Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

Colorado River Cotton Rat (*Sigmodon arizonae plenus*) (CRCR) Basic Conceptual Ecological Model for the Lower Colorado River

Photo courtesy of Nick Rice

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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Lower Colorado River
Multi-Species Conservation Program

Colorado River Cotton Rat (*Sigmodon arizonae plenus*) (CRCR) Basic Conceptual Ecological Model for the Lower Colorado River

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ACRONYMS AND ABBREVIATIONS

CEM	conceptual ecological model
CRCR	Colorado River Cotton Rat
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
Reclamation	Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service

Symbols

≈	approximately
>	greater than
<	less than

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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1 Species Conceptual Ecological Model Methodology for the Lower Colorado River Multi-Species Conservation Program

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Foreword

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) Habitat Conservation Plan requires the creation, and long-term stewardship, of habitat for 20 covered species. This is both an exciting and daunting challenge – exciting, in that success would mean a major conservation achievement in the lower Colorado River landscape, and daunting, in that we need to simultaneously manage our lands for the benefit of 20 species in a mosaic of land cover types. To do so, we need to develop a common understanding of the habitat requirements of each species and the stewardship required to meet those needs.

To provide a framework to capture and share the information that forms the foundation of this understanding, conceptual ecological models (CEMs) for each covered species have been created under the LCR MSCP's Adaptive Management Program. The LCR MSCP's conceptual ecological models are descriptions of the functional relationships among essential components of a species' life history, including its habitat, threats, and drivers. They tell the story of "what's important to the animal" and how our stewardship and restoration actions can change those processes or attributes for the betterment of their habitat. As such, CEMs can provide:

- A synthesis of the current understanding of how a species' habitat works. This synthesis can be based on the published literature, technical reports, or professional experience.

- Help in understanding and diagnosing underlying issues and identifying land management opportunities.

- A basis for isolating cause and effect and simplifying complex systems. These models also document the interaction among system drivers.

- A common (shared) framework or "mental picture" from which to develop management alternatives.

- A tool for making qualitative predictions of ecosystem responses to stewardship actions.

- A way to flag potential thresholds from which system responses may accelerate or follow potentially unexpected or divergent paths.

- A means by which to outline further restoration, research, and development and to assess different restoration scenarios.

- A means of identifying appropriate monitoring indicators and metrics.

- A basis for implementing adaptive management strategies.

Most natural resource managers rely heavily upon CEMs to guide their work, but few explicitly formulate and express the models so they can be shared, assessed, and improved. When this is done, these models provide broad utility for ecosystem restoration and adaptive management.

Model building consists of determining system parts, identifying the relationships that link these parts, specifying the mechanisms by which the parts interact, identifying missing information, and exploring the model's behavior (Heemskerk et al. 2003[1]). The model building process can be as informative as the model itself, as it reveals what is known and what is unknown about the connections and causalities in the systems under management.

It is important to note that CEMs are not meant to be used as prescriptive management tools but rather to give managers the information needed to help inform decisions. These models are conceptual and qualitative. They are not intended to provide precise, quantitative predictions. Rather, they allow us to virtually "tweak the system" free of the constraints of time and cost to develop a prediction of how a system might respond over time to a variety of management options; for a single species, a documented model is a valuable tool, but for 20 species, they are imperative. The successful management of multiple species in a world of competing interests (species versus species), potentially conflicting needs, goals, and objectives, long response times, and limited resources, these models can help land managers experiment from the safety of the desktop. Because quantitative data can be informative, habitat parameters that have been quantified in the literature are presented (in attachment 2) in this document for reference purposes.

These models are intended to be "living" documents that should be updated and improved over time. The model presented here should not be viewed as a definitive monograph of a species' life history but rather as a framework for capturing the knowledge and experience of the LCR MSCP's scientists and land stewards. While ideally the most helpful land management tool would be a definitive list of do's and don'ts, with exact specifications regarding habitat requirements that would allow us to engineer exactly what the species we care about need to survive and thrive, this is clearly not possible. The fact is, that despite years of active management, observation, and academic research on many of the LCR MSCP species of concern, there may not be enough data to support developing such detailed, prescriptive land management.

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[1] Heemskerk, M., K. Wilson, and M. Pavao-Zuckerman. 2003. Conceptual models as tools for communication across disciplines. Conservation Ecology 7(3):8.
http://www.consecol.org/vol7/iss3/art8/

The CEMs for species covered under the LCR MSCP are based on, and expand upon, methods developed by the Sacramento-San Joaquin Delta Ecosystem Restoration Program (ERP): https://www.dfg.ca.gov/ERP/conceptual_models.asp. The ERP is jointly implemented by the California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. The Bureau of Reclamation (Reclamation) participates in this program. (See attachment 1 for an introduction to the CEM process.)

