growth—maturation—in the pup life stage. Slower growth necessarily results in a smaller body size at fledging and/or a longer time between birth and fledging.

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[3] On the other hand, the CEM for WRBA dynamics at a regional scale might need to include such seasonal migration as a life-stage outcome as suggested by general species accounts such as AZGFD (2011) and NatureServe (2019).

Juveniles

This update does not incorporate any new information about the biology of the juvenile life stage, except to explicitly recognize the importance of morphological and physiological growth in this life stage, as well. Slower growth necessarily results in a smaller body size and/or a longer time between fledging and sexual maturity.

Adults

This update not only explicitly recognizes the importance of morphological and physiological growth in this life stage, but also incorporates new information about the biology of the adult life stage in general or in the Lower Colorado River Valley in particular, as follows (see updates to chapter 3 for details):

- The original WRBA conceptual ecological model (Marty and Unnasch 2015) did not discuss the timing of nighttime activity among WRBA adults, which affects monitoring practices and, possibly, vulnerability to predation. The AZGFD (2011) and LCR MSCP (2016) state that WRBA foraging begins 1 to 2 hours after dark; however, comparisons of mist-net captures versus acoustic monitoring detections (Calvert 2013) have found that WRBA in the Lower Colorado River Valley instead begin foraging immediately after dark. This finding is consistent with that of Pierson et al. (2006), who observed WRBA foraging within 15 minutes after dark. Nighttime mist netting for bats in the Lower Colorado River Valley therefore routinely begins at least a half-hour after sunset to allow WRBA and other bat species time to forage before being subjected to the stresses of capture. Acoustic monitoring along the Lower Colorado River Valley, conversely, begins a half-hour before sunset (Hill 2018). Information on the eastern red bat provides a useful comparison: Mcnamara (2019) found that eastern red bats in western Kentucky also begin foraging immediately after dark. Acoustic monitoring for his study in fact detected roughly constant foraging activity among eastern red bats from sunset to sunrise. Further, this approximate constancy of nighttime activity did not change in response to experimental broadcasts of recordings of calls from great horned owls (*Bubo virginianus*) or barred owls (*Strix varia*), known key predators of bats in that region.

- Acoustic detections and mist-net captures indicate that WRBA have become significantly more widely established and numerous along the Lower Colorado River Valley since approximately 2010 (Broderick 2012a, 2012b; Calvert 2017; Mixan and Diamond 2019a, 2019b). This geographic and demographic expansion has occurred concurrently with the maturation of large stands of Fremont cottonwood (*Populus fremontii*) mixed with Goodding's willow (*Salix gooddingii)* and coyote willow (*Salix exigua*) planted at habitat conservation areas, particularly the Beal Lake Conservation Area, the Cibola National Wildlife Refuge Unit #1 Conservation Area, the Cibola Valley Conservation Area (CVCA), and the Palo Verde Ecological Reserve (PVER). The woodland patches at these conservation areas have added significantly to the Fremont cottonwood-Goodding's willow (hereafter cottonwood-willow) stands present at other protected areas along the valley, which serve as long-term, system-wide monitoring sites for the LCR MSCP. The published evidence for this expansion has become clear largely since the preparation of the original WRBA conceptual ecological model (Marty and Unnasch 2015). The increased availability and geographic distribution of cottonwood-willow woodlands along the Lower Colorado River Valley is hypothesized to be the driving factor in the geographic and demographic expansion of WRBA occupancy along the valley (Mixan and Diamond 2019b).

- Intensive acoustic monitoring along the Lower Colorado River Valley since fiscal year 2010, both in habitat conservation areas and in established protected areas, has detected WRBA along the valley year round (Broderick 2016; Calvert 2017; Mixan 2015; Mixan and Diamond 2018a, 2018b, 2019a, 2019b; Mixan et al. 2015). Further, this monitoring has produced three types of evidence of possible month-to-month, season-to-season, and year-to-year movements of WRBA adults within the valley: (1) WRBA adult activity and occupancy appear to increase from one month to the next at some sites while concurrently decreasing at others; (2) WRBA adult activity and occupancy similarly appear to increase from one year to the next at some sites while concurrently decreasing at others; and (3) pulses of overnight activity suggest the passage of larger numbers of WRBA than are typically detected at these sites during normal foraging activity (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). However, the monitoring did not include tracking of individual WRBA to evaluate whether specific individual WRBA remained in the valley year round. The data indicate only where and when WRBA are present. Nevertheless, the pattern of year-round WRBA presence, combined with localized inter-annual movement, if confirmed, would be similar to WRBA behavior in California (NatureServe 2019). It is not clear how this pattern fits within the larger pattern across the Southwestern United States as a whole, with WRBA apparently moving seasonally in large numbers over longer distances to overwinter in Mexico (AZGFD 2011; NatureServe 2019). The increased availability and geographic distribution of cottonwood-willow woodlands along the valley may be crucial to the development of year-round presence and localized inter-site movement of WRBA adults within the Lower Colorado River Valley (Mixan and Diamond 2019b). The AZGFD (2011) states, "Cottonwood distribution throughout the range of this species is thought to determine this species ability to complete its annual migration." The same relationship may play out at the local scale as well (Mixan and Diamond 2019b).

- Studies in the Central Valley in California (Pierson et al. 2006) and the Mimbres River Valley in southwestern New Mexico (Andersen and Geluso 2018), together with ongoing studies along the Lower Colorado River Valley (e.g., recently, Calvert 2017; Mixan 2015; Mixan et al. 2015) have refined understanding of WRBA adult affinities for roosting habitat characteristics at the scale of the individual trees selected for roosting, the immediate vicinity of the roosting trees, the overall riparian woodland patch within which the roosting trees occur, and the landscape surrounding these patches. The evidence (see details in updates to chapter 3, "Roosting") indicates the following:

    - WRBA roost predominantly in the tallest, most mature riparian trees available, which in the Lower Colorado River Valley are overwhelmingly Fremont cottonwood; however, as discussed more fully in the updates to chapter 3 (see "Roosting"), they have been observed roosting in other species elsewhere (e.g., in central California and southwestern New Mexico). WRBA in the Lower Colorado River Valley will sometimes also roost in saltcedar (*Tamarix* spp.), mesquite (*Prosopis* spp.), and marsh vegetation but much less often and not in areas with higher densities of mesquite or marsh vegetation.

    - WRBA roost only in living trees with dense, mostly living (< 20% dead) foliage with canopy diameters up to 8 meters (m). Within these trees, they roost at heights averaging around 9 m, within 1.5 m of the outer edge of the canopy, at locations within the canopy that are shaded from above and open below.

    - WRBA may prefer to roost in patches with intermediate densities of woody vegetation: Anderson and Geluso (2018) found that the number of trees within a 0.1-hectare circular plot surrounding individual WRBA roosting trees in southwestern New Mexico, 9.1 ± 1.7, was significantly lower than the number surrounding randomly selected trees in the same patches, 13.1 ± 2.7.

    - WRBA predominantly roost within riparian woodland patches with larger (versus smaller) areas compared to other nearby patches and possibly also patches with greater widths that allow the WRBA to roost at greater distances from patch edges.

- WRBA adults usually are described as roosting solitarily (Andersen and Geluso 2018); however, Andersen and Geluso (2018) and Mixan et al. (2015) report WRBA roosting in clusters in the Mimbres River Valley of southwestern New Mexico and in the Lower Colorado River Valley, respectively. The clusters consist of 2–3 adults in direct contact with one another. Andersen and Geluso (2018) further observed that, "… if bats were observed in clusters, they typically exhibited greater roosting fidelity than solitary individuals." Neither Andersen and Geluso (2018) nor Mixan et al. (2015) discuss possible ecological implications of this behavior, and this update does not suggest any or suggest identifying this behavior as a distinct critical biological activity or process. Future investigations may clarify the ecological implications and importance of the behavior.

Updates to Chapter 3 – Critical Biological Activities and Processes

This update identifies 12 critical biological activities and processes that affect 1 or more WRBA life stages. The original WRBA conceptual ecological model (Marty and Unnasch 2015) identified nine. Table 2 lists the 12 critical biological activities and processes in this update, and their distribution across life stages, and indicates which are new to this update or renamed from the original WRBA conceptual ecological model.

Table 2.—(Revision of original table 2) WRBA critical biological activities and processes and their distribution among life stages
(Xs indicate the critical biological activities or processes that apply to each life stage.)

Life stage ➔ / **Critical biological activity or process 🡻**	**Pups**	**Juveniles**	**Adults**
Breeding (*new*)			X
Chemical stress	X	X	X
Competition (*new*)	X	X	X
Disease	X	X	X
Feeding (*replaces eating*)	X		
Foraging		X	X
Inter-site movement (*new*)			X
Maternal care (*replaces roost attendance*)			X
Mechanical stress	X	X	X
Predation	X	X	X
Roosting (*replaces roost site selection*)		X	X
Thermal stress	X	X	X

BREEDING

This update adds this critical biological activity or process to the WRBA conceptual ecological model to recognize the possibility that some adult females may not participate in reproduction in a given year. Here, the term, breeding, concerns the activities and processes of mating and gestation, but not maternal care, which is its own critical biological activity or process. As noted in the updates to chapter 2, observations of the very closely related eastern red bat suggest that not all WRBA adults participate in reproduction in any given year. Reports on WRBA adults captured in the Lower Colorado River Valley routinely distinguish reproducing from non-reproducing females caught at the same places and times (Calvert 2009, 2016a, 2016b; Hill 2018; LCR MSCP 2016) and also note that WRBA adult non-reproducing females have been captured together with adult males in areas where reproducing females have not (LCR MSCP 2016). Carter and Menzel (2007) similarly found that, among the closely related eastern red bat, reproductive females roost in warmer locations than do non-reproductive females and male eastern red bats; however, the reasons why some females participate in reproductive activities in a given year while others do not remain unstudied.

CHEMICAL STRESS

The definition of this critical biological activity or process remains unchanged except to note that locations with or potentially suitable for WRBA habitat, such as the PVER and CVCA, occur in former agricultural areas or adjacent to presently actively farmed lands. Both conservation areas incorporate former agricultural fields and lie immediately adjacent to farmlands actively in use to produce crops such as alfalfa and cotton. Chemical use on such adjacent fields potentially could result in contamination of WRBA habitat either through wind transport of sprayed chemicals or through chemical leaching into shallow groundwater. Bureau of Reclamation (Reclamation) biologists (R. Wydoski and S. Mark Nelson 2015, personal communications) observed one instance where cottonwoods exhibited damage consistent with herbicide exposure in a LCR MSCP conservation area. Mr. James Knowles (2015, personal communication) reports that farmers along the LCR may apply some pesticides (insecticides, fungicides, bactericides) by aerial spraying, and drift from aerially sprayed pesticides potentially could reach WRBA habitat sites. Cotton farmers may also aerially apply some herbicides to promote faster leaf drop prior to harvesting; however, the literature records no instances in which contaminants from adjacent farmlands are known or suspected to have affected any WRBA habitat sites; nevertheless, the CEM must at least recognize the possibility of such interactions.

COMPETITION

This update adds this critical biological activity or process to the WRBA conceptual ecological model to address an important ecological process that the original CEM did not cover. The process is defined for the WRBA conceptual ecological model as follows:

WRBA pups compete with each other for maternal care, particularly for their mother's milk. The larger the litter, the greater such competition. WRBA juveniles and adults compete for food with each other, other bats, insectivorous birds and other vertebrates, and possibly predatory insects. It does not appear that WRBA compete with each other for roosting sites: WRBA may roost either singly (with or without pups) or in clusters of multiple adults and their offspring (Andersen and Geluso 2018; Calvert 2017; NatureServe 2019). The reports on WRBA roosting site use (see updates to chapter 2; also see below, this chapter, "Roosting") do not mention any other bat species roosting together with WRBA. The literature also does not make any mention of whether WRBA must compete for access to water or whether WRBA compete for mates during breeding.

At least three mammals may compete with WRBA adults for habitat. As discussed in the updates to chapter 4 (see "Vertebrate Community"), beavers (*Castor canadensis*), mule deer (*Odocoileus hemionus*), and non-native cattle (*Bovidae*) and burros (*Equus asinus*) can alter riparian vegetation communities in the Southwestern United States by removing cottonwood and willow or preventing the establishment of their seedlings.

DISEASE

The definition of this critical biological activity or process remains unchanged. No new information was located on disease patterns or consequences among WRBA in the Lower Colorado River Valley or elsewhere.

FEEDING

This update renames the original critical biological activity or process, eating, to clarify the terminology for the pup life stage: Lactating WRBA feed their offspring. The pups, therefore, are passive recipients of their food, while juveniles and adults actively forage for their food. As noted in the original WRBA conceptual ecological model (Marty and Unnasch 2015), feeding success for a pup depends on the foraging success and provisioning rate of its mother (see below, this chapter, "Maternal Care") and competition from siblings in the same litter (see above, this chapter, "Competition"; also see updates to chapter 4, "Litter Size").

FORAGING

The definition of this critical biological activity or process is updated to address new information on the timing of foraging among WRBA and the closely related eastern red bat. As noted in the updates to chapter 2, intensive acoustic monitoring of eastern red bats in western Kentucky (Mcnamara 2019) and WRBA in the Lower Colorado River Valley (Calvert 2013) indicate that foraging activity in both species begins immediately after dark and continues at roughly the same level (call minutes per hour) until first light. This constancy of foraging activity among the bats in Kentucky did not change in response to experimental broadcasts of recordings of calls from the great horned owl or barred owl, known key predators of bats in that region. Otherwise, the definition of this critical biological activity or process remains the same as in the original WRBA conceptual ecological model (Marty and Unnasch 2015). Foraging is relatively unstudied among WRBA juveniles but presumably closely resembles foraging among WRBA adults.

The updated definition of this critical biological activity or process also takes note of a study by Clare et al. (2009) that used genetic markers extracted from prey fragments in the guano of eastern red bats in southern Ontario, Canada, to identify the species on which the bats preyed. The study results indicate that "… despite the robust jaws of *L. borealis*, most prey taxa were softer-bodied Lepidoptera. Surprisingly, more than 60% of the prey species were tympanate, with ears thought to afford protection against these echolocating bats. Moths of the family *Arctiidae*, which employ multiple defensive strategies, were not detected as a significant dietary component." The extent to which these findings apply to WRBA is not known, but the two species are closely related and biologically and ecologically similar.

The AZGFD (2011) and LCR MSCP (2016) state that WRBA forage within 600–1,000 yards (0.5–0.9 kilometers [km]) of their roosts, although they do not identify the source(s) of this information. Mixan et al. (2015) report findings on WRBA movements from tracking 30 WRBA from 2011–13. Their reported analysis mostly focuses on movements to and from roosting trees (see below, this chapter, "Roosting"), but it does describe the movements of several individuals during foraging. The reporting of foraging movements by Mixan et al. (2015) does not include data tabulations on total foraging distances; however, one narrative description provides sufficient information to support an estimate: An individual captured at the PVER foraged upstream as far as the Palo Verde Dam, a distance of approximately 2 km. On the other hand, the narrative descriptions indicate that most WRBA foraged in the immediate vicinity of their roosts. Anderson and Geluso (2018) captured foraging WRBA an average of 200 ± 10 m from their roost sites in the Mimbres River Valley in southwestern New Mexico. No studies have been conducted to look for possible relationships between habitat conditions or prey density and the WRBA foraging radius.

The original WRBA conceptual ecological model addressed WRBA foraging habitat affinities based mostly on work by Pierson et al. (2006) in central California and Calvert and Neiswenter (2012) and Vizcarra et al. (2010) in the Lower Colorado River Valley. This update incorporates the more detailed findings of Vizcarra (2011) (also see Vizcarra and Chambers 2011) for the valley; information on WRBA foraging habitat implied in the reports by Mixan et al. (2015) for the valley and Anderson and Geluso (2018) for southwestern New Mexico; and information from a study by Nelson and Gillam (2019) of landscape features that may affect bat activity in North Dakota, including the eastern red bat.

Vizcarra (2011) (also see Vizcarra and Chambers 2011) studied WRBA foraging habitat preferences in the Lower Colorado River Valley in 2008–10 based on nocturnal acoustic detections across different vegetation types at 72 sampling locations. The acoustic monitoring stations were located specifically in areas with four broad vegetation types—cottonwood/willow, mesquite (saltcedar/honey mesquite and saltcedar/screwbean mesquite), saltcedar, and marsh). Locations were selected based on a previous digital classification of vegetation types from aerial photographs taken in 2004 (BIO-WEST, Inc., and GEO/Graphics, Inc. 2006), updated to incorporate recent restoration areas. Vizcarra (2011) specifically assessed the relative percentage of the area within 300 m of each station dominated by each vegetation type. The study included all maturity classes of the four vegetation types but did not examine the effects of variation in the density or maturity of the vegetation within these types.

The results of the study by Vizcarra (2011) (also see Vizcarra and Chambers 2011) indicate that WRBA are much more likely to forage in cottonwood-willow vegetation, in settings in which even as little as 10% of the cover consists of cottonwood-willow vegetation. Vizcarra (2011) also notes the results "… showed that higher occupancy can be achieved through conversion of only a small percentage of saltcedar to cottonwood-willow. Occupancy models indicated that western red bat occupancy was very high with as little as 5% coverage of cottonwood-willow within 300 m." The results also indicate that WRBA are more likely to forage in areas that not only have their preferred vegetation but are also closer to surface water. "Competing models included distance to river as an important predictor of western red bat occupancy. Proximity to river showed a weak positive relationship with western red bat occupancy."

WRBA are generally classified as edge and gap insectivores (Frick et al. 2019). Broderick (2010, 2012a, 2012b, 2015) used acoustic detections to assess bat affinities for foraging habitat along the Lower Colorado River Valley and found that WRBA foraging activity was statistically significantly greater around detector stations with (a) a greater number of canopy layers within 100 m that consist of either different species or [different] ages of tree species and (b) smaller distances to the nearest edge (i.e., road, canal, field edge) from the sample point. The latter variable "… measures how close potential flyways are to the detector" (Broderick 2012a). The same studies also found that WRBA activity (measured by the number of minutes of acoustically detected activity per night) was statistically significantly greater, the greater the area of the cottonwood-willow patch within which they were detected as they foraged. Further, the same studies indicate that WRBA "… show increased activity in HCAs [habitat conservation areas] that exhibit canopy complexity. Complexity increases as trees and shrubs mature, creating canopy edges with different vegetation heights" (Broderick 2012a).

Numerous investigators of the Lower Colorado River Valley and elsewhere have remarked on the affinity of WRBA for foraging along vegetation edges and in openings within woodland patches (Broderick 2010, 2012a, 2012b, 2015; Calvert 2009, 2010a, 2010b, 2012a, 2012b, 2013; Hill 2018; Pierson et al. 2006; Vizcarra 2011); however, quantification of this affinity has been difficult, as noted by these same studies. Acoustic detections are not routinely triangulated to determine the precise locations of individual bats. Further, the bat monitoring protocols for the Lower Colorado River Valley call for the placement of acoustic detectors "… either along the edge of a habitat site or on a linear opening within the site that allows access to bat foraging (swoop zones)" (Broderick 2010), and the placement of mist nets along (perpendicular to) the edges of openings and flyways. These placement protocols bias detections and captures toward edge settings in the first place. Nevertheless, these investigators agree from their experiences that "Bats forage along edges that form between stands of different species such as tree willows adjacent to coyote willow and/or ages. Additionally, stochastic events such as wind throw or morning glory infestations that smother saplings create openings in otherwise dense, uniformly planted habitats. Bats also forage along edges created by roads, canals, field edges, and deliberately created wide spaces between plantings" (Broderick 2012a).

Nelson and Gillam (2019), assessing foraging habitat affinities for bats in North Dakota, found that eastern red bats foraged more in areas "near rivers and ponds with cluttered, edge, and corridor structural characteristics." Their study defined edge habitat as "… the border between cluttered and open landscapes," corridor habitat as "…linear features embedded within a dissimilar land type," and cluttered habitat as "… areas as those with dense woody vegetation throughout the understory."

The studies by Anderson and Geluso (2018) and Mixan et al. (2015), which focus on WRBA roosting habitat affinities (see below, this chapter, "Roosting"), potentially provide information on WRBA foraging habitat affinities as well. The studies relied on the capture of WRBA in mist nets while the bats foraged at night and the placement of radio transmitters on suitable individuals for subsequent tracking of their movements.[4] After removing long-distance, cold-season movements from the calculation of the distances WRBA traveled between roosting trees, Mixan et al. (2015) found that WRBA moved an average of only

[4] Anderson and Geluso (2018) tracked 14 WRBA but do not state the total number captured. Mixan et al. (2015) specifically captured 55 WRBA from 2011–13, of which only 30 were suitable for radio tracking.

120 m between roosts, with a median distance of 78 m. Given (a) the limited range of WRBA movement between roosts and (b) the limited radii within which WRBA forage around their roosts (see preceding paragraph), the habitat conditions at the locations where Anderson and Geluso (2018) and Mixan et al. (2015) captured WRBA therefore likely represent acceptable foraging habitat for WRBA.