Many of the LCR MSCP covered species are migratory. These models only address the species' life history as it relates to the lower Colorado River and specifically those areas that are potentially influenced by LCR MSCP land management. The models DO NOT take into account ecological factors that influence the species at their other migratory locations.

Finally, in determining the spatial extent of the literature used in these models, the goals and objectives of the LCR MSCP were taken into consideration. For species whose range is limited to the Southwest, the models are based on literature from throughout the species' range. In contrast, for those species whose breeding range is continental (e.g., yellow-billed cuckoo) or west-wide, the models primarily utilize studies from the Southwest.

How to Use the Models

There are three important elements to each CEM:

(1) The narrative description of the species' various life stages, critical biological activities and processes, and associated habitat elements.

(2) The figures that provide a visual snapshot of all the critical factors and causal links for a given life stage.

(3) The associated workbooks. Each CEM has a workbook that includes a worksheet for each life stage.

This narrative document is a basic guide, meant to summarize information on the species' most basic habitat needs, the figures are a graphic representation of how these needs are connected, and the accompanying workbook is a tool for land managers to see how on-the-ground changes might potentially change outcomes for the species in question. Reading, evaluating, and using these CEMs requires that the reader understand all three elements; no single element provides all the pertinent information in the model. While it seems convenient to simply read the narrative, we strongly recommend the reader have the figures and workbook open and refer to them while reviewing this document.

It is also tempting to see these products, once delivered, as “final.” However, it is more accurate to view them as “living” documents, serving as the foundation for future work. Reclamation will update these products as new information is available, helping to inform land managers as they address the on-the-ground challenges inherent in natural resource management.

The knowledge gaps identified by these models are meant to serve only as an example of the work that could be done to further complete our understanding of the life history of the LCR MSCP covered species. However, this list can in no way be considered an exhaustive list of research needs. Additionally, while identifying knowledge gaps was an objective of this effort, evaluating the feasibility of addressing those gaps was not. Finally, while these models were developed for the LCR MSCP, the identified research needs and knowledge gaps reflect a current lack of understanding within the wider scientific community. As such, they may not reflect the current or future goals of the LCR MSCP. They are for the purpose of informing LCR MSCP decisionmaking but are in no way meant as a call for Reclamation to undertake research to fill the identified knowledge gaps.

John Swett, Program Manager, LCR MSCP
Bureau of Reclamation
September 2015

Executive Summary

This document presents a conceptual ecological model (CEM) for the Colorado River cotton rat (*Sigmodon arizonae plenus*) (CRCR). The purpose of this model is to help the Bureau of Reclamation (Reclamation), Lower Colorado River Multi-Species Conservation Program (LCR MSCP), identify areas of scientific uncertainty concerning CRCR ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure CRCR habitat and population conditions. (Note: Attachment 1 provides an introduction to the CEM process. We recommend that those unfamiliar with this process read the attachment before continuing with this document.)

The identified research questions and gaps in scientific knowledge that are the result of this modeling effort serve as examples of topics the larger scientific community could explore to improve the overall understanding of the ecology of this species. These questions may or may not be relevant to the goals of the LCR MSCP. As such, they are not to be considered guidance for Reclamation or the LCR MSCP, nor are these knowledge gaps expected to be addressed under the program.

CONCEPTUAL ECOLOGICAL MODELS

CEMs integrate and organize existing knowledge concerning: (1) what is known about an ecological resource, with what certainty, and the sources of this information, (2) critical areas of uncertain or conflicting science that demand resolution to better guide management planning and action, (3) crucial attributes to use while monitoring system conditions and predicting the effects of experiments, management actions, and other potential agents of change, and (4) how we expect the characteristics of the resource to change as a result of altering its shaping/controlling factors, including those resulting from management actions.

The CEM applied to the CRCR expands on the methodology developed for the Sacramento-San Joaquin River Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al. 2012). The model distinguishes the major life stages or events through which the individuals of a species must pass to complete a full life cycle. It then identifies the factors that shape the likelihood that individuals in each life stage will survive to the next stage in the study area and thereby shapes the abundance, distribution, and persistence of the species in that area.

Specifically, the CRCR conceptual ecological model has five core components:

- **Life stages** – These consist of the major growth stages and critical events through which the individual CRCR must pass in order to complete a full reproductive cycle.

- **Life-stage outcomes** – These consist of the biologically crucial outcomes of each life stage, including the number of individuals recruited to the next life stage or age class within a single life stage (recruitment rate), or the number of offspring produced (fertility rate).

- **Critical biological activities and processes** – These consist of activities in which the species engages and the biological processes that take place during each life stage that significantly beneficially or detrimentally shape the life-stage outcome rates for that life stage.

- **Habitat elements** – These consist of the specific habitat conditions, the abundance, spatial and temporal distributions, and other qualities that significantly beneficially or detrimentally affect the rates of the critical biological activities and processes for each life stage.

- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the abundance, spatial and temporal distributions, and other qualities of the habitat elements for each life stage. Controlling factors are also called "drivers."

The CEM identifies the causal relationships among these components for each life stage. A causal relationship exists when a change in one condition or property of a system results in a change in some other condition or property. A change in the first condition is said to cause a change in the second condition. The CEM method applied here assesses four variables for each causal relationship: (1) the character and direction of the effect, (2) the magnitude of the effect, (3) the predictability (consistency) of the effect, and (4) the certainty of a present scientific understanding of the effect. CEM diagrams and a linked spreadsheet tool document all information on the model components and their causal relationships.

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE

The CRCR conceptual ecological model addresses the CRCR population along the river and lakes of the lower Colorado River (LCR) and other protected areas. The model thus addresses the landscape as a whole rather than any single reach or managed area.

The most widely used sources of the information for the CRCR conceptual ecological model are BIO-WEST, Inc. (2005), California Department of Fish and Game (2005), Reclamation (2008), and Neiswenter (2011). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The model also integrates numerous additional sources, particularly reports and articles completed since these publications, information on current research projects, and the expert knowledge of LCR MSCP biologists. Our purpose is not to provide an updated literature review but to integrate the available information and knowledge into a CEM so that it can be used for adaptive management.

The CRCR conceptual ecological model distinguishes and assesses two life stages and their associated outcomes as follows (table ES-1):

Table ES-1.—Outcomes of each of the two life stages of CRCR

Life stage	Life-stage outcome(s)
1. Nest	• Survival
2. Adult	• Survival • Reproduction

The model distinguishes eight critical biological activities and processes relevant to one or more of these two life stages, six habitat elements relevant to one or more of these eight critical biological activities and processes for one or more life stages, and five controlling factors that affect one or more of these six habitat elements. Because the LCR comprises a highly regulated system, the controlling factors exclusively concern human activities.

The eight critical biological activities and processes identified across all life stages are: disease, dispersal, foraging, gene flow, nest attendance, nursing, predation, and predator avoidance behavior. The six habitat elements identified across all life stages are: food availability, herbaceous vegetation assemblage, infectious agents, local hydrology, maternal care, and predator density. The five controlling factors identified across all habitat elements are: fire management, grazing, habitat management and restoration, nuisance species introduction and management, and water storage-delivery system design and operation.

RESULTS

The analysis of the causal relationships shows which critical biological activities and processes most strongly support or limit each life-stage outcome in the present system, which habitat elements most strongly affect the rates of these critical biological activities and processes, and which controlling factors most strongly affect the abundance, distribution, or condition of these habitat elements.

The analysis identifies several critical biological activities and processes that significantly affect survivorship across multiple life stages. Highlights of the results include the following:

- Nest attendance (adult stage)/maternal care (nest stage) is the main factor that determines whether or not a young rat will survive the nest stage to become an adult.

- Predation is a major determinant of individual survival in each life stage. Some researchers (Schnell 1968; Wiegert 1972) have identified avian predators as the main predator group that determines cotton rat population structure, but other predators (e.g., snakes and mammals) are also important.

- Foraging not only directly affects the survival of adult rats, foraging by female rats has a direct influence on their fecundity, playing an important role in reproductive output.

Finally, the analysis highlights several potentially important causal relationships about which scientific understanding remains low. These may warrant attention to determine if improved understanding might provide additional management options for improving CRCR survivorship and recruitment in the LCR. Specifically, the findings suggest a need to improve the understanding of the following:

- Recent work by Neiswenter (2011, 2014) has improved the understanding of basic vegetation characteristics such as height and species diversity; however, more detailed research is still needed, particularly on addressing stem density measurements and optimal structural components.

- More information is needed about CRCR habitat substrate and hydrology – soil type, quality, soil moisture, water depth, and proximity to water. How does water fluctuation affect nesting activity and habitat use (BIO-WEST, Inc. 2005)?

- How much habitat does a viable CRCR subpopulation require? Are there seasonal habitat requirements? Is there a minimal patch size? Is a network of connected patches sufficient? Is there an optimal habitat matrix that includes both adjacent upland and riparian habitat (BIO-WEST, Inc. 2005)? What habitat configuration will lessen the effects of a catastrophic event at a single site (Neiswenter 2014)?