Table 3, at the end of this chapter, summarizes findings by Anderson and Geluso (2018), Calvert and Neiswenter (2012), Mixan et al. (2015), Pierson et al. (2006), Vizcarra (2011), Vizcarra and Chambers (2011) and Vizcarra et al. (2010 concerning WRBA roosting habitat affinities in central California, southwestern New Mexico, and the Lower Colorado River Valley at three spatial scales: (1) the individual trees in which WRBA roost and their immediate vicinities within a riparian woodland patch, (2) the overall riparian woodland patch within which the roosting trees occur, and (3) the larger landscape that includes and surrounds these patches. Table 3 identifies these three scales using the terminology of Mixan et al. (2015): "micro-scale (roosting tree)," "meso-scale (roosting patch)," and "macro-scale (roosting landscape)," respectively. The findings (table 3) at the meso- and macro-scales consistently indicate that WRBA appear to forage preferentially in riparian habitat dominated by mature Fremont cottonwood, California sycamore (*Platanus racemosa*), and/or valley oak (*Quercus lobata*) close to surface water. WRBA may also forage preferentially in such vegetation patches when they are > 50 m wide with areas > 20 hectares.

INTER-SITE MOVEMENT

This update adds inter-site movement as a critical biological activity or process to capture the dynamics of shifting WRBA adult occupancy among sites along the Lower Colorado River Valley on monthly, seasonal, and annual time scales. As discussed in the updates to chapter 2, intensive acoustic monitoring along the valley since fiscal year 2010, both in habitat conservation areas and in established protected areas, has demonstrated that at least some WRBA remain in the valley year round (Broderick 2016; Calvert 2017; Mixan 2015; Mixan and Diamond 2018a, 2018b, 2019a, 2019b). However, as noted in the updates to chapter 2, this monitoring did not include tracking of individual WRBA to evaluate whether specific *individual* WRBA remained in the valley year round. The data indicate only where and when WRBA are present. Nevertheless, the absence of wholesale seasonal out-migration differs from the pattern seen among WRBA across Arizona as a whole (AZGFD 2011) while resembling the geographically more limited scale of seasonal movement seen in California (NatureServe 2019). Mixan et al. (2015) also report that WRBA move an average of 1.3 km between roost patches.

Further, the intensive acoustic monitoring in the Lower Colorado River Valley has produced three types of evidence of possible within-season, season-to-season, and year-to-year movements of WRBA adults within the valley: (1) WRBA adult activity and occupancy appear to increase from one month to the next at some sites while concurrently decreasing at others; (2) WRBA adult activity and occupancy similarly appear to increase from one year to the next at some sites while concurrently decreasing at others; and (3) pulses of overnight activity suggest the passage of larger numbers of WRBA than are typically detected at these sites during normal foraging activity (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b).

Mixan et al. (2015) also note that movement patterns differ between adult males and females and between adults and juveniles:

> *The longest western red bat movement between roosting sites was an adult male at the [Palo Verde Ecological Reserve] during the cold season. This bat moved 11.23 km between roosts on two separate occasions. In contrast, we observed a subadult male western red bat at the CVCA that moved only 6 m between tree roosts. The mean distance moved between western red bat roosts was 0.99 km, with a median distance of 0.081 km. This mean distance estimate was driven by cold season male western red bat movements. We removed these long-distance cold season movements and recalculated our mean distance between western red bat roosts to 0.12 km, with a median distance of 0.078 km. The distance traveled between roosts differed by gender and age. We documented six roost movements for female western red bats: the maximum movement was 0.19 km, the minimum was 0.031 km, the mean was 0.11 km, and the median was 0.084 km. For male western red bats, we detected 29 movements between roosts, with a maximum of 11.23 km, a minimum of 6 m, a mean of 1.12 km, and a median of 0.081 km. The mean for male movements was driven by four long-distance cold season movements. Once we removed these four events our mean distance between roosts declined to 0.12 km, and our median dropped to 0.078 km. We documented 22 roost movements for adults and 13 for subadults. Adult western red bats moved a maximum of 11.23 km, a minimum of 7 m, a mean of 1.51 km (0.12 km with the cold season movements excluded), and a median of 0.081 km. Subadult western red bats moved a maximum of 0.19 km, a minimum of 6 m, a mean of 0.12 km, and a median of 0.083 km. Roost movements also differed between the control and treatment sites. Western red bats moved between roosts a total of 24 times in the treatment sites. The maximum movement between roosts in the treatment sites was 11.23 km, the minimum was 6 m, the mean was 1.41 km (0.14 km with the cold season movements excluded), and the median was 0.12 km. We documented 11 roosting movements at the control sites, with a maximum movement of 0.19 km, a minimum of 31 m, a mean of 86 m, and a median of 0.078 km.*

The possible causes of within-season, season-to-season, and year-to-year movements of WRBA adults within the valley are poorly understood. Hypotheses include changes in roosting habitat quality (e.g., following a fire), changes in the availability of prey, use of some sites as stopovers rather than longer-term roosting areas, and seasonal changes in temperature (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). Changes in the distribution of predators conceivably might also matter.

MATERNAL CARE

This update renames the critical biological activity/process, roost attendance, for terminological clarity. This critical biological activity or process specifically concerns maternal care of pups—lactation, nursing, cleaning, guarding, etc.—rather than attendance to the roost site. Maternal care of pups affects adult fertility because more and/or higher quality maternal care improves pup survival; however, maternal care also has energetic costs that may affect adult growth and survival. Using the term, "maternal," also signifies that WRBA males play no role in the care of pups. In fact, WRBA males (and non-reproducing females) may roost elsewhere while reproducing females gestate and rear their litters (AZGFD 2011; NatureServe 2019).

MECHANICAL STRESS

The definition of this critical biological activity or process is updated to note that WRBA juveniles and adults may experience mechanical stress when captured and handled during mist-net monitoring and potentially also when they escape direct contact with predators. The protocols for bat monitoring in the Lower Colorado River Valley are designed to minimize mechanical stress during capture, handling, and release (Brown 2006; Hill 2018).

PREDATION

No new literature addresses predation on WRBA in the Lower Colorado River Valley or elsewhere. The subject remains largely unstudied; however, studies of predation on bats in general (Mikula 2015; Mikula et al. 2016) provide guidance for updating the WRBA conceptual ecological model.

This update revises the definition of this critical biological activity or process to note that predators may attack WRBA in three settings: (1) in their roosts, (2) from the air during foraging and inter-site movement, and (3) from the ground, when WRBA foraging activities bring them close to the ground. Further, because WRBA forage and travel only at night, their vulnerability to predation in the latter two settings occurs only at night.

As indicated in the original WRBA conceptual ecological model (Marty and Unnasch 2015), predators in the first of the three aforementioned settings include birds and climbing mammals. Climbing carnivorous reptiles presumably also could prey on roosting WRBA.

Chapter 4 (see "Vertebrate Community") discusses species that potentially could prey on roosting WRBA. Additionally, studies elsewhere have noted that large spiders (Nyffeler and Knörnschild 2013) and large centipedes (Molinari et al. 2005) also may prey on roosting bats; however, no spiders or centipedes in the region of the Lower Colorado River Valley are known to do so.

Avian predators are the main threat to bats in the second of these three settings (Mikula et al. 2016). In fact, Mikula et al. (2016) suggest,

> *Attacks on bats by diurnal raptors were found to be distributed globally and were present in the majority of extant raptor lineages. Attacks on bats by other diurnal birds were also occasionally recorded. Furthermore, the majority of extant bat families featured as prey. These results strongly suggest that predation by birds may act as a major factor affecting the scarcity of daytime activity in bats and as a driver in the evolution of bat nocturnality.*

Artificial nighttime lighting may attract moths, the favorite food of foraging WRBA; however, foraging around artificial nighttime lighting exposes WRBA to nocturnal, flying predators that hunt by sight.

The literature does not address circumstances that could make WRBA vulnerable to predation at ground level. Mikula (2015) suggests that even fishes and amphibians may prey on bats in the third of these three settings.

ROOSTING

This critical biological activity or process replaces the original, roost site selection, to clarify the terminology: Roosting behavior includes roost site selection and also behaviors such as roosting time(s) of day and persistence, and the size (spatial extent, density) of site occupancy.

Knowledge of WRBA roosting behavior and roost site preferences has expanded greatly since preparation of the original WRBA conceptual ecological model (Marty and Unnasch 2015). As noted in the updates to chapter 2, "Adults"), studies in the Mimbres River Valley in southwestern New Mexico (Andersen and Geluso 2018) and in the Lower Colorado River Valley (Calvert 2017; Mixan 2015; Mixan et al. 2015) have expanded on previous information on WRBA roosting in the Central Valley of California (Pierson et al. 2006) and the Lower Colorado River Valley (Calvert and Neiswenter 2012; Diamond 2012; Diamond et al. 2013; Vizcarra et al. 2010) and on inferences from eastern red bat roosting behavior (LCR MSCP 2016; Marty and Unnasch 2015).

Andersen and Geluso (2018) and Mixan et al. (2015) specifically expand on the understanding of WRBA adult affinities for roosting habitat characteristics at three spatial scales as discussed earlier (see above, this chapter, "Foraging"):

(1) the individual trees in which WRBA roost and their immediate vicinities within a riparian woodland patch, (2) the overall riparian woodland patch within which the roosting trees occur, and (3) the larger landscape that includes and surrounds these patches. Mixan et al. (2015) address these three scales under the headings of "micro-scale (roosting tree)," "meso-scale (roosting patch)," and "macro-scale (roosting landscape)," respectively. Andersen and Geluso (2018) assessed individual roost trees and randomly sampled trees within a 0.1-hectare circular plot surrounding each individual roosting tree and collected additional data on the nearest unoccupied tree with a diameter at breast height (DBH) > 9.5 centimeters (cm) within a distance of 50–100 m from each roost tree. Mixan et al. (2015) included not only the individual roost trees but also trees nearest to each roost tree (nearest neighbor trees) in their assessment of micro-scale conditions. This update applies the headings from Mixan et al. (2015) and considers the findings of Andersen and Geluso (2018) to apply to the micro- and meso-scales as defined by Mixan et al. (2015). The two studies also measured some micro-scale properties in slightly different ways. For example, Mixan et al. (2015) recorded foliage density as the percent canopy closure (Class 1, 0% closure, to Class 7, 100% closure) at three heights (3, 6, and 9 m). Andersen and Geluso (2018) recorded foliage density as the amount of light penetrating to the ground at midday (dense, > 75% shade; moderate, 50–75% shade; sparse, < 50% shade). Table 3 summarizes the findings of the studies of WRBA roosting habitat affinities in central California, southwestern New Mexico, and the Lower Colorado River Valley at the micro-, meso-, and macro-scales, incorporating and expanding on attachment 2, table 2-1 in the original WRBA conceptual ecological model.

Mixan et al. (2015) also present data on the distances WRBA may travel between roosting sites. Specifically, as noted above, this chapter (see "Foraging" and "Inter-Site Movement"), after removing long-distance, cold-season movements from the calculation of the distances WRBA traveled between roosting trees, Mixan et al. (2015) found that WRBA moved an average of only 120 m between roosts, with a median distance of 78 m and a minimum of only 6 m among WRBA that did change their roosting site. On the other hand, some WRBA did not change their roosting site at all during their period of observation. These data suggest a high degree of within-season roosting site fidelity.

As noted in the updates to chapter 2, Andersen and Geluso (2018) and Mixan et al. (2015) report WRBA adults roosting in clusters in the Mimbres River Valley of southwestern New Mexico and in the Lower Colorado River Valley, respectively. These observations contradict the standard description of WRBA adults as roosting solitarily (Andersen and Geluso 2018). The clusters consist of two to three adults in direct contact with one another. Andersen and Geluso (2018) further observed that, "… if bats were observed in clusters, they typically exhibited greater roosting fidelity than solitary individuals." Neither Andersen and Geluso (2018) nor Mixan et al. (2015) discuss possible ecological implications of this behavior, and this update does not suggest any or suggest identifying this behavior as a distinct critical biological activity or process.

THERMAL STRESS

The definition of this critical biological activity or process remains unchanged. No new information was located on thermal stress or its consequences among WRBA in the Lower Colorado River Valley or elsewhere.

Table 3.—WRBA roosting habitat affinities in central California, southwestern New Mexico, and the Lower Colorado River Valley at three spatial scales

Specific property	Value and/or range[1]	Location	Reference
Micro-scale			
Roosting tree: Species	Out of 52 roosting trees observed at naturally vegetated ("control") sites: 85% Fremont cottonwood, 4% Goodding's willow, 4% sycamore (*Platanus occidentalis*), 4% Mexican fan palm (*Washingtonia* spp.), 2% athel tree (*Tamarix aphylla*), 2% netleaf hackberry (*Celtis reticulata*).	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: Species	Predominantly cottonwood.	Lower Colorado River Valley	Diamond 2012
Roosting tree: Species	47% cottonwood (*Populus* spp.), 21% velvet ash (*Fraxinus velutina),* 16% box elder (*Acer negundo*), 16% red mulberry (*Morus rubra*).	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roosting tree: Height of live crown base	At naturally vegetated ("control") sites: 3.9 ± 1.036 m versus 2.6 ± 1.117 m for non-roosting trees. At habitat creation ("treatment") sites: 3.0 ± 1.572 m versus 4.3 ± 1.614 m for non-roosting trees. Results do not differ statistically between sexes or life stages.	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: Height	16.7 ± 1.4 m but not statistically different from randomly selected neighboring trees (see "Immediate neighbor trees: Height," below, this table).	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roosting tree: Height	At naturally vegetated ("control") sites: 16.1 ± 0.908 m versus 10.1 ± 0.931m for non-roosting trees (statistically significant difference). At habitat creation ("treatment") sites: 14.2 ± 0.742 m versus 14.4 ± 0.745 m for non-roosting trees. Results do not differ between sexes but do differ statistically significantly by life stage: 13.8 ± 1.091 m for adults versus 18.4 ± 1.579 m for juveniles.	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: DBH	89.6 ± 15.3 cm but not statistically different from randomly selected neighboring trees (see "Immediate neighbor trees: DBH," below, this table).	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roosting tree: DBH	At naturally vegetated ("control") sites: 66.8 ± 8.622 cm versus 26.7 ± 9.677 cm for non-roosting trees (statistically significant difference). At habitat creation ("treatment") sites: 38.7 ± 11.287 m versus 27.2 ± 12.181 m for non-roosting trees. Results differ statistically significantly between sexes: 70.0 ± 10.513 cm for males versus for females 39.3 ± 13.616 cm. Results also differ statistically significantly by life stage: 48.1 ± 9.443 cm for adults versus 84.6 ± 13.434 cm for juveniles.	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: Condition	100% living trees (versus dead).	Mimbres River Valley, New Mexico	Anderson and Geluso 2018

Table 3.—WRBA roosting habitat affinities in central California, southwestern New Mexico, and the Lower Colorado River Valley at three spatial scales

Specific property	Value and/or range[1]	Location	Reference
Roosting tree: Condition	At naturally vegetated ("control") sites: 15.4 ± 5.482 percent dead crown versus 11.6 ± 5.972 percent for non-roosting trees. At habitat creation ("treatment") sites: 27.3 ± 6.549 percent versus 34.9 ± 7.045 percent for non-roosting trees. Results differ between sexes: 14.7 ± 5.693 percent for males versus 26.8 ± 7 percent for females. Results also differ slightly and not statistically significantly by life stage: 17.0 ± 5.445 percent for adults versus 23.5 ± 7.503 percent for juveniles.	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: Canopy diameter	At naturally vegetated ("control") sites: 3.9 ± 0.688 m at base of tree, 4.91 ± 1.198 m at 2 m above the base, 7.6 ± 1.384 m at 4 m above the base, 8.7 ± 1.697 m at 6 m above the base, and 8.7 ± 1.506 m at 8 m above the base versus 2.9 ± 0.766 m, 4.4 ± 1.365 m, 4.4 ± 1.578 m, 4.3 ± 1.991, and 5.2 ± 1.738 m, respectively, for non-roosting trees. At habitat creation ("treatment") sites: 2.6 ± 0.639 m, 3.1 ± 1.814 m, 4.2 ± 2.189 m, 4.7 ± 2.745 m, and 4.8 ± 2.258 m, respectively, versus 1.8 ± 0.741 m, 2.3 ± 1.885 m, 3.1 ± 2.257 m, 3.8 ± 2.839 m, and 4.7 ± 2.309 m, respectively, for non-roosting trees. Results differ between sexes: 4.3 ± 0.936 m, 5.6 ± 1.333 m, 8.4 ± 1.663 m, 9.1 ± 2.072 m, and 8.3 ± 2.142 m, respectively, for males versus 2.1 ± 1.238 m, 2.5 ± 1.701 m, 4.1 ± 2.134 m, 5.9 ± 2.653 m, and 7.7 ± 3.044 m, respectively, for females. Results also differ (mostly statistically significantly) by life stage: 2.4 ± 0.776 m, 3.2 ± 1.173 m, 5.1 ± 1.461 m, 5.2 ± 1.532 m, and 4.7 ± 1.390 m, respectively, for adults versus 6.1 ± 1.123 m, 7.8 ± 1.706 m, 10.9 ± 2.144 m, 14.4 ± 2.241 m, and 14.7 ± 2.043 m, respectively, for juveniles.	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: Canopy diameter	Foliar width of roost trees mean: 3.7 m (range = 0.1–8 m); not significantly different from adjacent trees.	Lower Colorado River Valley	Diamond 2012
Roosting tree: Canopy diameter	Foliar width of roost trees mean: 3.4 m (range = 0.75–7.5 m); significantly different from adjacent trees.	Lower Colorado River Valley	Diamond et al. 2013
Roosting tree: Canopy density	Selected trees with > 75% shade; avoided trees with < 50% shade.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roosting tree: Canopy density	At naturally vegetated ("control") sites: vegetation closure at 3 m, 6 m, and 9 m above base of tree = 3.4 ± 0.602 m, 3.6 ± 0.586 m, and 5.5 ± 0.628 m, respectively. At habitat creation ("treatment") sites: 4.5 ± 0.545 m, 4.3 ± 0.531 m, and 5.0 ± 0.833 m, respectively. Results differ slightly and are not statistically significantly between sexes or between adults and juveniles.	Lower Colorado River Valley	Mixan et al. 2015
Roosting tree: Canopy apical meristem density	At naturally vegetated ("control") sites: 2.0 ± 0.857 versus 3.5 ± 0.961 for non-roosting trees. At habitat creation ("treatment") sites: 2.2 ± 1.208 versus 2.2 ± 1.279 for non-roosting trees. Results do not differ significantly between sexes or by life stage.	Lower Colorado River Valley	Mixan et al. 2015
Roost location within tree: Vertical distance from canopy edge	At bottom of canopy, shaded from above and open below.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roost location within tree:	No dominant orientation.	Mimbres River	Anderson and

Table 3.—WRBA roosting habitat affinities in central California, southwestern New Mexico, and the Lower Colorado River Valley at three spatial scales

Specific property	Value and/or range[1]	Location	Reference
Orientation		Valley, New Mexico	Geluso 2018
Roost location within tree: Horizontal distance from canopy edge	Within 1.5 m of canopy edge.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roost location within tree: Height above ground	9.4 ± 1.0 m; range 3.0 to 17.1 m.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Roost location within tree: Height above ground	At naturally vegetated (“control”) sites: 9.6 ± 1.318 m. At habitat creation (“treatment”) sites: 4.5 ± 1.725 m (statistically significant difference). Differences between control and treatment sites are not statistically significant. Results do not differ significantly between sexes or between adults and juveniles.	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: Tree density	The number of trees within a 0.1-hectare circular plot surrounding roosting trees, 9.1 ± 1.7, was significantly lower than the number surrounding randomly selected trees in the same patch, 13.1 ± 2.7.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Immediate neighbor trees: Species	Cottonwood-willow stands.	Lower Colorado River Valley	Vizcarra et al. 2010
Immediate neighbor trees: Species	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: Species	Black walnut (*Juglans nigra)*, cottonwood, and sycamore (*Platanus* spp.).	Arizona	Snow 1996 *in* Carter and Menzel 2007
Immediate neighbor trees: Height of live crown base	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: Height	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: Height	Height of roosting trees, 16.7 ± 1.5 m, was not statistically different from the height of randomly selected trees in the same patch, 17.2 ± 1.9.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Immediate neighbor trees: DBH	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: DBH	The DBH of roosting trees, 89.7 ± 15.4, was not statistically different from the DBH of randomly selected trees in the same patch, 72.1 ± 10.4 cm. The DBH of trees within a 0.1-hectare circular plot surrounding roosting trees, 48.9 ± 2.6, was slightly but not quite statistically significantly higher than the DBH of trees surrounding randomly selected trees in the same patch, 43.3 ± 2.0.	Mimbres River Valley, New Mexico	Anderson and Geluso 2018
Immediate neighbor trees:	(*Measured but quantitative results not yet reported*).	Mimbres River	Anderson and

Table 3.—WRBA roosting habitat affinities in central California, southwestern New Mexico, and the Lower Colorado River Valley at three spatial scales

Specific property	Value and/or range[1]	Location	Reference
Condition		Valley, New Mexico	Geluso 2018
Immediate neighbor trees: Condition	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: Canopy diameter	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Immediate neighbor trees: Canopy apical meristem density	(*Measured but quantitative results not yet reported*).	Lower Colorado River Valley	Mixan et al. 2015
Meso-scale			
Roost location within patch	The greater spacing of individual cottonwood trees at nursery plantings and the plot edges of treatment sites in the Lower Colorado River Valley (see "Micro-scale," above) "allows [these] trees to grow taller and develop larger DBH, which may provide more suitable western red bat roosting habitat."	Lower Colorado River Valley	Mixan et al. 2015
Roost location within patch	"Our data suggesting that levels of red bat activity were significantly higher in the more extensive (> 50 m wide) riparian stands were strikingly consistent with the finding by Hutchinson and Lacki (2000) that eastern red bats selected roosts that were on average 277 m, and never less than 50 m, from the forest edge."	Central California	Pierson et al. 2006
Patch species composition	WRBA occupancy is positively associated with the percent area of shrub and low forest < 5 m within patch: The investigators state that this specific property is one of three variables that predict site occupancy in preliminary occupancy modeling but have not yet published the data itself. Conversely, WRBA occupancy shows no statistical association (either positive or negative) with the percent area of shrub and forest > 5 m within a patch.	Lower Colorado River Valley	Mixan et al. 2015
Patch size	Quantitative results not yet separately reported but one of three variables that predict site occupancy in preliminary occupancy modeling.	Lower Colorado River Valley	Mixan et al. 2015
Macro-scale			
Percent riparian vegetation in 10 x 5 km sampling polygons centered on roost site locations	Quantitative results not yet separately reported but one of three variables that predict site occupancy in preliminary occupancy modeling.	Lower Colorado River Valley	Mixan et al. 2015
Percent agricultural vegetation in 10 x 5 km sampling polygons centered on roost site locations	Quantitative results not yet separately reported but one of two variables that specifically do **not** predict site occupancy in preliminary occupancy modeling.	Lower Colorado River Valley	Mixan et al. 2015

Updates to Chapter 4 – Habitat Elements

This update identifies 13 habitat elements that affect 1 or more critical biological activities or processes across the 3 WRBA life stages. The original WRBA conceptual ecological model (Marty and Unnasch 2015) identified 12 habitat elements. This update adds three new habitat elements, chemical contaminants, fire regime, and monitoring, capture, handling; integrates three original habitat elements (canopy cover, patch size, and riparian tree species composition) into a new habitat element, tree community; and renames four original habitat elements (food availability, genetic diversity and infectious agents, parent roost attendance, and predator density) to arthropod community, infectious agents, maternal care, and vertebrate community, respectively. Table 4 lists the 13 habitat elements in this update, indicates the critical biological activities and processes they *directly* affect across all WRBA life stages, and indicates which habitat elements are new to this update or renamed from the original WRBA conceptual ecological model.

Table 4.—(Revision of original table 3) WRBA habitat elements and the critical biological activities or processes they directly affect across all life stages
(Xs indicate the habitat elements that affect each critical biological activity or process.)

Critical biological activity or process ➔ / **Habitat element 🡻**	Breeding	Chemical stress	Competition	Disease	Feeding	Foraging	Inter-site movement	Maternal care	Mechanical stress	Predation	Roosting	Thermal stress
Anthropogenic disturbance								X	X		X	
Arthropod community (*renamed*)						X	X			X	X	
Chemical contaminants (*new*)		X										
Fire regime (*new*)												X
Infectious agents(*renamed*)				X								
Litter size (*renamed*)			X			X		X				
Maternal care (*renamed*)					X							X
Matrix community						X					X	
Monitoring, capture, handling (*new*)									X			
Temperature							X				X	X
Tree community (*new*)						X	X				X	
Vertebrate community (*renamed*)			X				X			X	X	
Water availability		X									X	

ANTHROPOGENIC DISTURBANCE

The definition and discussion of this habitat element is updated as follows:

Full name: **Noise and other physical disturbances associated with human activity in and around existing or potential WRBA roosting and foraging habitat**. This element refers to the existence and level of human disturbance near WRBA roosting habitat, including physical contact with WRBA, agitation of vegetation, and noise. The disturbance of roost sites may be a cause for bat decline along the LCR in areas that are near development and/or areas that receive varying levels of human use. Human activities may affect roosting and reproduction, especially if pregnant and lactating females are roosting in orchards subject to high levels of human activity (Constantine 1959). Human talking and walking around roost sites does not appear to substantially disturb bats, but any attempt to handle them may. Active work in the forests or in other habitat where WRBA are roosting may adversely affect roosting individuals and potentially disrupt reproduction (e.g., tending to young during early development phases) (Dudek and ICF International 2012).

ARTHROPOD COMMUNITY

This is a new habitat element included so that the CEM better distinguishes different broad categories of food resources for WRBA juveniles and adults, competitors with WRBA for food resources, potential predators of WRBA, and species that may shape the environment in and around WRBA roosting sites.

Full name: **The taxonomic composition, size range, spatial and temporal distributions, and abundance of the arthropod community in and around existing or potential WRBA roosting and foraging habitat**. The arthropods of concern may include ants, beetles, butterflies and moths, centipedes, spiders, and other insects that WRBA may consume or that may compete with or prey on WRBA, or otherwise contribute to ecological dynamics in and around WRBA roosting sites. This new habitat element addresses aspects of habitat that the original WRBA conceptual ecological model (Marty and Unnasch 2015) addressed under the label, food availability, and also partially under the label, predator density. Additionally, this new habitat element recognizes that predatory arthropods may also compete with WRBA juveniles and adults for prey and that herbivorous arthropods in general may affect ecological—particularly vegetation—dynamics in and around WRBA roosting sites.

WRBA prey exclusively on flying arthropods (see original CEM; also see above, this chapter, “Foraging”). The species and abundances of flying arthropods available at night necessarily affect WRBA juvenile and adult foraging success and nutrition (Tietje et al. 2015). A review of the literature and data on the arthropod communities at and around WRBA roosting sites in and immediately around the Lower Colorado River Valley (compared to similar sites without WRBA roosts) (Anderson 2012; Andersen and Nelson 2013; Eckberg 2011, 2012; Nelson 2009; Nelson and Wydoski 2013; Nelson et al. 2015; Ohmart et al. 1988; Pratt and Wiesenborn 2009, 2011; Trathnigg and Phillips 2015; Wiesenborn 2010, 2012, 2013, 2014a, 2014b; Wiesenborn et al. 2008) is beyond the scope of this update.

Predatory arthropods such as mantises, spiders, and wasps that prey on other arthropods may compete with WRBA for food resources; further, they may prey on these shared food resources by preying on their eggs and larvae or when the adult prey are resting on the ground or in vegetation; however, as noted above, a review of the literature and data on the arthropod communities at and around WRBA roosting sites in and immediately around the Lower Colorado River Valley (compared to similar sites without WRBA roosts) is beyond the scope of this update.

Conceivably, some carnivorous arthropods potentially could prey on WRBA as noted in the updates to chapter 3, "Predation"); however, there are no data on such interactions affecting WRBA or any other bat species in the region. This update merely notes the possibility based on general ecological concepts.

Arthropods, particularly insects, can significantly affect vegetation dynamics in all ecosystems, presumably including riparian communities. The effects of the non-native northern tamarisk beetle (*Diorhabda carinulata*) on saltcedar along the Colorado River Valley provides one particularly clear example. Resource managers intentionally released the beetle in 2001 in the Upper Colorado River Basin as a biocontrol for the invasive saltcedar (Bean and Dudley 2018). The beetle has spread widely, including down the Colorado River Valley into the LCR ecosystem, where it currently occurs as far south as the Imperial National Wildlife Refuge as of January 2019 (RiversEdge West 2019). Repeated defoliation by the beetle usually causes the canopy to die-back within 1 to 4 years, and causes plant death within 2 years or more, depending on the site (Bean and Dudley 2018). The literature reviewed for this update does not document effects of native arthropods on riparian vegetation along the Lower Colorado River Valley, and a review of such information is beyond the scope of this update.

CHEMICAL CONTAMINANTS

The original WRBA conceptual ecological model (Marty and Unnasch 2015) did not propose a separate habitat element for chemical contaminants; however, the original CEM did note that WRBA are vulnerable to chemical stress (see updates to chapter 3) and identified some possible sources of contaminants that could result in such stress.

This update adds this new habitat element to the CEM so that the CEM better identifies the causal chains that could result in chemical stress to WRBA in any life stage.

Full name: **The concentrations of chemical contaminants in the air, on plant surfaces, and/or on the ground in and around existing or potential WRBA roosting and foraging habitat**. This element includes chemicals that may contaminate arthropods on which WRBA juveniles and adults feed, drift in the air or leach into the groundwater to reach WRBA habitat, or occur at WRBA habitat sites restored from former land uses. In principal, the element includes biocides, fertilizers, and industrial wastes. The literature reviewed to prepare this update does not identify any specific chemical contaminants of potential concern for WRBA food resources or habitat sites, and a full review of the potential literature on chemical contaminants that could affect WRBA or their food resources in the Lower Colorado River Valley is beyond the scope of this update.

FIRE REGIME

The original WRBA conceptual ecological model (Marty and Unnasch 2015) did not propose a separate habitat element for fire regime, but it did note several ways in which wildfire and prescribed fire can affect WRBA habitat. This update adds this new habitat element to the CEM so that the CEM better identifies the causal chains through which wildfire and prescribed fire can affect WRBA habitat.

Full name: **The frequency, timing, spatial extent, and intensity of fire in and around existing or potential WRBA roosting and foraging habitat**. Wildfire is a natural type of disturbance in the riparian plant communities across the geographic range of WRBA, including the Lower Colorado River Valley, and wildfires today also occur through human accidents (Conway et al. 2010; LCR MSCP 2014; Meyer 2005; Steel et al., unpublished; Stromberg et al. 2009). The LCR MSCP sometimes uses prescribed fire as a tool for habitat management (LCR MSCP 2014). Wonkka et al. (2018) provide a recent review of the literature on the effects of fire on riparian communities containing both cottonwood and saltcedar in the Western United States; and Steel et al. (unpublished) provide a recent review of the effects of wildfire on bat—including WRBA—occupancy in the Sierra Nevada in California. Fire can affect WRBA roosting habitat along the LCR by facilitating the replacement of large cottonwood trees by non-native species such as saltcedar and arrowweed (*Tessaria sericea*) (Busch 1995), potentially reducing the availability of trees in the size range that WRBA prefer for roosting. Mixan and Diamond (2017b) report evidence that fire at WRBA roosting habitat sites can significantly affect WRBA occupancy. These authors note that a fire at the Cibola National Wildlife Refuge-Island habitat site for WRBA in August 2011 burned cottonwood-willow vegetation that may have provided roosting and foraging habitat for WRBA. Acoustic monitoring detection rates for WRBA subsequently were very low at this site from 2012 through 2015, with some variation between years, but began to rebound strongly in 2016 as the cottonwood-willow habitat began to recover to pre-fire levels. Fire at WRBA monitoring sites can also damage monitoring equipment installed at these sites (Mixan et al. 2013) or create openings useful for placing mist nets (Hill 2018).

INFECTIOUS AGENTS

The original WRBA conceptual ecological model (Marty and Unnasch 2015) included genetic diversity and infectious agents under the label of a single habitat element; however, the literature reviewed for the original CEM did not turn up any information on WRBA genetic diversity, threats to WRBA genetic diversity, or effects of genetic diversity (or its impairment) on WRBA ecology. This update therefore simplifies the CEM by setting aside concerns about genetic diversity. On the other hand, the WRBA conceptual ecological model does need to address infectious agents as a habitat element in order to characterize the causal chains affecting the incidence of disease.

Full name: **The species, abundances, spatial and temporal distributions, and activity levels of infectious agents to which WRBA are susceptible at locations in and around existing or potential WRBA roosting and foraging habitat**. WRBA in every life stage presumably are vulnerable to infection, as are all animals. Infectious agents include viruses, bacteria, fungi, and parasites. Non-lethal infections may make the affected individuals vulnerable to mortality from other causes; however, the literature reviewed for the original WRBA conceptual ecological model and for this update does not identify any specific infectious agents known or suspected to affect WRBA in the Lower Colorado River Valley or elsewhere. NatureServe (2019) specifically notes that WRBA are “not known or expected to be affected by white-nose syndrome.”

LITTER SIZE

This update renames the habitat element in the original WRBA conceptual ecological model, number of pups, to litter size for consistency with the terminology in other bird and mammal CEMs prepared for the LCR MSCP. The definition of this habitat element otherwise remains unchanged.

MATERNAL CARE

This update renames the habitat element in the original WRBA conceptual ecological model, parent roost attendance, to maternal care for consistency with the updated name for the critical biological activity or process with the latter name. WRBA pups experience maternal care as a habitat element, while WRBA adult females engage in maternal care as a critical biological activity or process. The definition of this habitat element otherwise remains unchanged; however, this update does recognize that, when their litter contains more than one individual, WRBA pups presumably compete for maternal care.

MATRIX COMMUNITY

The definition and discussion of this habitat element is updated as follows:

Full name: **The taxonomic composition, size range, spatial and temporal distributions, and abundances of shrubs and herbaceous plants in and around existing or potential WRBA roosting and foraging habitat**. As noted in the "Definitions" immediately following the acronym list in this update, the WRBA conceptual ecological model recognizes plant communities as consisting of canopy, understory, shrub, and herbaceous layers. Trees (i.e., woody vegetation) greater than 2.0 m in height, make up the canopy layer and may also occur in the understory as subcanopy trees. This update addresses trees as a separate habitat element (see below, this chapter, "Tree Community"). Where trees are present, shrubs and herbaceous plants make up the understory. In the absence of trees, shrubs comprise the uppermost layer of vegetation.

The matrix community may be assessed at three spatial scales relevant to WRBA roosting and foraging: (1) the immediate vicinity of the roosting trees, (2) the overall riparian woodland patch within which the roosting trees occur (see updates to chapter 3, "Roosting"), and (3) the surrounding landscape across which WRBA may forage (see updates to chapter 3, "Foraging"). The matrix community at these three spatial scales provides the habitat for all arthropods on which WRBA may feed, and habitat for vertebrates and arthropods that may compete with or prey on WRBA, and it may provide nursery habitat for trees. The foraging radii around WRBA roosting sites may also include some agricultural vegetation such as herbaceous crops and orchards. AZGFD (2011) and LCR MSCP (2016) state that WRBA forage within 600–1,000 yards (0.5–0.9 km) of their roosts, although they do not identify the source(s) of this information. As noted in the updates to chapter 2, the reporting of foraging movements by Mixan et al. (2015) does not include data tabulations on total foraging distances, but does include a narrative description of one individual foraging as far as 2 km from its roost site in the PVER, as well as narratives of WRBA foraging mostly in the immediate vicinity of their roosts. In turn, Anderson and Geluso (2018) typically captured foraging WRBA an average of 200 ± 10 m from their roost sites in southwestern New Mexico. As a rough estimate, therefore, the shrub and herbaceous vegetation within approximately a radius of 1,000 yards (or 0.9 km) of trees used or potentially usable by WRBA as roosting habitat therefore constitutes the matrix community for that riparian patch.

The LCR MSCP has collected data on shrub and herbaceous vegetation within and around riparian tree stands in the LCR ecosystem, both at habitat development sites and in protected areas including (BIO-WEST, Inc. 2010, 2011; Calvert 2008; Nelson and Andersen 1999; Nelson et al. 2014, 2015; Parametrix Inc., and GeoSystems Analysis, Inc. 2012, 2013, 2014, 2015; Pratt and Wiesenborn 2009; Reynolds et al. 2014). However, these investigations were carried out for other purposes and did not specifically seek to characterize the matrix community associated with WRBA roosting sites.

MONITORING, CAPTURE, HANDLING

This is a new habitat element in the CEM.

Full name: **The methods, frequencies, timing, and duration of (a) monitoring of WRBA habitat and (b) monitoring, capture, and handling of WRBA during field investigations**. Including this habitat element makes it possible for the CEM to address two topics: (1) the potential ways in which monitoring, capture, and handling can affect WRBA, for example by causing mechanical stress and (2) the potential ways in which WRBA behaviors, such as foraging and roosting behaviors, can affect the ability of different methods to detect the WRBA and affect decisions about monitoring practices. The monitoring of bats in the Lower Colorado River Valley, including WRBA, has long followed clear protocols for all monitoring practices, with routine reporting of protocols and their refinements (Berry et al. 2017; Broderick 2010, 2012a, 2012b, 2013, 2016; Brown 2006, 2010, 2013; Calvert 2010a, 2010b, 2012a, 2012b, 2013, 2016a, 2016b; Hill 2018; LCR MSCP 2008; Mixan and Diamond 2014, 2016, 2017a, 2017b, 2018a, 2018b, 2019a, 2019b; Mixan et al. 2012, 2013; Vizcarra and Piest 2009, 2010; Vizcarra et al. 2010). These protocols cover visual surveys, mist netting, the use of radio tracking devices, and acoustic monitoring and the digital processing of acoustic recordings. The protocols explicitly recognize and address needs to: (1) minimize stress and harm to bats captured in mist nets, (2) raise mist nets at specific times of the night to ensure they capture bats not as they leave their roosts but instead later during foraging, and (3) begin acoustic recording before sunset and end it after sunrise to ensure complete coverage of bat foraging activity. These protocols also require that radio tracking devices be attached only to larger individuals that can carry a device without stress (Mixan et al. 2015). Because of this latter requirement, the rate of growth in juvenile and adult WRBA affects the availability of individuals suitable for the attachment of a tracking device.

TEMPERATURE

The definition and discussion of this habitat element is updated as follows:

Full name: **The mean air temperature in and around existing or potential WRBA roosting and foraging habitat**. This element refers to the average temperature in the roosting habitat. Thermal regulation is necessary for survival WRBA in all life stages. Tree-roosting bats, in general, are more exposed to temperature fluctuations than cave- and mine-dwelling bats. WRBA exhibit adaptations to cold conditions, including thick fur and rounded ears. They may hibernate or migrate to the southern part of their range in winter, which includes the LCR (AZGFD 2011). Extreme temperatures in the LCR region in summer may kill pups or roosting adult WRBA. As noted in the updates to chapter 2, red bat pups (eastern and western species not distinguished) initially completely rely on the mother to maintain their body temperature in cold conditions by hanging onto the mother's fur with their teeth, thumb claws, and hind feet (Shump and Shump 1982).

TREE COMMUNITY

This is a new habitat element in the CEM.

Full name: **The taxonomic composition, size range, vertical and horizontal structure, canopy structure, patch size, abundances, and temporal (e.g., successional) dynamics of riparian woody canopy vegetation in and around existing or potential WRBA roosting and foraging habitat**. The original WRBA conceptual ecological model identified three habitat elements related to the tree community at and surrounding WRBA roosting sites: canopy cover, patch size, and riparian tree species composition. This update recognizes additional characteristics of the tree community at and surrounding WRBA roosting sites that may also affect WRBA ecology. The full name of the new habitat element identifies these additional, potentially relevant characteristics. This update also recognizes that ongoing investigations may yet identify other characteristics that also affect WRBA ecology. Rather than expand the number of habitat elements in the WRBA conceptual ecological model, each focused on a single characteristic of the tree community, this update addresses all such characteristics under the label of the single habitat element, tree community.

As noted in the "Definitions" immediately following the acronym list in this update, the WRBA conceptual ecological model recognizes plant communities as consisting of canopy, understory, shrub, and herbaceous layers. Trees, as well as woody vegetation greater than 2.0 m in height, make up the canopy layer and may also occur in the understory as subcanopy trees. Where trees are absent, shrubs comprise the uppermost layer of vegetation; where trees are present, shrubs and herbaceous plants make up the understory. This update addresses the shrubs and herbaceous layers together as a separate habitat element (see above, this chapter, "Matrix Community").

The discussion of roosting in the updates to chapter 3 summarizes the current understanding of characteristics of the tree community at locations where WRBA roost in the Lower Colorado River Valley, central California, and southwestern New Mexico. As indicated in that discussion, knowledge of WRBA roosting habitat affinities has expanded greatly since preparation of the original WRBA conceptual ecological model (Marty and Unnasch 2015). Table 3 summarizes numerous studies that have refined the understanding of characteristics of the tree community at WRBA roosting sites at three spatial scales: (1) the individual trees selected for roosting, including tree species, height, canopy closure, and canopy density, (2) the immediate vicinity of the roosting trees, including the species of tree present, and their heights and density, and (3) the overall riparian woodland patch within which the roosting trees occur, including patch size and tree density. These studies both confirm and expand on the inferences (LCR MSCP 2016; Marty and Unnasch 2015) previously drawn from knowledge of eastern red bat roosting behavior.

It should also be noted that some properties of the tree community may interact with each other in ways that increase the likelihood of WRBA roosting in one tree versus another. Specifically, as noted in table 3, the greater spacing of individual cottonwood trees at nursery plantings and the plot edges of treatment sites in the Lower Colorado River Valley "allows [these] trees to grow taller and develop larger DBH, which may provide more suitable western red bat roosting habitat" (Mixan et al. 2015). Similarly, a lack of crowding may allow isolated wild cottonwoods and trees on the edges of wild stands of cottonwood (e.g., along the Bill Williams River) also to grow taller and develop larger DBH. In turn, trees that rise above their neighbors or have no tall neighbors in at least some directions (e.g., trees on the edges of planted areas) likely develop larger (i.e., wider, taller, and/or more dense) canopies, conditions that further favor their use by WRBA as roosts.

Similarly, the discussion of foraging in the updates to chapter 3 summarizes the current understanding of the tree community at locations where WRBA forage in these same areas. As indicated in that discussion, knowledge of WRBA foraging habitat affinities also has expanded greatly since preparation of the original WRBA conceptual ecological model (Marty and Unnasch 2015). It is increasingly clear that WRBA forage preferentially in areas of the same cottonwood-willow vegetation type where they prefer to roost and show greater affinity for patches with larger areas, greater canopy complexity, greater availability of openings and edges within and along which to forage, and greater proximity to open water.

VERTEBRATE COMMUNITY

This is a new habitat element in the CEM.

Full name: **The taxonomic, functional, and size composition; abundance; activity levels; and temporal dynamics of the community of vertebrates—birds, mammals, reptiles, and amphibians— that may occur in or around existing or potential WRBA roosting and foraging habitat**. This element refers to the range of vertebrate species known or suspected to interact with WRBA or its habitat along the LCR, particularly as competitors, predators, or ecosystem engineers. The original WRBA conceptual ecological model identified a single habitat element related to the vertebrate community, predator density. This update recognizes that vertebrates may also compete with WRBA for food and habitat (see updates to chapter 3, "Competition"); that arthropods conceivably may also prey on WRBA (see updates to chapter 3, "Predation," and above, this chapter, "Arthropod Community"); and that vertebrates such as beavers (*Castor canadensis*), mule deer, and non-native cattle and burros can act as ecosystem engineers, altering riparian vegetation communities. The new habitat element, vertebrate community, therefore subsumes and expands on the habitat element, predator density, included in the original WRBA conceptual ecological model.

The discussion of predation on WRBA (chapter 3) identifies the three settings in which WRBA may be vulnerable to predation: (1) in their roosts; (2) from the air during foraging and inter-site movement; and (3) from the ground, when WRBA foraging activities bring them close to the ground. Further, because WRBA forage and travel only at night, their vulnerability to predation in the latter two settings occurs only at night. As also noted in the updates to chapter 3, the subject of predation on WRBA remains largely unstudied. On the other hand, studies of predation on bats in general (Mikula 2015; Mikula et al. 2016) and the list of settings in which WRBA may be vulnerable to predation provide a basis for identifying possible vertebrate predators of WRBA.

Climbing vertebrates that potential could prey on roosting WRBA mentioned in the original WRBA conceptual ecological model (Marty and Unnasch 2015) include opossums (*Didelphis virginiana*) and domestic cats (*Felis catus*); however, these two species are likely not threats to WRBA in the Lower Colorado River Valley. The former may prey on eastern red bats and the latter may prey on WRBA elsewhere in their range, but neither has been reported in the protected areas or habitat conservation areas along the Lower Colorado River Valley where WRBA are known to occur. This update identifies two other species as potential predators of roosting WRBA. The native ringtail cat (*Bassariscus astutus*) preys on small animals and is a highly capable climber that does occur along the Lower Colorado River Valley, including in riparian habitat (Mueller 2006). The native

Sonoran lyresnake (*Trimorphodon lambda*) (Brennan 2008), a climbing snake known to prey on roosting bats (Esbérard and Vrcibradic 2007),[5] also occurs in the greater Lower Colorado River Valley: An individual photographed in the Planet Ranch section of the Lower Bill Williams River Valley in 2014 was recently confirmed as *T. lambda* (J. Hill 2019, personal communication).

Following Mikula (2015; Mikula et al. 2016), this update identifies nocturnal raptors as a crucial category of likely predators of WRBA in flight. Owls that potentially could prey on WRBA at night along the Lower Colorado River Valley include the barn owl (*Tyto alba*), ferruginous pygmy-owl (*Glaucidium brasilianum*), great horned owl, and western screech-owl (*Otus kennicottii*) (Arizona-Sonora Desert Museum 2019); however, the subject of owl predation on WRBA has not been studied.

As noted in the discussion of competition with WRBA (chapter 3), other bats and other insectivorous vertebrates may compete for food with WRBA adults; however, the literature reviewed for this update provides no information on such competition with WRBA for food in the Lower Colorado River Valley or elsewhere. On the other hand, the literature does identify at least three vertebrates that may compete with WRBA for habitat or otherwise modify WRBA roosting habitat. Beavers can alter riparian vegetation communities in the Southwestern United States by removing cottonwood and willow. Both species were once common in the LCR ecosystem (Grinnell 1914; Minckley and Rinne 1985; Ohmart et al. 1988) and is increasingly active there today (Hautzinger 2010; Mueller 2006; Shafroth and Beauchamp 2006; Vizcarra and Piest 2010). Beaver activity may alter riparian vegetation communities in other ways, as well. Their activity along one section of the Bill Williams River has "… maintain[ed] fluctuating water levels and pathways, which has limited colonization of saltcedar and promoted growth of native wetland vegetation" (Cotten and Grandmaison (2013) while simultaneously favoring colonization of saltcedar immediately around such inundated areas (Miller and Leavitt 2015; O'Donnell and Leavitt 2017a, 2017b).

Grazing by mule deer and by non-native cattle and burros across the arid Southwestern United States, in turn, can degrade riparian habitat. For example, grazing may thin the understory or prevent the establishment of cottonwood and willow seedlings (Kauffman et al. 1997). Krueper (1993) and Krueper et al. (2003) report that fencing cattle out of sensitive riparian habitats in the San Pedro Riparian National Conservation Area in southeastern Arizona led to improved habitat quality and increased riparian bird density within 4 years.

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[5] Esbérard and Vrcibradic (2007) specifically address *T. biscutatus*, the western lyresnake, of which the Sonoran lyresnake was until recently considered a subspecies.

WATER AVAILABILITY

The definition and discussion of this habitat element is updated as follows:

Full name: **The spatial and temporal availability of water, particularly the presence and distance of surface water, including small pools, and the depth of the water table in and around existing or potential WRBA roosting and foraging habitat**. This element refers to the presence of surface water near roost sites, which may be an important landscape-scale factor for WRBA roost site selection. A study of eastern red bat roosting habitat preferences found this species to prefer mature riparian forests near trails, open water, and wetlands (Limpert et al. 2007). This element may affect WRBA indirectly by affecting the arthropod, matrix, tree, and vertebrate communities (see above, this chapter). For example, falling water tables, in turn, have been linked to changes in the riparian vegetation community, with declines in cottonwood and willow species and increases in non-native saltcedar (Stromberg 1998).

Updates to Chapter 5 – Controlling Factors

This update identifies seven controlling factors that affect one or more habitat elements and/or critical biological activities or processes across the three WRBA life stages. The original WRBA conceptual ecological model (Marty and Unnasch 2015) identified eight controlling factors. This update adds one entirely new controlling factor, conservation monitoring and research programs; integrates three original controlling factors (grazing, tree thinning, and pesticide application) into a new controlling factor, surrounding land use, which also addresses land uses such as recreation and agriculture; renames the controlling factor identified in the spreadsheet as fire to fire management; and renames habitat restoration to habitat development and management. The reasons for these changes are presented below in this chapter. Table 5 lists the seven controlling factors in this update, indicates which habitat elements they *directly* affect, and indicates which controlling factors are new to this update or renamed from the original WRBA conceptual ecological model.

Table 5.—(Revision of original table 4) WRBA controlling factors and the habitat elements they directly affect

(Xs indicate the habitat elements that affect each critical biological activity or process. The table does not show three habitat elements that are not directly affected.)

Habitat element ➔ **Controlling factor 🡻**	Anthropogenic disturbance	Arthropod community	Chemical contaminants	Fire regime	Infectious agents	Matrix community	Monitoring, capture, handling	Tree community	Vertebrate community	Water availability
Conservation monitoring and research programs (*new*)							X			
Fire management (*renamed in workbook*)				X						
Habitat development and management (*renamed*)	X					X		X		
Nuisance species introduction and management		X	X	X	X	X		X	X	
Surrounding land use (*new*)	X	X	X			X		X	X	
Water storage-delivery system design and operation										X
Wind energy development	X									

As noted in the original WRBA conceptual ecological model, a hierarchy of controlling factors exists, affecting every ecosystem, with long-term dynamics of climate and geology at the top; however, this CEM focuses on controlling factors that are within the scope of potential human manipulation. Further, as also noted in the original WRBA conceptual ecological model, the controlling factors identified do not constitute individual variables; rather, each identifies a category of variables (including human activities) that share specific features that make it useful to treat them together.

CONSERVATION MONITORING AND RESEARCH PROGRAMS

This update adds this controlling factor to provide a driver for monitoring activities.

Full Name: **The types, frequencies, and duration of monitoring and research activities carried out by the LCR MSCP, U.S. Fish and Wildlife Service, States, and Tribes focused on species and habitats of concern to their respective wildlife conservation programs**. The Habitat Conservation Plan (HCP) (Reclamation 2004) for the LCR mandates the LCR MSCP, in particular, to carry out conservation measures to meet the biological needs of 5 threatened or endangered species and 19 other covered species, and to potentially benefit 5 evaluation species. The LCR MSCP carries out many of these conservation measures in partnership with other agencies. The conservation measures include monitoring of species distributions as well as several types of research investigations. The current LCR MSCP annual work plan and 5-year monitoring and research priorities specifically call for field-based research investigations to characterize habitat requirements and habitat conditions, including conditions at created and managed habitat sites, for 22 species, including WRBA (LCR MSCP 2018a, 2018b).

FIRE MANAGEMENT

This update renames this controlling factor in the WRBA conceptual ecological model workbook, where it was named simply fire. The original WRBA conceptual ecological model used the label, fire management, in the report, but only fire in the workbook. Further, the original workbook addressed both fire management and the fire regime itself under the umbrella of this controlling factor. This update separates the controlling factor, fire management, from the habitat element, fire regime, as discussed in the updates to chapter 4. This update also revises the definition of the controlling element as follows:

Full name: **The types, frequencies, and duration of activities intended to control and/or suppress fire in and around existing or potential WRBA roosting and foraging habitat and across lands surrounding these locations**. The LCR MSCP and other land management agencies along the Lower Colorado River and Bill Williams River Valleys may use prescribed fire as a management tool and may actively manage wildfires through fire suppression and the construction of fire control breaks (LCR MSCP 2018a). Wildfire is a natural type of disturbance in the riparian plant communities of the Lower Colorado River Valley, and wildfires today also occur through human accidents (Conway et al. 2010; LCR MSCP 2018a). In fact, wildfires have occurred recently at LCR MSCP restoration sites (Hunters Hole and Yuma East Wetlands) and in riparian habitat at the Havasu National Wildlife Refuge and Cibola National Wildlife Refuge-Island Unit (J. Hill and C. Ronning 2018, joint personal communication; Hill 2018; LCR MSCP 2018a).

HABITAT DEVELOPMENT AND MANAGEMENT

This update renames the controlling factor in the original WRBA conceptual ecological model, habitat restoration, to habitat development and management, to clarify that the factor includes both the development and management of conservation habitat. Further, this update revises the definition of this factor as follows:

Full name: **The types, frequencies, and durations of actions taken by the LCR MCP to create and manage habitat for species conservation in and around existing or potential WRBA roosting and foraging habitat, including actions to affect the taxonomic composition, abundance, condition, and spatial distribution of vegetation**. The HCP mandates the LCR MSCP to carry out conservation measures to meet the biological needs of 5 threatened or endangered species and 19 other covered species, and to potentially benefit 5 evaluation species. These measures include creating and managing habitat to meet these biological needs through the manipulation particularly of vegetation and hydrology. The LCR MSCP and other land managers along the Lower Colorado River and Bill Williams River Valleys use a range of methods to establish and manage the vegetation (see updates to chapter 4, "Matrix Community" and "Tree Community") on lands under their authorities, including prescribed fire, surface irrigation and subirrigation, planting, fertilizing, thinning and hand removal, discing and plowing, and the application of herbicides (Reclamation 2004; LCR MSCP 2014, 2018a). Agencies and irrigation and drainage districts may also remove vegetation to maintain roads and canals under their authorities. The renamed controlling factor partially incorporates two controlling factors from the original WRBA conceptual ecological model, pesticide/herbicide application and tree thinning, to the extent that those original categories concerned actions taken to create and manage habitat for species conservation (versus taken on surrounding lands; see below).

NUISANCE SPECIES INTRODUCTION AND MANAGEMENT

The definition of this controlling factor is updated as follows:

Full name: **The introduction and management of nuisance species that potentially may interact with WRBA in and around existing or potential WRBA roosting and foraging habitat**. Nuisance species are non-native animals, plants, and micro-organisms that were not introduced and/or are not managed for recreational purposes; and may poison, infect, prey on, compete with, or present alternative food resources for native species; cause other alterations to the food web that affect native species; or affect habitat features such as vegetation cover. The factor includes the legacy of past introductions, and the potential for additional introductions, and includes both intentional and accidental introductions. Management activities may include efforts to control the spread of nuisance species through interdiction and education, and may include efforts to reduce the abundance and/or geographic range of species through mechanical removal, prescribed fire, applications of biocidal chemicals, and releases of biological controls. Agencies involved in nuisance species management along the Lower Colorado River and Bill Williams River Valleys include the Bureau of Land Management, State of Arizona U.S. Fish and Wildlife Service, Reclamation, Indian Tribes, and irrigation districts.

SURROUNDING LAND USE

This update adds this new controlling factor to the original WRBA conceptual ecological model.

Full name: **The types and intensities of human activity on lands surrounding habitat conservation areas and other protected areas used or potentially usable by WRBA as roosting and/or foraging habitat**. The lands surrounding LCR MSCP habitat conservation areas and other protected areas—particularly surrounding locations used or potentially usable by WRBA as roosting sites—are subject to a wide range of uses. These uses include irrigation farming, grazing, recreation, and multi-purpose range management. These uses frequently affect the taxonomic composition, abundance, condition, and spatial distribution of vegetation on these lands. Irrigation farming, in particular, replaces native and otherwise uncontrolled vegetation with annual crops and orchards. Farmlands are subject to surface irrigation and subirrigation, planting, fertilizing, thinning and hand removal, discing and plowing, and the application of herbicides. The renamed controlling factor partially incorporates three controlling factors in the original WRBA conceptual ecological model—grazing, pesticide/herbicide application, and tree thinning—to the extent that those original categories concerned human activities on surrounding lands (versus taken on sites created and managed as habitat for species conservation; see below).

WATER STORAGE-DELIVERY SYSTEM DESIGN AND OPERATION

Full name: **The design and operation of the water storage, diversion, and delivery system that regulates the elevation of surface water in and around existing or potential WRBA roosting and foraging habitat**. The Colorado River through the Lower Colorado River Valley consists of a chain of reservoirs separated by flowing reaches. The water moving through this system is highly regulated by Reclamation for storage and delivery to numerous international, Federal, State, Tribal, municipal, and agricultural holders of water rights, as well as for hydropower generation. The Bill Williams River below Alamo Dam similarly is regulated by the U.S. Army Corps of Engineers for flood control, recreation, water conservation, and wildlife conservation. This system of water management and its infrastructure, together with regulated discharges from the Upper Colorado River Basin and local weather conditions, determine surface water elevations and groundwater elevations along the Lower Colorado River and Bill Williams River Valleys, and it deliveries of water to off-channel locations, including protected areas and habitat conservation areas (Reclamation 2004). River regulation and entrenchment of the LCR between the reservoirs have eliminated almost all opportunities for the river to deliver pulses of water onto its former floodplain and have altered water table elevations throughout the valley. Reclamation, the U.S. Fish and Wildlife Service, and other agencies have rights to use some of the water in the LCR on lands managed as wildlife habitat, delivered through surface water diversions and groundwater wells (LCR MSCP 2014, 2018a).

WIND ENERGY DEVELOPMENT

The definition of this controlling factor is updated as follows:

Full name: **The construction, operation, and maintenance of wind energy facilities and their associated infrastructure in and around existing or potential WRBA roosting and foraging habitat or migratory routes**. While there are currently no wind turbines located along the LCR, it is likely that bats foraging near active wind turbines, including WRBA migrating to and from the LCR, could be killed. Lasiurines tend to be disproportionately affected by these facilities (Arnett 2005; Arnett and Baerwald 2013; Hayes 2013; Kunz et al. 2007).

Updates to Chapter 6 – Conceptual Ecological Model by Life Stage

The following sections identify all changes made to the WRBA conceptual ecological model workbook other than changes that involve only updates to names. These latter changes are listed separately in table 6 (see “Summary of Updated of Terms for WRBA Conceptual Ecological Model” at the end of this chapter). The items in each section of this chapter are arranged alphabetically. The abbreviations, CF for controlling factor, HE for habitat element, CAP for critical activity or process, and LSO for life-stage outcome are provided to identify component types where needed. Each item also identifies the life stage(s) to which the item applies.

NEW LINKS WITH CONTROLLING FACTORS AS CAUSAL AGENTS

- Habitat Development and Management effects on Conservation Monitoring and Research Programs (CF): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model. The effect node in this link is a new controlling factor added to the CEM. LCR MSCP and partner decisions on habitat development and management determine where monitoring of WRBA should occur and also affects where research studies may occur. In addition, LCR MSCP management of habitat management sites can affect monitoring of WRBA at the sites when the clearing of fire-control zones, thinning or removal of vegetation, or creation of linear patches affects lines of sight for visual monitors and the availability of openings for placement of mist nets or acoustic monitoring stations. The link is hypothesized to be complex and unidirectional with proposed high intensity, spatial scale, and temporal scale; high predictability; and high understanding. *Applies to all life stages*.

- Habitat Development and Management effects on Fire Management (CF): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model. The effect node in this link is a clarification: the original CEM included fire management as a controlling factor in the report, but included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics. Managers of protected areas and habitat conservation sites that presently or potentially could support WRBA take habitat development or management objectives into account when making decisions about fire management at these sites; however, the reports reviewed for this update do not discuss how WRBA habitat development or conservation objectives are taken into account in fire management decisions. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Habitat Development and Management effects on Nuisance Species Introduction and Management (CF): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model. The effect node in this link is unchanged from the original CEM. Managers of protected areas and habitat conservation sites that presently or potentially could support WRBA take habitat development or management objectives into account when making decisions about nuisance species management at these sites; however, the reports reviewed for this update do not discuss how WRBA habitat development or conservation objectives are taken into account in decisions concerning the management of nuisance species at WRBA habitat development or conservation sites. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Habitat Development and Management effects on Water Storage-Delivery System Design and Operation (CF): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model. The effect node in this link is unchanged from the original CEM. The LCR MSCP manages water applications on known and potential WRBA habitat sites to achieve habitat development and management objectives, through the exercise of its water rights, which requires calls on the surface water delivery system and on groundwater. The link is hypothesized to be complex and unidirectional with proposed high intensity, high spatial scale, and low temporal scale; medium predictability; and high understanding. *Applies to all life stages*.

- Surrounding Land Use effects on Fire Management (CF): The causal node in this link is a new controlling factor added to the original WRBA conceptual ecological model. The effect node in this link is a clarification: the original CEM included fire management as a controlling factor in the report, but included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics. Management of lands surrounding known and potential WRBA habitat sites may affect the incidence of wildfires or escaped prescribed fires on these sites to which site fire managers must respond. Management of wildfires and the use of prescribed fire are commonplace across the portions of the Lower Colorado River Valley that include WRBA habitat and are likely zones of origin of fires that could affect WRBA sites. The link is hypothesized to be complex and unidirectional with proposed medium intensity, spatial scale, and temporal scale; high predictability; and medium understanding. Although the specifics will differ from one WRBA habitat site to the next, it will always be the case that fire managers for these habitat sites will take surrounding land conditions into consideration when thinking about how to manage fire conditions onsite; however, while the principles of this relationship are well understood in general, the relationship has not been studied specifically for WRBA habitat and its surroundings along the Lower Colorado River Valley. *Applies to all life stages.*

- Surrounding Land Use effects on Wind Energy Development (CF): The causal node in this link is a new controlling factor added to the original WRBA conceptual ecological model. The effect node in this link is unchanged. Theoretically, the siting of wind turbines and associated access roads and utility corridors depends on the distribution of compatible land uses, and the siting of such infrastructure, in turn, can affect land use within their vicinities. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The reports reviewed for this update do not discuss whether or to what extent wind energy development is taking place along the Lower Colorado River Valley or how it relates to existing land uses. The information on this link can be updated if/as wind energy development takes place along the valley. *Applies to all life stages.*

- Water Storage-Delivery System Design and Operation effects on Nuisance Species Introduction and Management (CF): The causal and effect nodes are unchanged from the original WRBA conceptual ecological model, but the original CEM did not address their interaction. Theoretically, surface water deliveries from regulated waters can carry in nuisance plant propagules and small aquatic fauna to habitat management areas, and water deliveries may be managed in part to help suppress nuisance species through intentionally prolonged inundation or drying of habitat management areas. The link is hypothesized to be complex and bi-directional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The reports reviewed for the original CEM and this update do not discuss whether or to what extent water deliveries may introduce nuisance species to known or potential WRBA habitat along the Lower Colorado River Valley or the extent to which water deliveries may be used by habitat managers as a tool for controlling nuisance species in such habitat. *Applies to all life stages.*

- Conservation Monitoring and Research Programs effects on Monitoring, Capture, Handling (HE): Both the causal and effect nodes are new additions to the original WRBA conceptual ecological model. The HCP mandates the LCR MSCP, in particular, to carry out conservation measures to meet the biological needs of 5 threatened or endangered species and 19 other covered species, and to potentially benefit 5 evaluation species. The HCP identifies the WRBA as a covered species (Reclamation 2004). The LCR MSCP carries out many of these conservation measures in partnership with other agencies. The conservation measures include monitoring of species distributions as well as several types of research investigations. The current LCR MSCP annual work plan and 5-year monitoring and research priorities specifically call for field-based research investigations to characterize habitat requirements and habitat conditions, including conditions at created and managed habitat sites, for 22 species including WRBA (LCR MSCP 2018a, 2018b). The AZGFD has carried out several studies for the LCR MSCP in order to develop recommendations for best monitoring practices of WRBA management. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional, with high intensity, spatial scale, and temporal scale; high predictability; and high understanding. *Applies to all life stages*.

- Fire Management effects on the Fire Regime (HE): The causal and effect nodes in this link are clarifications: the original WRBA conceptual ecological model included fire management as a controlling factor in the report, but included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics. Current and potential WRBA habitat sites in the Lower Colorado River Valley are located in a landscape highly managed for fire control and in which fire patterns are determined by decisions on wildfire suppression or control and on the use of prescribed fire to manage vegetation. The link is hypothesized to be complex and unidirectional with proposed high intensity, spatial scale, and temporal scale; high predictability; and medium understanding. Fire management is the dominant determinant of the fire regime at current and potential WRBA habitat sites, both through the management of wildfire and through prescribed fire; however, while the principles of this relationship are well understood in general, the relationship has not been studied specifically with respect to WRBA habitat. *Applies to all life stages*.

- Habitat Development and Management effects on Anthropogenic Disturbance (HE): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model. The effect node in this link is unchanged from the original CEM. Activities associated with habitat development and management may result in human disturbance in areas with WRBA roosting habitat. Human activities may affect roosting and reproduction, especially if pregnant and lactating females are present in areas of habitat development or management, by analogy with such effects observed among WRBA roosting in orchards subject to high levels of human activity (Constantine 1959). Humans merely talking and walking around roost sites does not appear to substantially disturb bats, but active work in the forests or in other habitat where WRBA are roosting may adversely affect roosting individuals and potentially disrupt reproduction (e.g., tending of young during early development phases) (Dudek and ICF International 2012). The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; high predictability; and medium understanding. The reports reviewed for this update do not discuss whether or to what extent habitat development and management at known or potential WRBA habitat sites involves human activities that could disturb WRBA activities. *Applies to all life stages*.

- Habitat Development and Management effects on the Matrix Community (HE): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model, incorporating and expanding on the original definition to include several activities, such as tree thinning, that the original CEM handled separately. The effect node in this link is unchanged from the original CEM. Habitat development and management at known or potential WRBA habitat sites may change the matrix community significantly by replacing other vegetation types with riparian vegetation or by managing the composition of the matrix community itself such as through the removal of nuisance species. The link is hypothesized to be complex and unidirectional with proposed medium intensity, medium spatial scale, and high temporal scale. Spatially, habitat development and management decisions are made at the scale of individual habitat sites. Temporally, habitat development and management sites are heavily managed to achieve long-term objectives under the LCR MSCP Habitat Conservation Plan. The proposed link predictability is high: Other factors, such as grazing, fire and, water management, also affect vegetation at known and potential WRBA habitat sites along the Lower Colorado River Valley, but their effects on link predictability are also well understood. The proposed link understanding is medium: The LCR MSCP continues to adapt its habitat development and management practices as its knowledge increases concerning what practices work better than others. *Applies to all life stages*.

- Habitat Development and Management effects on the Tree Community (HE): The causal node in this link is an update of the controlling factor, habitat restoration, in the original WRBA conceptual ecological model. The effect node in this link is a new addition to the CEM that incorporates and expands on the several separate habitat elements in the original CEM focused on the tree community (see updates to chapter 4). Habitat development and management practices are the dominant factors shaping the tree community at all LCR MSCP habitat sites managed for riparian vegetation to support LCR MSCP threatened and covered species. Associated habitat development and management practices include earth moving, tilling, irrigation, and mechanical thinning, and the LCR MSCP is authorized to use prescribed fire and herbicides as management tools as well. Planting and thinning may be designed to achieve particular goals of stand composition, density, and vertical structure, and the duration of habitat development and management determines overall stand age and maturity. The link is hypothesized to be complex and unidirectional with proposed high intensity, low spatial scale, and high temporal scale, for three reasons: (1) Habitat development and management regimes have the ability to greatly affect vegetation, (2) habitat development and management decisions are made at the scale of individual habitat sites, and (3) habitat development and management sites are heavily managed to achieve long-term objectives under the LCR MSCP Habitat Conservation Plan. The link is proposed to have high predictability because, while other factors such as grazing, fire and water management, etc., also affect vegetation at known and potential WRBA habitat sites along the Lower Colorado River Valley, their effects are known and taken into account. The link is proposed to have medium understanding. The LCR MSCP continues to adapt its habitat development and management practices as its knowledge increases concerning what practices work better than others. *Applies to all life stages*.

- Nuisance Species Introduction and Management effects on the Arthropod Community (HE): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The effect node is a new addition to the CEM, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). The arthropod community may include non-native species with food value for WRBA and/or different ecological characteristics compared to native arthropods. For example, the northern tamarisk beetle, introduced as a biocontrol agent, strongly affects vegetation through its strong impact on saltcedar. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. For example, the introduced northern tamarisk beetle has affected saltcedar stands along the Lower Colorado River Valley, but there are no data on any other possible effects of this species on the arthropod community. *Applies to all life stages*.

- Nuisance Species Introduction and Management effects on Chemical Contaminants (HE): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The original CEM did not propose a separate habitat element for chemical contaminants; however, it did note that WRBA are vulnerable to chemical stress (see updates to chapter 3) and identified some possible sources of contaminants that could result in such stress. This update adds this new habitat element to the CEM so that the CEM better identifies the causal chains that could result in chemical stress to WRBA in any life stage (see updates to chapter 4). Spraying of biocides (herbicides, pesticides) to control nuisance plants and insects on surrounding lands could introduce chemical contaminants into protected areas and habitat conservation sites used by WRBA. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The link is proposed as a theoretical possibility; however, the subject has not been studied for the Lower Colorado River Valley. *Applies to all life stages.*

- Nuisance Species Introduction and Management effects on Infectious Agents (HE): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The effect node in this link is a revision to a similar habitat element in the original CEM that also nominally included, but did not substantively address, WRBA genetic diversity (see updates to chapter 4). Nuisance species may include or carry pathogens to which WRBA are susceptible. NatureServe (2019) specifically notes that WRBA are "not known or expected to be affected by white-nose syndrome." However, the range of this non-native infectious agent is expanding westward in the United States. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional based on the assumption that the greater the number of nuisance mammal and arthropod species arriving in the Lower Colorado River Valley, the greater the chances one or more will carry or be an infectious agent for WRBA. The link has unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding; however, the subject has not been studied for the Lower Colorado River Valley or WRBA in general. *Applies to all life stages.*

- Nuisance Species Introduction and Management effects on the Matrix Community (HE): The causal and effect nodes in this link are unchanged from the original WRBA conceptual ecological model, but the original CEM did not include their interaction as a causal link. Invasive species can change the structure of entire vegetation communities, as has occurred in the Lower Colorado River Valley with the spread of saltcedar. The link is hypothesized to be complex and unidirectional, with effects that vary by species and community type. The link is proposed to have high intensity, spatial scale, and temporal scale. Invasive species can significantly alter the structure of entire communities with widespread and lasting effects as they spread across entire regions and cause changes that can last decades. Predictability is low: Effects vary by species and community type, and it is usually not known how the introduction of exotic species will affect the natural community. Understanding is medium: The effects of some exotic species (e.g., saltcedar) are fairly well-known in the Lower Colorado River Valley. *Applies to all life stages.*

- Nuisance Species Introduction and Management effects on the Vertebrate Community (HE): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The effect node is a new addition to the original CEM, replacing and expanding on the original habitat element, predator density (see updates to chapter 4). Nuisance species in the Lower Colorado River Valley include terrestrial vertebrates such as feral pigs, burros, bullfrogs, etc., that at the very least can alter habitat for WRBA; however, there are no studies of how introduced terrestrial vertebrates have affected the overall structure or ecology of the Lower Colorado River Valley terrestrial vertebrate community. The link is hypothesized to be complex and unidirectional, with effects that vary by species and community type, with proposed high intensity, spatial scale, and temporal scale; high predictability; and low understanding. *Applies to all life stages*.

- Surrounding Land Use effects on Anthropogenic Disturbance (HE): The causal node in this link is a new controlling factor added to the original WRBA conceptual ecological model. The effect node in this link is unchanged from the original CEM. Surrounding land use can be an important source of anthropogenic disturbance such as noise. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional, and it assumes that the greater the intensity of surrounding land use, the greater the likelihood of anthropogenic disturbance to WRBA habitat. The link has unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Surrounding Land Use effects on the Arthropod Community (HE): The causal and effect nodes are both new additions to the original WRBA conceptual ecological model. Surrounding land uses can affect the arthropod community across WRBA habitat by fostering or suppressing the abundances of arthropods on which WRBA may feed or which may compete with WRBA for prey. The link is hypothesized to be complex and unidirectional, with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Surrounding Land Use effects on Chemical Contaminants (HE): The causal node is a new addition to the original WRBA conceptual ecological model. The effect node is an existing habitat element in the CEM. Surrounding land uses may entail applications of herbicides, pesticides, or fertilizers, or releases of other chemicals that may cause harm to WRBA if they spread into WRBA habitat. The link is hypothesized to be complex and unidirectional with medium intensity, low spatial scale, and low temporal scale. The most likely scenario involves pesticide applications at individual agricultural fields affecting nearby patches and the effects dissipating within a decade after application. Predictability and understanding are both low: It is not known when pesticide applications may occur, which pests may be targeted, or how landowners will apply the pesticides. Pesticides harm arthropods by design, but impacts on WRBA will depend on pesticide type, mode of application, and other factors. *Applies to all life stages*.

- Surrounding Land Use effects on the Matrix Community (HE): The causal node in this link is a new addition to the original WRBA conceptual ecological model, incorporating and expanding on controlling factors in the CEM that addressed more activities such as grazing, tree thinning, etc. The effect node in the link is unchanged from the original CEM. Surrounding land uses, including farming, livestock grazing, and habitat management, all necessarily affect many aspects of the matrix community vegetation structure and composition. The link is hypothesized to be complex and unidirectional with proposed high intensity, spatial scale, and temporal scale. Surrounding land uses are typically stable over long periods of time across large areas. Predictability and understanding are medium: The effects depend on the type of land use, with range and habitat management having the fewest effects and farming the greatest. These relationships are well understood in general, even if not systematically studied along the Lower Colorado River Valley. *Applies to all life stages*.

- Surrounding Land Use effects on the Tree Community (HE): The causal node in this link is a new addition to the original WRBA conceptual ecological model, incorporating and expanding on controlling factors in the CEM that addressed more specific activities such as grazing, tree thinning, etc. The effect node in the link also is a new addition to the CEM, incorporating and expanding on habitat elements in the original CEM that addressed more specific aspects of tree community structure and composition. Surrounding land uses, including farming, livestock grazing, and habitat management, may affect tree community vegetation structure and composition at and around WRBA roosting habitat by intruding into this habitat (e.g., livestock) or altering the surroundings in ways that affect dynamics within this habitat. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Surrounding Land Use effects on the Vertebrate Community (HE): The causal node in this link is a new addition to the original WRBA conceptual ecological model, incorporating and expanding on controlling factors in the original CEM that addressed more specific activities such as grazing, tree thinning, etc. The effect node in the link also is a new addition to the CEM, incorporating and expanding on an single habitat element in the original related to the vertebrate community, predator density. Surrounding land uses, including farming, livestock grazing, and habitat management. may affect the abundance and composition of the vertebrate community at and around WRBA roosting habitat. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Wind Energy Development effects on Anthropogenic Disturbance (HE): The causal and effect nodes in this proposed link both exist in the original WRBA conceptual ecological model, but the original CEM did not include their interaction as a causal link. Noise, unusual winds and turbulence, and electromagnetic disturbances associated with wind turbine installation and operation are thought to pose hazards to bats, although these possible relationships have not been studied for the Lower Colorado River Valley or WRBA in particular. Nevertheless, it is highly likely that bats foraging in proximity to active wind turbines will be killed and that lasiurines tend to be disproportionately impacted by these facilities (Arnett 2005; Hayes 2013). The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley; however, the link assumes that the greater the extent and intensity of future wind energy development in and around WRBA habitat, the greater the potential for anthropogenic disturbances affecting WRBA. *Applies to all life stages*.

DELETED LINKS WITH CONTROLLING FACTORS AS CAUSAL AGENTS

- Effects of Fire on Nuisance Species Introduction and Management (CF). This update corrects the original WRBA conceptual ecological model spreadsheet use of the label, fire, to refer to either the controlling factor, fire management, or the habitat element, fire regime, depending on the details of the causal relationship. Further, this update clarifies that fire management does not directly affect nuisance species management. Instead, fire management affects the fire regime, which both affects and is affected by the composition and structure of various vegetation communities, which in turn both affect and are affected by nuisance species introductions and management. *Applies to all life stages*.

- Effects of Fire on Canopy Cover. This update corrects the original WRBA conceptual ecological model spreadsheet use of the label, fire, to refer to the controlling factor, fire management. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Fire on Patch Size. This update corrects the original WRBA conceptual ecological model spreadsheet use of the label, fire, to refer to the controlling factor, fire management. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Fire on Riparian Tree Species Composition. This update corrects the original WRBA conceptual ecological model spreadsheet use of the label, fire, to refer to the controlling factor, fire management. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Grazing on Patch Size (HE). This update incorporates grazing into the new controlling factor, surrounding land use, which also addresses several other activities such as tree thinning and pesticide application formerly also addressed as separate controlling factors. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Grazing on Riparian Tree Species Composition (HE). This update incorporates grazing into the new controlling factor, surrounding land use, which also addresses several other activities such as tree thinning and pesticide application formerly also addressed as separate controlling factors. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Grazing on the Matrix Community (HE). This update incorporates grazing into the new controlling factor, surrounding land use, which also addresses several other activities such as tree thinning and pesticide application formerly also addressed as separate controlling factors. *Applies to all life stages*.

- Effects of Habitat Restoration on Canopy Cover. This update incorporates the original controlling factor, habitat restoration, into the new controlling factor, habitat development and management, which also incorporates specific vegetation management practices, such as tree thinning, that the original WRBA conceptual ecological model treated as a separate controlling factor. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Habitat Restoration on Patch Size. This update incorporates the original controlling factor, habitat restoration, into the new controlling factor, habitat development and management, which also incorporates specific vegetation management practices, such as tree thinning, that the original WRBA conceptual ecological model treated as a separate controlling factor. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Habitat Restoration on Riparian Tree Species Composition. This update incorporates the original controlling factor, habitat restoration, into the new controlling factor, habitat development and management, which also incorporates specific vegetation management practices, such as tree thinning, that the original WRBA conceptual ecological model treated as a separate controlling factor. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Habitat Restoration on the Matrix Community (HE). This update incorporates the original controlling factor, habitat restoration, into the new controlling factor, habitat development and management, which also incorporates specific vegetation management practices, such as tree thinning, that the original WRBA conceptual ecological model treated as a separate controlling factor. *Applies to all life stages*.

- Effects of Nuisance Species Introduction and Management on Riparian Tree Species Composition. This update incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Pesticide Application on Food Availability (HE). This update drops pesticide application as a controlling factor, treating this activity instead as an aspect of both habitat development and management and surrounding land use. In turn, this update drops food availability as a habitat element, incorporating the associated information into the definition of the new habitat element, arthropod community. *Applies to all life stages*.

- Effects of Tree Thinning on Canopy Cover. This update incorporates tree thinning into two new controlling factors, habitat development and management, and surrounding land use. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Tree Thinning on Riparian Tree Species Composition. This update incorporates tree thinning into two new controlling factors, habitat development and management, and surrounding land use. This update also incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Tree Thinning on the Matrix Community (HE). This update incorporates tree thinning into two new controlling factors, habitat development and management, and surrounding land use. *Applies to all life stages*.

- Effects of Tree Thinning on the Tree Community (HE). This update incorporates tree thinning into two new controlling factors, habitat development and management, and surrounding land use, both of which address other activities such as pesticide application formerly also addressed as separate controlling factors. *Applies to all life stages*.

- Effects of Water Storage-Delivery System Design and Operation on Riparian Tree Species Composition (HE). This update incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Wind Energy Development on the Matrix Community (HE). This update drops this link because the impacts of wind energy development on the matrix community do not appear to be ecologically sufficiently relevant to include. They are not known to be occurring, and if they were to occur, would likely be too small in spatial scale to affect WRBA ecology.

UPDATED LINKS WITH CONTROLLING FACTORS AS CAUSAL AGENTS

- Effects of Nuisance Species Introduction and Management on the Tree Community. This update replaces the separate habitat elements, canopy cover, patch size, and riparian tree species composition with the new habitat element, tree community. This update also revises the link reason to state that invasive species can change the structure of entire vegetation communities, as has occurred in the Lower Colorado River Valley with the spread of saltcedar. *Applies to all life stages*.

NEW LINKS WITH HABITAT ELEMENTS AS CAUSAL AGENTS THAT AFFECT HABITAT ELEMENTS

- Chemical Contaminants effects on the Arthropod Community (HE): The original WRBA conceptual ecological model did not propose a separate habitat element for chemical contaminants; however, it did note that WRBA are vulnerable to chemical stress (see updates to chapter 3) and identified some possible sources of contaminants that could result in such stress. This update adds chemical contaminants as a new habitat element so that the CEM better identifies the causal chains that could result in chemical stress to WRBA in any life stage (see updates to chapter 4). The effect node also is a new addition to the original CEM, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). Chemical contaminants in and around WRBA roosting and foraging habitat presumably can affect the abundance of arthropods and the composition of the arthropod community there either directly when directly harmful to arthropods or indirectly when the contaminants affect the vegetation. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Chemical Contaminants effects on the Matrix Community (HE): The original WRBA conceptual ecological model did not propose a separate habitat element for chemical contaminants; however, it did note that pesticide use within WRBA habitat or on surrounding lands could alter habitat conditions that affect WRBA. This update adds chemical contaminants as new habitat element so that the CEM better identifies the causal chains that could result in such effects on WRBA habitat (see updates to chapter 4). Chemical contaminants on lands surrounding WRBA roosting and foraging habitat presumably might affect the density and composition of the matrix community there either by directly affecting the vegetation or by affecting fauna (arthropods, vertebrates) that help shape the community. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages.*

- Chemical Contaminants effects on the Tree Community (HE): The original WRBA conceptual ecological model did not propose a separate habitat element for chemical contaminants; however, it did note that pesticide use within WRBA habitat or on surrounding lands could alter habitat conditions that affect WRBA. This update adds chemical contaminants as new habitat element so that the CEM better identifies the causal chains that could result in such effects on WRBA habitat (see updates to chapter 4). The effect node in this link is a new addition to the CEM that incorporates and expands on the several separate habitat elements in the original CEM focused on the tree community (see updates to chapter 4). Chemical contaminants in and around WRBA roosting and foraging habitat presumably can affect the density and composition of the tree community there either by directly affecting the vegetation or by affecting fauna (arthropods, vertebrates) that help shape the community. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages.*

- Chemical Contaminants effects on the Vertebrate Community (HE): The original WRBA conceptual ecological model did not propose a separate habitat element for chemical contaminants; however, it did note that pesticide use within WRBA habitat or on surrounding lands could alter habitat conditions that affect WRBA. This update adds chemical contaminants as new habitat element so that the CEM better identifies the causal chains that could result in such effects on WRBA habitat (see updates to chapter 4). The effect node in this link is a new addition to the CEM, incorporating and expanding on an single habitat element in the original related to the vertebrate community, predator density. Chemical contaminants in and around WRBA roosting and foraging habitat presumably can affect the density and composition of the vertebrate community there either by directly affecting the fauna or by affecting the vegetation in ways that affect the fauna. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Fire Regime effects on the Arthropod Community (HE): The original WRBA conceptual ecological model included fire management as a controlling factor in the report, but it included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics (see updates to chapter 4). The effect node also is a new addition to the CEM, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). The fire regime in and around WRBA roosting and foraging habitat presumably can affect the density and composition of the arthropod community there either by directly affecting the arthropods or by affecting the vegetation in ways that affect the arthropods. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Fire Regime effects on the Matrix Community (HE): The original WRBA conceptual ecological model included fire management as a controlling factor in the report, but used the label, fire, for this controlling factor in the spreadsheet, and also used the latter term to cover both fire management and the fire regime itself. This update separates these two distinct topics (see updates to chapter 4). The effect node is unchanged from the original WRBA conceptual ecological model. Fire affects many aspects of vegetation structure and composition and can destroy WRBA habitat (Busch 1995). Reciprocally, matrix community conditions such as species composition, density, and moisture levels affect the fire regime. The link is hypothesized to be complex and bi-directional with proposed high intensity, high spatial scale, and low temporal scale. Fire can have great effects on vegetation structure, but the dynamic nature of both fire and matrix communities surrounding riparian zones means that the effects of fire will likely last less than a decade. This update proposes rating link predictability and link understanding as medium. The effects of fire on vegetation are at least broadly predictable and understood both in general and in the Lower Colorado River Valley. *Applies to all life stages*.

- Fire Regime effects on the Tree Community (HE): The original WRBA conceptual ecological model included fire management as a controlling factor in the report, but used the label, fire, for this controlling factor in the spreadsheet, and also used the latter term to cover both fire management and the fire regime itself. This update separates these two distinct topics (see updates to chapter 4). The effect node in this link is a new addition to the CEM that incorporates and expands on the several separate habitat elements in the original CEM focused on the tree community (see updates to chapter 4). Fire affects many aspects of vegetation structure and composition and can destroy WRBA habitat (Busch 1995). Reciprocally, tree community conditions such as species composition, density, and moisture levels affect the fire regime. The link is hypothesized to be complex and bi-directional with proposed high intensity, medium spatial scale, and medium temporal scale. This update proposes rating link predictability and link understanding as medium. The effects of fire on vegetation are at least broadly predictable and understood both in general and in the Lower Colorado River Valley. *Applies to all life stages*.

- Fire Regime effects on the Vertebrate Community (HE): The original WRBA conceptual ecological model included fire management as a controlling factor in the report, but included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics (see updates to chapter 4). The effect node in this link is a new addition to the CEM, incorporating and expanding on a single habitat element in the original CEM related to the vertebrate community, predator density. The fire regime in and around WRBA roosting and foraging habitat presumably can affect the density and composition of the vertebrate community there either by directly affecting the vertebrates or by affecting the vegetation in ways that affect the vertebrates. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Matrix Community effects on the Arthropod Community (HE): The causal node is unchanged from the original WRBA conceptual ecological model. The effect node in this link replaces food availability in the CEM. The original CEM posited a link between these two original habitat elements, but the new habitat element, the arthropod community, significantly expands the meaning of this node and changes the contents of several fields in the spreadsheet entry, resulting in a *new* link rather than simply an updated link. The density and composition of the matrix community surrounding roost habitat affect the abundance and composition of the arthropod community in the matrix vegetation community. Reciprocally, the abundance and composition of the arthropod community may affect the density and composition of the matrix vegetation community through herbivory, pollination, etc. The link is hypothesized to be complex and bi-directional with unknown intensity, medium spatial scale, and medium temporal scale; medium predictability; and low understanding. There are no studies of these interactions for the Lower Colorado River Valley. An effect of a change in the matrix community would likely persist over a medium time scale. *Applies to all life stages*.

- Matrix Community effects on the Vertebrate Community (HE): The causal node is unchanged from the original WRBA conceptual ecological model. The effect node in this link replaces predatory density in the CEM. The original CEM posited a link between these two original habitat elements, but the new habitat element, the vertebrate community, significantly expands the meaning of this node and changes the contents of several fields in the spreadsheet entry, resulting in a *new* link rather than simply an updated link. The density and composition of the matrix community surrounding roost habitat affects the abundance and composition of the vertebrate community in the matrix vegetation community. Reciprocally, the abundance and composition of the vertebrate community may affect the density and composition of the matrix vegetation community through herbivory. The link is hypothesized to be complex and bi-directional with unknown intensity, medium spatial scale, and medium temporal scale; medium predictability; and low understanding. There are no studies of these interactions for the Lower Colorado River Valley. An effect of a change in the matrix community would likely persist over a medium time scale. *Applies to all life stages*.

- Temperature effects on the Fire Regime (HE): The causal node in this link is unchanged from original WRBA conceptual ecological model, but the CEM did not include a link for its effects on the fire regime. The original WRBA conceptual ecological model included fire management as a controlling factor in the report, but included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics (see updates to chapter 4). Air temperatures affect the likelihood and intensity of fires. The link is hypothesized to be complex and unidirectional with proposed high intensity, spatial scale, and temporal scale; and high link predictability and understanding. The relationships are well studied and predictable. *Applies to all life stages*.

- Tree Community effects on the Arthropod Community (HE): The causal node in this link is a new addition to the original WRBA conceptual ecological model that incorporates and expands on the several separate habitat elements in the original CEM focused on the tree community (see updates to chapter 4). The effect node in this link is a new addition to the

CEM, incorporating and expanding on an single habitat element in the original CEM related to the vertebrate community, food availability. The density and composition of the tree community at WRBA roost sites affects the abundance and composition of the arthropod community there. Reciprocally, the abundance and composition of the arthropod community may affect the density and composition of the tree community through herbivory. The link is hypothesized to be complex and bi-directional with proposed medium intensity, spatial scale, and temporal scale; and medium predictability and low understanding. Factors other than tree community composition may affect arthropod abundance and vice versa, and these factors have received little study in the Lower Colorado River Valley. *Applies to all life stages*.

- Tree Community effects on Temperature (HE): The causal node in this link is a new addition to the original WRBA conceptual ecological model that incorporates and expands on the several separate habitat elements in the original CEM focused on the tree community, including canopy cover (see updates to chapter 4). The effect node in this link is unchanged from the original CEM, which noted that canopy cover can affect air temperature in riparian tree stands. Canopy cover provides shade, likely resulting in decreased temperature (Carter and Menzel 2007). The link is hypothesized to be complex and unidirectional: Canopy cover provides shade, likely resulting in decreased temperature (Carter and Menzel 2007), but other properties of riparian tree stands, such as vertical structure and the species mix, may affect temperature in other ways. The link is proposed to have medium intensity, low spatial scale, and low temporal scale: The link operates on the scale of the patch and the roost site, and other factors, such as weather and water management, affect temperature. An effect of a change in canopy cover likely does not last long in the ephemeral riparian ecosystem, although the condition of vegetation on restoration sites is likely more stable. The link is proposed to have medium predictability and understanding: In general, greater canopy cover should reduce temperatures around roost sites; however, other factors (weather, humidity) also impact the temperature around roost sites. *Applies to all life stages*.

- Tree Community effects on the Vertebrate Community (HE): The causal node in this link is a new addition to the original WRBA conceptual ecological model that incorporates and expands on the several separate habitat elements in the CEM focused on the tree community (see updates to chapter 4). The effect node in this link is a new addition to the CEM, incorporating and expanding on an single habitat element in the original CEM related to the vertebrate community, predator density. The patch size, density, composition, and vertical structure of the tree community at WRBA roost sites affects the abundance, composition, and patterns of activity of the vertebrate community there. Reciprocally, the abundance and composition of the vertebrate community may affect the density and composition of the tree community through herbivory. The link is hypothesized to be complex and bi-directional with proposed medium intensity, spatial scale, and temporal scale; and medium predictability and low understanding. Factors other than tree community composition may affect vertebrate abundance and vice versa, and these factors have received little study in the Lower Colorado River Valley. *Applies to all life stages*.

- Water Availability effects on the Arthropod Community (HE): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The effect node in this link is a new addition to the CEM, incorporating and expanding on an single habitat element in the original CEM related to the vertebrate community, food availability. The timing, duration, magnitude, and consistency of water availability affect the abundance of arthropods and the composition of the arthropod community (Hagen and Sabo 2012). The link is hypothesized to be complex and unidirectional with proposed high intensity, medium spatial scale, and low temporal scale. Areas near water likely serve as arthropod population sources, influencing insect abundance at a landscape scale (Pierson et al. 2006); however, because of the fluctuating nature of water availability in the arid Southwest, the temporal effect is limited. This update proposes rating link predictability as medium, because other factors also may affect arthropod abundance, and link understanding as low because there is little information on the factors affecting arthropod abundance studied along the Lower Colorado River Valley. *Applies to all life stages*.

- Water Availability effects on the Matrix Community (HE): The original WRBA conceptual ecological model included both of these habitat elements but did not address their interaction. The timing, duration, magnitude, and consistency of water availability affect the density of the matrix community and its composition (Stromberg 1998). The link is hypothesized to be complex and unidirectional with proposed high intensity, spatial scale, and temporal scale; and high predictability and low understanding. This is a key and increasingly well-understood set of relationships that shape riparian vegetation throughout the Southwest. *Applies to all life stages*.

- Water Availability effects on the Tree Community (HE): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The effect node in this link is a new addition to the CEM that incorporates and expands on the several separate habitat elements in the original CEM focused on the tree community (see updates to chapter 4). The timing, duration, magnitude, and consistency of water availability affect the density of the tree community at WRBA habitat and its composition (Stromberg 1998). For example, groundwater declines have been linked to changes in the riparian vegetation community across the Southwestern United States, with declines in cottonwood and willow species and increases in the non-native saltcedar (Stromberg 1998). The link is hypothesized to be complex and unidirectional with proposed high intensity, medium spatial scale, and high temporal scale; medium predictability; and high understanding. This is a key and increasingly well-understood set of relationships that shape riparian vegetation throughout the Southwest, but other factors, such as substrate, propagule availability, elevation, and management (to name a few), can also affect riparian tree species composition and other properties of the community. *Applies to all life stages*.

- Water Availability effects on the Vertebrate Community (HE): The causal node in this link is unchanged from the original CEM. The effect node in this link is a new addition to the CEM, incorporating and expanding on an single habitat element in the original related to the vertebrate community, predator density. The timing, duration, magnitude, and consistency of water availability affect the abundance of vertebrates and the composition of the vertebrate community in and around WRBA habitat. The link is hypothesized to be complex and unidirectional with proposed high intensity, medium spatial scale, and medium temporal scale. Most vertebrates get their water by drinking rather than through the foods they consume, but many desert fauna can travel to reach water and, their distributions therefore, are not limited to surface water occurrences. This update proposes rating link predictability as medium, because other factors also may affect vertebrate abundance, and link understanding as low because there is little information on the factors affecting vertebrate abundance studied along the Lower Colorado River Valley. *Applies to all life stages*.

NEW LINKS WITH HABITAT ELEMENTS AS CAUSAL AGENTS THAT AFFECT CRITICAL ACTIVITIES OR PROCESSES

- Anthropogenic Disturbance effects on Foraging (CAP): The causal and effect nodes in this link are unchanged from the original CEM, but the CEM did not include a link between the two. Anthropogenic disturbance such as farming, recreational use, and forestry may impact WRBA foraging activity. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional, with low intensity and unknown spatial and temporal scales because of the lack of information about the significance of human disturbance on WRBA foraging. The link is proposed to have low predictability because other factors, such as food availability and the matrix community, affect foraging,. The link is also proposed to have low understanding: While understood in principle, there are no data on the subject in the Lower Colorado River Valley or elsewhere. *Applies only to the juvenile and adult life stages*.

- Anthropogenic Disturbance effects on Maternal Care (CAP): The causal node in this link is unchanged from the original CEM. The effect node in this link replaces parent roost attendance in the CEM. The CEM also did not include a link representing the interaction between these two nodes during the adult life stage. Maternal care in this update is a critical biological activity or process for WRBA adults but a habitat element for WRBA pups. Anthropogenic disturbance may impact roost attendance. Active work in the forests or in other habitats where WRBA are roosting may adversely affect roosting individuals and could potentially disrupt reproduction (e.g., tending of young during early development phases) (Dudek and ICF International 2012). The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with proposed medium intensity and unknown spatial and temporal scales. The literature suggests this could be a medium to strong effect, but there are no data on its possible spatial or temporal occurrence in the Lower Colorado River Valley or elsewhere in the WRBA range. Link predictability correspondingly is unknown and link understanding low. *Applies only to the adult life stage*.

- Anthropogenic Disturbance effects on Mechanical Stress (CAP): The causal and effect nodes in this link are unchanged from the original CEM, but the CEM did not include a link representing their interactions. Encounters with artificial wind turbulence and capture and handling during monitoring and research can result in mechanical stress to bats unless precautions are taken to avoid or minimize harmful encounters. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Anthropogenic Disturbance effects on Roosting (CAP): The causal node in this link is unchanged from the original CEM. The effect node in this link replaces roost site selection in the CEM. The original CEM also did not include a link representing the interaction between these two nodes during the juvenile life stage. Anthropogenic disturbance may impact roost site selection. This relationship is posited based on evidence that active work in forests or in other habitats where WRBA are roosting may disturb roosting individuals (Dudek and ICF International 2012). One possible response to such disturbance would be to move to another roosting location. On the other hand, years of field experience has not shown that human activity, at least during the daytime around roosting

WRBA, disturb them and cause them to flee. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with proposed low intensity, spatial scale, and temporal scale. Anthropogenic disturbance would likely be short term except in areas with agricultural activities near roost sites, and there is no evidence of significant intensity. This link is proposed to have low predictability and understanding because of the lack of information available on the prevalence or effects of human disturbance near WRBA roost sites within the Lower Colorado River Valley. *Applies only to the juvenile life stage (link already included in the original CEM for the adult life stage).*

- Arthropod Community effects on Foraging (CAP): The causal node is a new addition to the original WRBA conceptual ecological model, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). The effect node is unchanged from the original CEM. The species of arthropods present at night around WRBA roosting sites, and their abundances, necessarily must affect WRBA foraging success. The link is hypothesized to be complex and unidirectional: A greater abundance of nocturnal, flying arthropods should result in greater foraging success, but only if the arthropods are palatable to and nutritious for WRBA juveniles or adults. The link is proposed to have high intensity, spatial scale, and temporal scale; medium predictability; and low understanding. Other factors than arthropod abundance and species composition also may affect WRBA foraging activity. Further, while this relationship is understood in principle, there are no data on the subject in the Lower Colorado River Valley. *Applies only to the juvenile and adult life stages.*

- Arthropod Community effects on Inter-Site Movement (CAP): The causal node is a new addition to the original CEM, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). The effect node is a new addition to the CEM (see updates to chapter 3). The possible causes of within-season, season-to-season, and year-to-year movements of WRBA juveniles within the Lower Colorado River Valley are poorly understood. Hypotheses include changes in roosting habitat quality (e.g., following a fire), changes in the availability of prey (arthropods), use of some sites as stopovers rather than longer-term roosting areas, and seasonal changes in temperature (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). Changes in the distribution of predators conceivably might also matter. The link is hypothesized to be complex and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies only to the juvenile and adult life stages.*

- Arthropod Community effects on Predation (CAP): The causal node also is a new addition to the original CEM, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). The effect node is unchanged from the original CEM. Theoretically, some arthropods may prey on WRBA (see updates to chapter 3). Greater predator density and diversity presumably are associated with greater predation rates in general; however, there is no information on whether any arthropods in the LCR ecosystem actually do prey on WRBA in any life stage. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies to all life stages*.

- Arthropod Community effects on Roosting (CAP): The causal node also is a new addition to the original WRBA conceptual ecological model, replacing and expanding on the original habitat element, food availability (see updates to chapter 4). The effect node in this link replaces roost site selection in the original CEM. The CEM also did not include a link representing the interaction between food availability and roost site selection in the juvenile life stage. WRBA may select a roost site that is close to areas with higher food availability. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed medium intensity, spatial scale, and temporal scale; medium predictability; and medium understanding. Factors in addition to food availability likely also affect roost site selection, particularly factors related to the vegetation, and the effects of food availability have not been studied. *Applies only to the juvenile and adult life stages*.

- Chemical Contaminants effects on Chemical Stress (CAP): The original CEM did not propose a separate habitat element for chemical contaminants; however, it did note that WRBA are vulnerable to chemical stress (see updates to chapter 3) and identified some possible sources of contaminants that could result in such stress. This update adds chemical contaminants as a new habitat element so that the CEM better identifies the causal chains that could result in chemical stress to WRBA in any life stage (see updates to chapter 4). The effect node is unchanged from the original CEM. Chemical contaminants are often hypothesized to be causes of harm to bats; however, the subject has not been studied specifically for WRBA or for the LCR ecoregion or adjacent regions. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Chemical Contaminants effects on Inter-Site Movement (CAP): The causal node in this link is unchanged from the original CEM. The effect node is new to this update. The possible causes of within-season, season-to-season, and year-to-year movements of WRBA adults within the Lower Colorado River Valley are poorly understood. Hypotheses include changes in roosting habitat quality (e.g., following a fire), changes in the availability of prey, use of some sites as stopovers rather than longer-term roosting areas, and seasonal changes in temperature (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). Changes in the distribution of predators conceivably might also matter. This link hypothesizes that WRBA may also move to a different site to remove themselves from localities where they have encountered noxious chemicals in order to avoid chemical stress; however, the subject has not been studied along the Lower Colorado River Valley. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. The relationship is proposed on basic principles but has not been studied for the Lower Colorado River Valley. *Applies only to the juvenile and adult life stages*.

- Fire Regime effects on Thermal Stress (CAP): The original CEM included fire management as a controlling factor in the report, but included fire as the associated controlling factor in the spreadsheet, and used the term to cover both fire management and the fire regime itself. This update separates these two distinct topics (see updates to chapter 4). The effect node is unchanged from the original CEM. Even if not directly harmed by fire and smoke, WRBA presumably could be harmed simply through exposure to the high temperatures associated with fires. The frequency and severity of fires therefore could affect the frequency and severity of thermal stress in WRBA; however, the subject has not been studied for the Lower Colorado River Valley. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Matrix Community effects on Roosting (CAP): The causal node is unchanged from the original CEM. The effect node in this link replaces roost site selection in the CEM. The CEM also did not include a link representing the interaction between these two nodes during the juvenile life stage. The composition of the landscape surrounding WRBA roosting patches may influence juvenile roost site selection. Mixan et al. (2015) found that the percent riparian vegetation in 10 x 5 kilometer (km) sampling polygons centered on roost site locations predicted the likelihood of roosting occupancy at these locations, while the percent agricultural vegetation in the same 10 x 5 km sampling polygons did not. The link is hypothesized to be complex and unidirectional with proposed medium intensity and unknown spatial and temporal scales. The preliminary evidence from occupancy modeling (Mixan et al. 2015) indicates that some properties of the matrix community affect occupancy, while others do not, but the full analysis has not yet been published. The link is proposed to have unknown predictability and low understanding. *Applies only to the juvenile life stage (link already included in the original CEM for the adult life stage)*.

- Monitoring, Capture, Handling effects on Mechanical Stress (CAP): The causal node in this link is a new addition to the original CEM (see updates to chapter 4). The effect node is unchanged from the CEM. Capture and handling during monitoring and research potentially can cause mechanical stress to WRBA. Pups are rarely captured or handled, but for later life stages, LCR MSCP and partner field protocols explicitly recognize and address needs to minimize stress and harm to bats captured in mist nets and subsequently handled for measurement, collection of tissue samples, and/or attachment of radio tracking devices, if any (see updates to chapter 4). The link is hypothesized to be positive with no (or unknown) threshold and unidirectional. In principle, the greater the frequency and intensity of capture and handling of WRBA during monitoring or research, the greater the potential for mechanical stress; however, field protocols are designed to minimize any such stress (Brown 2006; Hill 2018). The link has unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. LCR MSCP and partner field protocols are designed to minimize the incidence or severity of mechanical stress during monitoring and handling; however, no data are available on the success of such efforts. On the other hand, the field protocols for minimizing the incidence and severity of mechanical stress during monitoring and handling were developed through years of experience and testing not only with WRBA but with numerous bat species across the Western United States. This suggests that they are effective and well understood. *Applies to all life stages*.

- Temperature effects on Inter-Site Movement (CAP): The causal node is unchanged from the original CEM. The effect node is a new addition to the CEM (see updates to chapter 3). The possible causes of within-season, season-to-season, and year-to-year movements of WRBA juveniles within the Lower Colorado River Valley are poorly understood. Hypotheses include changes in roosting habitat quality (e.g., following a fire), changes in the availability of prey, use of some sites as stopovers rather than longer-term roosting areas, and seasonal changes in temperature (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). Changes in the distribution of predators conceivably might also matter. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Temperature effects on Roosting (CAP): The causal node is unchanged from the original CEM. The effect node in this link replaces roost site selection in the CEM. The original CEM also did not include a link representing the interaction between these two nodes during the juvenile life stage. WRBA juveniles may seek roosting site locations that provide safe temperature ranges. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed medium intensity, spatial scale, and temporal scale. While the effect of temperature on either juvenile or adult roosting may be important on a range-wide scale, there may not be a wide enough range of variation in thermal conditions along the Lower Colorado River Valley to affect roost site selection other than as affected by vegetation. The link is proposed to have low predictability and understanding. While understood in principle, no analyses of the subject have been carried out with data from the Lower Colorado River Valley. *Applies only to the juvenile life stage (link already included in the original CEM for the adult life stage)*.

- Tree Community effects on Foraging (CAP): The causal node in this link is a new addition to the original CEM that incorporates and expands on the several separate habitat elements in the CEM focused on the tree community (see updates to chapter 4). The effect node in this link is unchanged from the original CEM. Several aspects of tree community composition and structure may affect WRBA foraging behavior. In particular, WRBA in the Lower Colorado River Valley forage preferentially in areas of cottonwood-willow vegetation and show greater affinity for patches with larger areas, greater canopy complexity, greater availability of openings and edges within and along which to forage, and greater proximity to open water. Patch size may affect WRBA foraging rates because of its effects on the proportion of edge. WRBA are more active in larger patches than smaller patches (Calvert and Neiswenter 2012; Diamond 2012; Pierson et al. 2006;). Vertical and horizontal structure of vegetation also influence the density of vegetation within the foraging area of WRBA and, therefore, may influence the foraging strategy employed. Calvert and Neiswenter (2012) note higher WRBA activity rates in areas with riparian habitat greater than 20 hectares. Pierson et al. (2006) concluded that their recording of more WRBA activity in riparian stands dominated by mature trees that were greater than 50 m wide suggests the WRBA populations require large stands of riparian forests not only for roosting but for foraging as well. The link is hypothesized to be complex and unidirectional, and it is proposed to have medium intensity, medium spatial scale, and high temporal scale; medium predictability; and medium understanding. *Applies only to the juvenile and adult life stages.*

- Tree Community effects on Inter-Site Movement (CAP): The causal node in this link is a new addition to the original CEM that incorporates and expands on the several separate habitat elements in the CEM focused on the tree community (see updates to chapter 4). The effect node in this link is a new addition. The possible causes of within-season, season-to-season, and year-to-year movements of WRBA juveniles within the Lower Colorado River Valley are poorly understood. Hypotheses include changes in roosting habitat quality (e.g., following a fire), changes in the availability of prey, use of some sites as stopovers rather than longer-term roosting areas, and seasonal changes in temperature (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). Changes in the distribution of predators conceivably might also matter. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Tree Community effects on Predation (CAP): The causal and effect nodes are unchanged from the original CEM, but the CEM did not propose a link between the two. The size and shape of riparian woodland patches may affect predation rates because of its effects on the proportion of edge to area. A larger patch size should have fewer edge predators, hence less risk of predation. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional, with medium intensity, medium spatial scale, and low temporal scale. Patch size works on the scale of the individual patch. The link is proposed to have low predictability, because other factors may affect predation, and low understanding because, while the link is understood in principle. There are no data on the subject in the Lower Colorado River Valley. *Applies to all life stages*.

- Tree Community effects on Roosting (CAP): The causal node in this link is a new addition to the original CEM that incorporates and expands on the several separate habitat elements in the CEM focused on the tree community (see updates to chapter 4). WRBA select roosting sites based on several characteristics of the riparian tree community at the micro- (roosting tree and immediate neighbors) and meso- (patch) scales, including (1) roosting tree species, height, DBH, condition, canopy diameter and density, and the species and density of immediate neighboring trees and (2) riparian patch tree composition, area, and width (see table 3 and citations within). Additional modeling of occupancy and variables that predict it are underway (Mixan et al. 2015). The link is hypothesized to be complex and unidirectional with high intensity, spatial scale, and temporal scale; high predictability; and medium understanding. *Applies only to the juvenile and adult life stages*.

- Vertebrate Community effects on Competition (CAP): The causal node in this link is a new addition to the original CEM, incorporating and expanding on a single habitat element related to the vertebrate community, predator density. The effect node is a completely new addition to the CEM (see updates to chapter 3). Theoretically, other bat species, as well as nocturnal insectivorous birds, may compete with WRBA for food items in the Lower Colorado River Valley. However, the subject has not been studied, and WRBA may be sufficiently generalized in their prey selection that competition is kept low. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Vertebrate Community effects on Inter-Site Movement (CAP): The causal node in this link is a new addition to the original CEM, incorporating and expanding on the original habitat element, predator density. The effect node is a new addition to the CEM (see updates to chapter 3). The possible causes of within-season, season-to-season, and year-to-year movements of WRBA adults within the Lower Colorado River Valley are poorly understood. Hypotheses include changes in roosting habitat quality (e.g., following a fire), changes in the availability of prey, use of some sites as stopovers rather than longer-term roosting areas, and seasonal changes in temperature (Calvert 2017; Mixan 2015; Mixan and Diamond 2019a, 2019b). Changes in the distribution of predators conceivably might also matter. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Vertebrate Community effects on Predation (CAP): The causal node in this link is a new addition to the original CEM, incorporating and expanding on the original habitat element, predator density (see updates to chapter 4). The effect node in this link is unchanged from the original CEM. The LCR ecosystem supports several vertebrate species likely to prey on WRBA (see updates to chapter 3). Greater predator density and diversity presumably are associated with greater predation rates in general. However, there is no information on which vertebrates in the LCR ecosystem actually prey on WRBA in any life stage. The link is hypothesized to be complex and unidirectional with unknown intensity, high spatial scale, and high temporal scale; unknown predictability; and low understanding. There are no data on which vertebrates in the LCR ecosystem may prey on WRBA in any life stage, but there are several likely candidates, all of which would be active year round throughout the valley (see updates to chapter 3). Further, even though there are no data on which vertebrates prey on WRBA (in general or in the Lower Colorado

River Valley in particular), predation by vertebrates is highly predictable based on what is known about eastern and western red bat ecology in general. *Applies to all life stages.*

- Vertebrate Community effects on Roosting (CAP): The causal node in this link is a new addition to the original WRBA conceptual ecological model, incorporating and expanding on an single habitat element in the original related to the vertebrate community, predator density. The effect node in this link replaces roost site selection in the original CEM. Further, the original CEM did not include a link representing the interaction between predator density and roost site selection during the juvenile life stage. Conceivably, WRBA juveniles and adults may select roost sites that have fewer threats from predators. Predation risk may impact a number of aspects of bat behavior, including roost site selection, the nature of sleep and torpor, evening roost departures, and landscape-related movement patterns (Lima and O'Keefe 2013). However, the subject has not been studied for WRBA or eastern red bats. Conceivably, the greater the abundance and species diversity of vertebrates present in and around potential roosting sites, the greater the effect on WRBA roosting behaviors, but along several dimensions of behavior. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. Factors other than predator density also affect roost site selection, and nothing is known about predation of WRBA in the Lower Colorado River Valley. *Applies only to the juvenile and adult life stages).*

- Water Availability effects on Chemical Stress (CAP): The causal and effect nodes are unchanged from the original WRBA conceptual ecological model, but the CEM did not posit a link between the two nodes. The link pertains only to WRBA juveniles and adults because WRBA pups obtain all of their water from their mothers by nursing (see updates to chapter 3, "Maternal Care"). Lack of adequate hydration results in chemical stress in all vertebrates; however, WRBA select roost sites, in part, for the availability of water (see link from water availability to roosting) and conceivably may move to other sites if water availability is not adequate at a site. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with low intensity, spatial scale, and temporal scale; low predictability; and medium understanding. The relationship is understood in principle, and some data are available. *Applies only to the juvenile and adult life stages.*

- Water Availability effects on Roosting (CAP): The causal node in this link is unchanged from the original CEM. The effect node in this link replaces roost site selection in the CEM. The original CEM did not include a link representing the interaction between water availability and roost site selection during the juvenile life stage. The proximity of open water and wetlands to appropriate roost habitat may be an important landscape-scale factor for WRBA protection. A study of eastern red bat roosting habitat preferences found this species to prefer mature riparian forests near trails, open water, and wetlands (Limpert et al. 2007). This element affects WRBA indirectly by impacting the availability of prey as well as the availability of roosting habitat (Hagan and Sabo 2012). The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with high intensity, low spatial scale, and medium temporal scale. Water availability is one of several factors that may affect roost site selection; it operates at the local scale and over the period of time that the roost is active. While some studies have suggested that water availability is important for eastern red bat roost site selection, little information is available for WRBA in the Lower Colorado River Valley. Consequently, link predictability and understanding are low. *Applies only to the juvenile life stage (link already included in the original CEM for the adult life stage)*.

DELETED LINKS WITH HABITAT ELEMENTS AS CAUSAL AGENTS

- Effects of Anthropogenic Disturbance on Parent Roost Attendance (HE) for the pup life stage. This update renames parent roost attendance to maternal care and addresses all drivers of maternal care under the CEM for the adult life stage. *Applies only to the pup life stage*.

- Effects of Canopy Cover on Food Availability (HE): This update replaces canopy cover with the more inclusive habitat element, tree community, and replaces food availability with the more inclusive habitat element, arthropod community. *Applies only to the juvenile and adult life stages*.

- Effects of Canopy Cover on Temperature (HE): This update replaces canopy cover with the more inclusive habitat element, tree community. *Applies to all life stages*.

- Effects of Number of Pups on Parent Roost Attendance (HE) for the pup life stage. This update renames number of pups to litter size and parent roost attendance to maternal care. Further, this update addresses all drivers of maternal care under the CEM for the adult life stage. *Applies only to the pup life stage*.

- Effects of Riparian Tree Species Composition on Canopy Cover (HE): This update incorporates both of these nodes into a single new habitat element, tree community. *Applies to all life stages*.

- Effects of the Food Availability on Parent Roost Attendance (HE) for the pup life stage: This update incorporates food availability into the new habitat element, arthropod community, and renames parent roost attendance to maternal care, and it addresses all drivers of maternal care under the CEM for the adult life stage. *Applies only to the pup life stage*.

- Effects of Water Availability on Riparian Tree Species Composition (HE): This update incorporates originally separate habitat elements, canopy cover, patch size, and riparian tree species composition, into the new habitat element, tree community. *Applies to all life stages*.

- Effects of Anthropogenic Disturbance on Foraging (CAP): This link, as articulated in the original WRBA conceptual ecological model, skips over the central relationship in this causal chain, which is posited to involve disturbances to arthropods, which in turn affects foraging. This update breaks this chain into its two constituent steps. *Applies only to the juvenile and adult life stages*.

- Effects of Canopy Cover on Roost Site Selection (CAP): This update replaces canopy cover with the more inclusive habitat element, tree community, and replaces roost site selection with the more inclusive critical activity or process, roosting. *Applies only to the juvenile and adult life stages*.

- Effects of Canopy Cover on Thermal Stress (CAP): This update replaces canopy cover with the more inclusive habitat element, tree community, and recognizes that the causal chain implied in the original WRBA conceptual ecological model involves two steps, involving the effects of vegetation on temperature and the effects of temperature on thermal stress. This update breaks out these separate steps. *Applies to all life stages*.

- Effects of Patch Size on Foraging (CAP): This update replaces patch size with the more inclusive habitat element, tree community. *Applies only to the juvenile and adult life stages*.

- Effects of Patch Size on Predation (CAP): This update replaces patch size with the more inclusive habitat element, tree community, and recognizes that the causal chain implied in the original WRBA conceptual ecological model involves two pairs of steps, involving the effects of the tree community on both the arthropod and vertebrate communities, and the effects of these two communities on predation. *Applies to all life stages*.

- Effects of Patch Size on Roost Site Selection (CAP): This update replaces patch size with the more inclusive habitat element, tree community, and replaces roost site selection with the more inclusive critical activity or process, roosting. *Applies only to the juvenile and adult life stages*.

- Effects of Riparian Tree Species Composition on Foraging (CAP): This update replaces riparian tree species composition with the more inclusive habitat element, tree community. *Applies only to the juvenile and adult life stages*.

- Effects of Riparian Tree Species Composition on Roost Site Selection (CAP): This update replaces riparian tree species composition with the more inclusive habitat element, tree community, and replaces roost site selection with the more inclusive critical activity or process, roosting. *Applies only to the juvenile and adult life stages*.

- Effects of the Matrix Community on Anthropogenic Disturbance (CAP): This update replaces this link with a new one, recognizing the effects of surrounding land use on anthropogenic disturbance, to capture the full causal chain. *Applies to all life stages*.

- Effects of the Matrix Community on Chemical Stress Chemical Stress (CAP): This update replaces this link with a sequence of links from surrounding land use to chemical contaminants to chemical stress in order to capture the full causal chain. *Applies to all life stages*.

- Effects of the Matrix Community on Mechanical Stress (CAP): This update replaces this link with a sequence of links from wind energy development to anthropogenic disturbance to mechanical stress in order to capture the full causal chain. *Applies only to the juvenile and adult life stages*.

UPDATED LINKS WITH HABITAT ELEMENTS AS CAUSAL AGENTS

- Anthropogenic Disturbance effects on Roosting (CAP): The causal node in this link is unchanged from the original CEM The effect node in this link replaces the original critical activity, roost site selection. The CEM also did not address the interaction between these two nodes during the juvenile life stage but did do so for the adult stage, the entries for which were updated as follows: Anthropogenic disturbance may impact roost site selection. This relationship is posited based on evidence that active work in the forests or in other habitat where WRBA are roosting may disturb roosting individuals (Dudek and ICF International 2012). One possible response to such disturbance would be to move to another roosting location. On the other hand, years of field experience have not shown that human activity, at least during the daytime around roosting WRBA, disturb them and cause them to flee. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with proposed low intensity, spatial scale, and temporal scale. Anthropogenic disturbance would likely be short term, except in areas with agricultural activities near roost sites, and there is no evidence of significant intensity. This link is proposed to have low predictability and understanding because of the lack of information available on the prevalence or effects of human disturbance near WRBA roost sites within the Lower Colorado River Valley. *Applies only to adult life stage*.

- Infectious Agents effects on Disease (CAP): The causal node in this link is updated and simplified from the original habitat element, genetic diversity and infectious agents. The effect node is unchanged from the original WRBA conceptual ecological model. Infectious agents cause disease; the greater the diversity of infectious agents present in the environment to which WRBA may be exposed, the greater the likelihood of infection. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. Disease is not well studied among WRBA. *Applies to all life stages*.

- Litter Size effects on Competition (CAP): The causal link in this relationship renames the original habitat element, number of pups. The effect link in this relationship is a new addition to the original WRBA conceptual ecological model that subsumes aspects of the original critical activity for pups, eating. The reasoning for the link is updated as follows: Litter size affects the intensity of competition WRBA pups experience for food and other aspects of maternal care; the larger the liter, presumably the greater the intensity of such competition. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional, with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. Larger litter sizes should entail greater competition, in principle, but there are no data on the intensity of this relationship among WRBA anywhere. *Applies only to the pup life stage*.

- Litter Size effects on Foraging (CAP): The causal link in this relationship renames the original habitat element, number of pups. The effect link in this relationship is unchanged from the original WRBA conceptual ecological model. The reasoning for the link is updated as follows: The number of pups affects the amount of time the mother must spend foraging versus attending the roost. The larger the number of pups, the more demand is placed on the mother to provision the young. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional, with high intensity, low spatial scale, and low temporal scale. Pressure on female WRBA to care for young can be intense, but it acts on the scale of an individual roost and only during the time when young are dependent on the mother for food. The link is proposed to have medium predictability because the magnitude likely depends on resource levels. The link is proposed to have low understanding because little research has been done regarding provisioning rates of WRBA. *Applies only to the adult life stage*.

- Litter Size effects on Maternal Care (CAP): The causal link in this relationship renames the original habitat element, number of pups. The name of the effect node in this relationship replaces the original critical activity, parent roost attendance. The literature mentions only maternal care of pups, not paternal care. As in the original WRBA conceptual ecological model, the causal node functions as a habitat element for pups but as a critical activity or process for adults. Litter size affects the amount of time the mother must spend foraging versus attending the nest. The larger the number of pups, the more demand is placed on the mother to provision the young. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional, with high intensity, low spatial scale, and low temporal scale. Pressure on female WRBA to care for young can be intense, but it acts on the scale of an individual roost and only during the time when young are dependent on the mother. The link is proposed to have medium predictability because the magnitude likely depends on resource levels. The link is proposed to have low understanding because little research has been done regarding provisioning rates of WRBA. *Applies only to the adult life stage*.

- Maternal Care effects on Feeding (CAP): This link pertains only to the pup life stage. The name of the causal node in this relationship replaces the original term, parent roost attendance. The literature mentions only maternal care of pups, not paternal care. As in the original WRBA conceptual ecological model, the causal node functions as a habitat element for pups but as a critical activity or process for adults. The node in question here concerns feeding for the pup life stage. The name of the effect node in this relationship replaces the term, eating, in the original CEM. The reasoning for the link also is updated as follows: The mother feed the pups. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional: Maternal care includes feeding the pups. Higher quality maternal care would entail greater provisioning success. The link is proposed to have high intensity, spatial scale, and temporal scale; high predictability; and high understanding. Pups completely rely on their mother for food. This is a basic aspect of WRBA biology. *Applies only to the pup life stage*.

- Maternal Care effects on Thermal Stress (CAP): This link pertains only to the pup life stage. The name of the causal node in this relationship replaces the term, parent roost attendance, in the original WRBA conceptual ecological model. The literature mentions only maternal care of pups, not paternal care. As in the original CEM, the causal node functions as a habitat element for pups but as a critical activity or process for adults. The node in question here concerns feeding for the pup life stage. The effect node in this relationship is unchanged from the original CEM. The reasoning for the link also is updated as follows: Pups are born completely hairless and thus rely on the mother to maintain their body temperature initially. The pups hang from the mother's fur with their teeth and thumb claws (Shump and Shump 1982). The link is hypothesized to be positive with no (or unknown) threshold and unidirectional: Maternal care includes providing thermal protection for the pups. Higher quality maternal care would entail greater success in thermal protection. The link is proposed to have high intensity, spatial scale, and temporal scale; high predictability; and high understanding. Maternal care is crucial to temperature regulation for the very young pups but that need tapers down as the pup grows in a matter of weeks. This is a basic feature of WRBA biology. *Applies only to the pup life stage*.

- Matrix Community effects on Foraging (CAP): The causal and effect nodes are unchanged from the original WRBA conceptual ecological model, but the reasoning is updated as follows: WRBA may prefer to forage in open areas without taller trees; consequently, the spatial structure of the matrix community may affect foraging behaviors and rates of success. The link is hypothesized to be complex and unidirectional with medium intensity, spatial scale, and temporal scale. Matrix communities, by definition, operate at scales larger than an individual patch. Any effect of a change in the matrix community affecting WRBA foraging behaviors would likely persist over a medium time scale. Link predictability is unknown and understanding low: The subject has not been studied systematically. *Applies only to the juvenile and adult life stages*.

- Matrix Community effects on Roosting (CAP): The causal node is unchanged from the original WRBA conceptual ecological model. The effect node in this link replaces roost site selection in the CEM. The original CEM did not include a link representing the interaction between these two nodes during the juvenile life stage but did do so for the adult life stage. The link reasoning for the adult life stage is updated as follows: The composition of the landscape surrounding WRBA roosting patches may influence adult roost site selection. Mixan et al. (2015) found that the percent riparian vegetation in 10 x 5 km sampling polygons centered on roost site locations predicted the likelihood of roosting occupancy at these locations, while the percent agricultural vegetation in the same 10 x 5 km sampling polygons did not. The link is hypothesized to be complex and unidirectional with proposed medium intensity and unknown spatial and temporal scales. The preliminary evidence from occupancy modeling (Mixan et al. 2015) indicates that some properties of the matrix community affect occupancy while others do not, but the full analysis has not yet been published. The link is proposed to have unknown predictability and low understanding. *Applies only to the adult life stage)*.

- Temperature effects on Roosting (CAP): The causal node is unchanged from the original WRBA conceptual ecological model. The effect node in this link replaces roost site selection in the CEM. The original CEM did not include a link representing the interaction between these two nodes during the juvenile life stage but did do so for the adult life stage. The link reasoning for the adult life stage is updated as follows: WRBA adults may seek roosting site locations that provide safe temperature ranges. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with proposed medium intensity, spatial scale, and temporal scale. While the effect of temperature on either juvenile or adult roosting may be important on a range-wide scale, there may not be a wide enough range of variation in thermal conditions along the Lower Colorado River Valley to affect roost site selection other than as affected by vegetation. The link is proposed to have low predictability and understanding. While understood in principle, no analyses of the subject have been carried out with data from the Lower Colorado River Valley. *Applies only to the adult life stage)*.

- Temperature effects on Thermal Stress (CAP): The causal and effect nodes in this link are unchanged from the original WRBA conceptual ecological model. The link reasoning is updated as follows: WRBA in any life stage will experience thermal stress if exposed to excessively high or low temperatures for excessively long periods without recourse to means for reducing their exposure. The link is hypothesized to be complex and unidirectional with medium intensity, medium spatial scale, and low temporal scale. The likelihood of thermal stress increases with the severity of departure from tolerable temperatures and the duration of exposure. Temperature is affected by patch and microhabitat conditions. Temperatures fluctuate often, so a given change in temperature will likely be short lived. Further, juveniles and adults can move to seek more tolerable temperatures, and mothers will carry their pups with them when they do so. Other factors affect the level of thermal stress experienced by WRBA and may include humidity, clustering in roosts, maternal care for pups, and fat stores. Link predictability and link understanding are proposed to be medium. While understood in principle, there are no data on the subject in the Lower Colorado River Valley. *Applies to all life stages*.

- Water Availability effects on Roosting (CAP): The causal node in this link is unchanged from the original WRBA conceptual ecological model. The effect node in this link replaces roost site selection in the CEM. The original CEM did not include a link representing the interaction between water availability and roost site selection during the juvenile life stage but did do so for the adult life stage. The link reasoning for the adult life stage is updated as follows: The proximity of open water and wetlands to appropriate roost habitat may be an important landscape-scale factor for WRBA protection. A study of eastern red bat roosting habitat preferences found this species to prefer mature riparian forests near trails, open water, and wetlands (Limpert et al. 2007). This element affects WRBA indirectly by impacting the availability of prey as well as the availability of roosting habitat (Hagan and Sabo 2012). The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with high intensity, low spatial scale, and medium temporal scale. Water availability is one of several factors that may affect roost site selection. It operates at the local scale and over the period of time that the roost is active. While some studies have suggested that water availability is important for eastern red bat roost site selection, little information is available for WRBA in the Lower Colorado River Valley. Consequently, link predictability and understanding are low. *Applies only to the adult life stage).*

NEW LINKS WITH CRITICAL BIOLOGICAL ACTIVITIES OR PROCESSES AS CAUSAL AGENTS

- Competition effects on Feeding (CAP): This link pertains only to the pup life stage. The causal node is a new addition to the original WRBA conceptual ecological model. The effect node replaces the original critical activity or process, eating. Competition for maternal care (nursing) presumably can affect feeding success in WRBA pups, although the subject has not been studied. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the pup life stage.*

- Disease effects on Feeding (CAP): This link pertains only to the pup life stage. The causal node is unchanged from the original WRBA conceptual ecological model. The effect node replaces the original critical activity or process, eating. Illness presumably can affect feeding success in WRBA pups, although the subject has not been studied. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the pup life stage.*

- Disease effects on Thermal Stress (CAP): The causal and effect nodes for this link are unchanged from the original WRBA conceptual ecological model, but the CEM did not address the potential link between the two. Disease may have a range of effects, which may affect many activities or processes, including thermal self-regulation in an infected individual. Reciprocally, thermally stressed bats may be more susceptible to disease. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. Disease is not well studied among WRBA. *Applies to all life stages*.

- Foraging effects on Maternal Care (CAP): The causal node in this proposed link is unchanged from the original WRBA conceptual ecological model. The effect link replaces the original critical activity or process, parent roost attendance. The original CEM did not include a link between these two nodes. Maternal care in this update is a critical biological activity or process for WRBA adults but a habitat element for WRBA pups. Foraging success affects the ability of the mother to provision her young and attend the roost. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with high intensity, spatial scale, and temporal scale; medium predictability; and medium understanding. Pressure on the mother to provision her young can be intense, but the cause-effect relationship between foraging and maternal care only applies during the time when young are dependent on the mother for food. Further, other factors than food availability may affect roost attendance, and little research has been done regarding provisioning rates of WRBA. *Applies only to the adult life stage*.

- Foraging effects on Monitoring, Capture, Handling (HE): The causal node in this proposed link is unchanged from the original WRBA conceptual ecological model. The effect node is a new addition to the CEM (see updates to chapter 4). The timing of WRBA foraging—the timing of their daily departure from and return to their roosts—affects when acoustic monitoring must begin and end to capture different parts of the nightly cycle, and also affects when it is appropriate to raise and lower mist nets to ensure capture of WRBA without interfering with their foraging success (Calvert 2013). Further, as stated by Mixan and Diamond (2019a):

  "In a given year, habitat near a detector may be optimal for a roost, maternity roost or foraging, leading to an increase in average nightly call minutes but not necessarily nights occupied. Vegetation structure or prey base may change the following season, becoming less optimal near the detector but perhaps more optimal elsewhere in the conservation area, leading to a decrease in average nightly call minutes near the detector site that does not reflect a true decrease in bat use across the entire conservation area. An example of this can be found at CVCA1. If you relied solely on average nightly call minutes as an assessment of bat use, you would conclude that the 2016 season had a nearly two-fold level of activity more than the 2015 season, when in fact, the 2015 season had a slightly greater proportion of nights occupied. The alternative to this is comparing the 2016 and 2017 seasons. The 2017 season has roughly half the average nightly call minutes than the 2016 season. Another example is PVER1. Relying only on average nightly call minutes would lead to the conclusion that the 2015 season had considerably more bat use (2.85 versus 1.09 [2015] and 2.26 [2017]), while the proportion of nights occupied did not show such a large disparity (0.71 versus 0.55 [2015] and 0.78 [2017]), with 2017 actually having a greater proportion of nights occupied despite lower average nightly call minutes. Therefore, the proportion of nights occupied may be the best way to describe bat use through acoustic detectors at conservation areas."

Mixan and Diamond (2019a) further state:

"While the Kaleidoscope auto-classifier results were similar to the Analook visual verification methods (in that they generally identified the sites with the greatest and lowest activity levels), the Kaleidoscope method considerably overestimated western red bat activity at the conservation areas. If only the Kaleidoscope results were relied upon to assess bat use, BLCA1 would have been the acoustic station with the greatest western red bat activity. Through the Analook visual verification methods, BLCA1 had the third greatest activity and occupancy for western red bats behind CVCA1 and PVER1. Previous capture surveys also support the Analook visual verification methods, as captures for western red bats were greatest at the PVER and CVCA. The auto-classifier works much like the Analook filters but is considered to be more sophisticated in terms of analyzing call parameters for identification of each species. The auto-classifier identified more potential western red bat calls than the Analook filters overall, but differences between the results from these methods varied among monitoring sites, with the Analook filters identifying more potential calls at several locations. The greater potential western red bat calls identified by the auto-classifier likely represent misidentified calls from other species, but it cannot be discounted that the auto-classifier may have identified some western red bat calls the Analook filters did not detect. An in-depth comparative analysis between these two methods was not an objective for this report but could prove to be useful as a management tool as its fit is improved in the future. Because these methods identify a different number of calls, which could potentially impact the verified results, it would be useful to determine which method identifies the greater number of verified calls."

The link is hypothesized to be complex and unidirectional with medium intensity, spatial scale, and temporal scale; medium predictability; and high understanding. LCR MSCP and partner field protocols are designed specifically to address this interaction. Long experience among Reclamation and partner scientists has led to the evolved protocols in use. *Applies only to the juvenile and adult life stages*.

- Inter-Site Movement effects on Chemical Stress (CAP): The causal node in this proposed link is a new addition to the original WRBA conceptual ecological model. The effect node is unchanged from the original CEM. If WRBA juveniles or adults change their locations for foraging or roosting in response to the presence of chemical contaminants (see link from chemical contaminants to inter-site movement), then the resulting movement will affect the occurrence and intensity of chemical stress WRBA experience. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Inter-Site Movement effects on Foraging (CAP): The causal node in this proposed link is a new addition to the original WRBA conceptual ecological model. The effect node is unchanged from the CEM. If WRBA juveniles or adults change their locations for foraging or roosting in response to variation in the availability of prey (see link from arthropod community to inter-site movement), then the resulting movement will affect WRBA foraging. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Inter-Site Movement effects on Predation (CAP): The causal node in this proposed link is a new addition to the original WRBA conceptual ecological model. The effect node is unchanged from the CEM. If WRBA juveniles or adults change their locations for foraging or roosting in response to variation in the presence and activity of predators (see link from vertebrate community to inter-site movement), then the resulting movement will affect the occurrence and intensity of predation WRBA experience. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Inter-Site Movement effects on Roosting (CAP): The causal node in this proposed link is a new addition to the original WRBA conceptual ecological model. The effect node replaces and expands on the critical activity or process, roost site selection. If WRBA juveniles or adults change their locations for roosting in response to variation in the availability of suitable roosting habitat, then the resulting movement will affect WRBA roosting. The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Inter-Site Movement effects on Thermal Stress (CAP): The causal node in this proposed link is a new addition to the original WRBA conceptual ecological model. The effect node is unchanged from the CEM. If WRBA juveniles or adults change their locations for foraging or roosting in response to the presence of unsuitable temperatures (see link from temperature to inter-site movement), then the resulting movement will affect the occurrence and intensity of thermal stress WRBA experience.

The link is hypothesized to be complex and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Predation effects on Foraging (CAP): The causal and effect nodes in this proposed link are unchanged from the original WRBA conceptual ecological model, but it did not posit a link between the two. Conceivably, WRBA that detect prowling predators while the WRBA are foraging may seek shelter or alter their foraging behaviors to reduce the chances of becoming a meal for another species; however, Mcnamara (2019) found that eastern red bats did not alter their hunting activity patterns when they encountered broadcast sounds of major predators – owls. This suggests that foraging WRBA may not be disrupted by predator activity in their midst; however, the subject has not been studied along the Lower Colorado River Valley. The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Predation effects on Mechanical Stress (CAP): The causal and effect nodes in this proposed link are unchanged from the original WRBA conceptual ecological model, but the original CEM did not posit a link between the two. Unsuccessful predator attacks can cause injury to the escaped prey if the predator makes contact with but fails to capture its prey. Presumably, the likelihood of such interactions increases with the intensity of predator pressure; however, no data are available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Breeding effects on Adult Fertility (LSO): The causal node in this proposed link is a new addition to the original WRBA conceptual ecological model. The effect node replaces the original life-stage outcome, reproduction. The rate of participation of WRBA adults in breeding and their breeding success (fecundity), together with adult survival, determine WRBA adult fertility. There are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the adult life stage*.

- Chemical Stress effects on (1) Pup Growth, (2) Juvenile Growth, and (3) Adult Growth (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes are new life-stage outcomes added to the CEM. Chemical stress can impair growth in any life stage of any animal species. Presumably, the higher the level of chemical stress experienced by WRBA, the lower their likely rate of growth; however, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Disease effects on (1) Pup Growth, (2) Juvenile Growth, and (3) Adult Growth (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes are new life-stage outcomes added to the CEM. Illness can impair growth in any life stage of any animal species. The higher the frequency and severity of illness experienced by WRBA, the lower their likely rate of growth; however, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Feeding effects on Pup Growth (LSO): The causal node in this proposed link replaces eating as a critical activity for pups in the original WRBA conceptual ecological model. The effect node is a new addition to the CEM. Obtaining food is essential for growth. Pups need to eat enough to maintain metabolic processes and support growth. If a pup doesn't eat well, it will grow more slowly; however, the provisioning rate of WRBA adult females and its effects on pup growth have not been studied along the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, high spatial scale, and high temporal scale; high predictability; and low understanding. *Applies only to the pup life stage*.

- Foraging effects on (1) Juvenile Growth and (2) Adult Growth (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The two similar effect nodes are new life-stage outcomes added to the CEM. Obtaining food is essential for juvenile and adult growth; if a bat does not eat well, it will grow more slowly. However, the incidence of sufficient versus insufficient feeding among WRBA is unknown in the Lower Colorado River Valley or elsewhere, and there are no studies of WRBA growth rates in relation to foraging. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, high spatial scale, and high temporal scale; high predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Mechanical Stress effects on (1) Pup Growth, (2) Juvenile Growth, and (3) Adult Growth (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes are new life-stage outcomes added to the CEM. Injuries presumably can impair WRBA growth in any life stage by diverting metabolic resources to repairing the injury; however, there are no data available on the incidence or effects of injury to WRBA in any life stage in the Lower Colorado River Valley or elsewhere. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Mechanical Stress effects on Pup Survival (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The effect node is a new life-stage outcome added to the CEM. The original CEM recognized the possible effects of mechanical stress on juvenile and adult survival but did not include an equivalent link for the pup life stage. Injuries presumably can result in pup mortality; however, there are no data available on the incidence or effects of injury to WRBA pups in the Lower Colorado River Valley or elsewhere. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the pup life stage*.

- Thermal Stress effects on (1) Pup Growth, (2) Juvenile Growth, and (3) Adult Growth (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes are new life-stage outcomes added to the CEM. Thermal stress can impair growth in any life stage of any animal species. The higher the level of such stress experienced by WRBA juveniles or adults presumably the lower their likely rate of growth; however, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

Deleted Links with Critical Biological Activities or Processes as Causal Agents

Updating the WRBA conceptual ecological model did not result in the deletion of any links with critical activities or processes as the causal agents.

Updated Links with Critical Biological Activities or Processes as Causal Agents

- Chemical Stress effects on (1) Pup Survival, (2) Juvenile Survival, and (3) Adult Survival (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes replace the shared life-stage outcome, survival, in the CEM to differentiate survival in the three life stages. Only the link reason is updated, as follows, with all other spreadsheet fields unchanged: Chemical stress can result in death in any life stage of any animal species. The higher the level of chemical stress experienced by WRBA in a given life stage, the lower their likely rate of survival. *Applies to all life stages*.

- Disease effects on (1) Pup Survival, (2) Juvenile Survival, and (3) Adult Survival (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes replace the shared life-stage outcome, survival, in the CEM to differentiate survival in the three life stages. Only the link reason is updated, as follows, with all other spreadsheet fields unchanged: Illness can result in death in any life stage of any animal species. The higher the frequency and severity of illness experienced by WRBA in a given life stage, the lower their likely rate of survival. *Applies to all life stages*.

- Feeding effects on Pup Survival (LSO): The causal node in this proposed link replaces eating as a critical activity for pups in the original WRBA conceptual ecological model. The effect node simply differentiates pup survival from survival in other life stages. Obtaining food is essential for survival. Pups presumably can die if they do not obtain sufficient food to maintain basic metabolic processes; however, the incidence of sufficient versus insufficient feeding among WRBA is unknown in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, high spatial scale, and high temporal scale; high predictability; and low understanding. *Applies only to the pup life stage*.

- Foraging effects on (1) Juvenile Survival and (2) Adult Survival (LSO): The causal node in these two proposed links is unchanged from the original WRBA conceptual ecological model. The two similar effect nodes simply differentiate survival in each life stage from survival in other life stages. Obtaining food is essential for survival. The higher the foraging success among WRBA juveniles or adults, presumably the higher their survival rate, other things being equal. WRBA juveniles or adults that do not forage effectively simply die or suffer higher levels of predation. This relationship is posited to be significant and applicable at all times and locations in the LCR ecosystem and, theoretically, should be a predictable relationship. However, there do not appear to be any studies assessing rates or effects of foraging success versus failure among WRBA or related species. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with high intensity, high spatial scale, and high temporal scale; high predictability; and low understanding. *Applies only to the juvenile and adult life stages*.

- Maternal Care effects on Adult Fertility (LSO): The causal node in this link is an updated, renamed version of parent roost attendance from the original WRBA conceptual ecological model. The effect node is an updated, renamed version of reproduction from the CEM. Maternal care likely has a large effect on reproductive success. Maternal care includes guarding the roost and nursing young and, therefore, increases fecundity. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with high intensity, low spatial scale, and low temporal scale. Changes in roost attendance likely occur at the patch scale, and the effects likely only last for a generation. The link is proposed to have high predictability but low understanding because the effects of maternal care on WRBA fertility remains unstudied. *Applies only to the adult life stage*.

- Mechanical Stress effects on (1) Juvenile Survival and (2) Adult Survival (LSO): The causal node in these two proposed links is unchanged from the original WRBA conceptual ecological model. The two similar effect nodes replace the shared life-stage outcome, survival, in the CEM to differentiate survival in the two life stages. Injuries presumably can result in juvenile and adult mortality; however, there are no data available on the incidence or effects of injury to WRBA in any life stage in the Lower Colorado River Valley or elsewhere. The primary potential source of mechanical stress on WRBA juveniles and adults considered here is that of collisions with wind energy facilities. While wind energy facilities are not currently located along the Lower Colorado River Valley, mortality from wind energy facilities in areas where WRBA may migrate to and from have been recorded (Kunz et al. 2007). The link is hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale. The link is proposed to have high predictability given the likelihood that bats foraging in proximity to active wind turbines will be killed (Hayes 2013); however, the link is also proposed to have low understanding: While the subject is understood in principle, there are no data on the subject in the Lower Colorado River Valley. *Applies only to the juvenile and adult life stages*.

- Predation effects on (1) Pup Survival, (2) Juvenile Survival, and (3) Adult Survival (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes replace the shared life-stage outcome, survival, in the original CEM to differentiate survival in the three life stages. Predation can be a direct cause of mortality in all animal species. The higher the rate of predation on WRBA in any life stage, the lower their rate of survival, other things being equal. Birds and mammals that are known to prey on WRBA are present throughout the riparian areas along the Lower Colorado River Valley; however, no information exists on the effect of predators of WRBA juvenile or adult survival in the Lower Colorado River Valley. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

- Roosting effects on Adult Fertility (LSO): The causal node in this proposed link replaces roost site selection in the original WRBA conceptual ecological model. The effect node replaces reproduction in the CEM. The reasoning for the link is also updated as follows: Successful roosting, including site selection and movement when needed (with pups clinging to the mother's back), are crucial to successful rearing. Roost site selection should strongly affect fecundity, and WRBA select roosting sites at multiple and large scales. Although this is a tenet of habitat selection theory, it has not been directly assessed for WRBA along the Lower Colorado River Valley. The link is hypothesized to be complex and unidirectional with high intensity, spatial scale, and temporal scale; high predictability; and low understanding. *Applies only to the adult stage*.

- Thermal Stress effects on (1) Pup Survival, (2) Juvenile Survival, and (3) Adult Survival (LSO): The causal node in these three proposed links is unchanged from the original WRBA conceptual ecological model. The three similar effect nodes replace the shared life-stage outcome, survival, in the CEM to differentiate survival in the three life stages. The link reasoning is updated as follows: Thermal stress can result in death in any life stage of any animal species. The higher the level of such stress experienced by WRBA in any life stage, the lower their likely rate of survival. There are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The links are hypothesized to be negative with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies to all life stages*.

NEW LINKS WITH LIFE-STAGE OUTCOMES AS CAUSAL AGENTS

- Adult Growth effects on Breeding (CAP): The causal and effect nodes are new additions to the original WRBA conceptual ecological model and apply specifically to the adult life stage. Theoretically, prolonged or delayed growth or loss of healthy condition in any animal species could lower their rate of participation in breeding. Reciprocally, individuals that grow well and at a healthy pace and/or maintain good health presumably have higher rates of participation in breeding; however, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the adult life stage.*

- Pup Growth effects on Pup Survival (LSO): The causal node is a new addition to the original WRBA conceptual ecological model and applies specifically to the pup life stage. The effect node simply differentiates pup survival from survival in other life stages. Theoretically, prolonged or delayed growth in the young of any animal species could increase the exposure of e affected individuals to threats to their survival over a longer span of time. Reciprocally, young that grow well and at a healthy pace presumably have greater rates of survival. However, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the pup life stage.*

- Juvenile Growth effects on Juvenile Survival (LSO): The causal node is a new addition to the original WRBA conceptual ecological model and applies specifically to the juvenile life stage. The effect node simply differentiates juvenile survival from survival in other life stages. Theoretically, prolonged or delayed growth or loss of healthy condition in any animal species could increase the exposure of the affected individuals to threats to their survival over a longer span of time. Reciprocally, individuals that grow well and at a healthy pace and/or maintain good health presumably have greater rates of survival. However, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the juvenile life stage.*

- Adult Growth effects on Adult Survival (LSO): The causal node is a new addition to the original WRBA conceptual ecological model and applies specifically to the adult life stage. The effect node simply differentiates adult survival from survival in other life stages. Theoretically, prolonged or delayed growth or loss of healthy condition in any animal species could increase the exposure of the affected individuals to threats to their survival over a longer span of time. Reciprocally, individuals that grow well and at a healthy pace and/or maintain good health presumably have greater rates of survival. However, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the adult life stage.*

- Adult Survival effects on Adult Fertility (LSO): The causal node simply differentiates adult survival from survival in other life stages. The effect node replaces reproduction from the original WRBA conceptual ecological model. Adult survival, together with the rate of participation of WRBA adults in breeding and their breeding success (fecundity), determine WRBA adult fertility. However, there are no data available on the subject for WRBA in the Lower Colorado River Valley or elsewhere. The link is hypothesized to be positive with no (or unknown) threshold and unidirectional with unknown intensity, spatial scale, and temporal scale; unknown predictability; and low understanding. *Applies only to the adult life stage.*

Summary of Updated Terms for the WRBA Conceptual Ecological Model

Table 6.—Updated WRBA conceptual ecological model component names
(Blue indicates new or revised items; orange indicates replaced items. Italicized entries are explanatory comments.)

WRBA conceptual ecological model updated terms, 2019	WRBA conceptual ecological model original terms, 2016
Life stages	
Pup	Pup
Juvenile	Juvenile
Adult	Breeding Adult
Life-stage outcomes	
Pup Survival	[Pup] Survival
Pup Growth	*(new)*
Juvenile Survival	[Juvenile] Survival
Juvenile Growth	*(new)*
Adult Survival	[Breeding Adult] Survival
Adult Fertility	[Breeding Adult] Reproduction
Adult Growth	*(new)*
Critical biological activities and processes	
Breeding *(applies only to adults)*	*(new)*
Chemical Stress	Chemical Stress
Competition	*(new)*
Disease	Disease
Feeding *(applies only to pups)*	Eating
Foraging *(applies only to juveniles and adults)*	Foraging
Inter-Site Movement	*(new)*
Maternal Care *(applies only to adults)*	Roost Attendance
Mechanical Stress	Mechanical Stress
Predation	Predation
Roosting *(applies only to juveniles and adults)*	Roost Site Selection
Thermal Stress	Thermal Stress
Habitat elements	
Anthropogenic Disturbance	Anthropogenic Disturbance
Arthropod Community	Food Availability
Chemical Contaminants	*(new)*
Fire Regime[1]	*(new)*
Infectious Agents	*(new)*
(eliminated; see infectious agents)	Genetic Diversity and Infectious Agents
Litter Size	Number of Pups
Maternal Care (*applies only to pups*)	Parent Roost Attendance
Matrix Community	Matrix Community
Monitoring, Capture, Handling	*(new)*
(eliminated; see tree community)	Patch Size
(eliminated; see tree community)	Riparian Tree Species Composition
Temperature	Temperature
(eliminated; see tree community)	Canopy Cover
Tree Community	*(new)*
Vertebrate Community	Predator Density
Water Availability	Water Availability
Controlling factors	
Conservation Monitoring and Research Programs	*(new)*
Fire Management[1]	Fire[1]
(eliminated; see surrounding land use)	Grazing
Habitat Development and Management	Habitat Restoration
Nuisance Species Introduction and Management	Nuisance Species Introduction and Management
(eliminated; see habitat development and management; surrounding land use)	Pesticide Application
(eliminated; see habitat development and management; surrounding land use)	Tree Thinning
Surrounding Land Use	*(new)*
Water Storage-Delivery System Design and Operation	Water Storage-Delivery System Design and Operation
Wind Energy Development	Wind Energy Development

[1] The original WRBA conceptual ecological model used the term, fire, in its workbook to refer to both fire management and the fire regime itself, but the report only discussed fire management. This update corrects the terminology.

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