- How important is dispersal in maintaining CRCR populations and in colonizing new habitats? Is landscape connectivity critical? What distances can a CRCR move? What type of habitat is used by dispersing animals? Who moves? Males, females? Young? And when?

- What are the population density estimates for CRCR in occupied habitats along the LCR, and how do these numbers fluctuate over time (Reclamation 2008)?

- What are the limiting factors that influence habitat selection (i.e., availability of certain food types, soil moisture, and vegetation density) (Reclamation 2008)?

- How important are agricultural fields and vegetated irrigation canals to CRCR persistence and dispersal (BIO-WEST, Inc. 2005)? If they are important, what characteristics make these habitats beneficial? Are CRCR considered a pest in agricultural systems? If CRCR are using irrigation canals, are agricultural practices harmful to them?

The research questions and gaps in scientific knowledge identified in this modeling effort serve as examples of topics the larger scientific community could explore to improve the overall understanding of the ecology of CRCR. These questions may or may not be relevant to the goals of the LCR MSCP. As such, they are not to be considered guidance for Reclamation or the LCR MSCP, nor are these knowledge gaps expected to be addressed under the program.

Chapter 1 – Introduction

This document presents a conceptual ecological model (CEM) for the Colorado River cotton rat (*Sigmodon arizonae plenus*) (CRCR). The purpose of this model is to help the Bureau of Reclamation (Reclamation), Lower Colorado River Multi-Species Conservation Program (LCR MSCP), identify areas of scientific uncertainty concerning CRCR ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure CRCR habitat and population conditions. The CEM methodology follows that developed for the Sacramento-San Joaquin River Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al. 2012), with modifications. (Note: Attachment 1 provides an introduction to the CEM process. We recommend that those unfamiliar with this process read the attachment before continuing with this document.)

The CEM addresses the CRCR population along the river and lakes of the lower Colorado River (LCR) and other protected areas. The model thus addresses the landscape as a whole rather than any single reach or managed area.

The most widely used sources of information for the CRCR conceptual ecological model are BIO-WEST, Inc. (2005), California Department of Fish and Game (2005), Reclamation (2008), and Neiswenter (2011). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The CEM also integrates numerous additional sources, particularly reports and articles completed since the aforementioned publications, information on current research projects, and the expert knowledge of LCR MSCP biologists. The purpose of the conceptual ecological model is not to provide an updated literature review but to integrate the available information and knowledge into a CEM so it can be used for adaptive management.

This document is organized as follows: The remainder of chapter 1 provides a general description of the reproductive ecology of the CRCR, the purposes of the model, and introduces the underlying concepts and structure of the CEM. Succeeding chapters present and explain the model for the CRCR in the LCR and evaluate the implications of this information for management, monitoring, and research needs.

COLORADO RIVER COTTON RAT REPRODUCTIVE ECOLOGY

The reproductive ecology of CRCR is likely similar to the hispid cotton rat (*Sigmodon hispidus*), which has a short but fecund life. Hispid cotton rats typically reach maturity around 40 days, live an average of 6 months (Cameron and Spencer 1981; Reclamation 2008), and can reproduce throughout the year. A critical component of their ecology is their ability to disperse to new habitats. Most cotton rat populations exist in isolated patches of suitable habitat, but they can rapidly recolonize old patches or reach new habitats quite readily, especially if not too distant (on the scale of hectares/kilometers). Dispersal in hispid cotton rats seems to be density dependent and correlated with changes in environmental conditions (Joule and Cameron 1975); however, more research is needed to determine if this is always the case for related cotton rats.

CONCEPTUAL ECOLOGICAL MODEL PURPOSES

Adaptive management of natural resources requires a framework to help managers understand the state of knowledge about how a resource "works," what elements of the resource they can affect through management, and how the resource will likely respond to management actions. The "resource" may be a population, species, habitat, or ecological complex. The best such frameworks incorporate the combined knowledge of many professionals accumulated over years of investigations and management actions. CEMs capture and synthesize this knowledge (Fischenich 2008; DiGennaro et al. 2012).

CEMs explicitly identify: (1) the variables or attributes that best characterize resource conditions, (2) the factors that most strongly shape or control these variables under both natural and altered (including managed) conditions, (3) the character, strength, and predictability of the ways in which these factors do this shaping/controlling, and (4) how the characteristics of the resource vary as a result of the interplay of its shaping/controlling factors.

By integrating and explicitly organizing existing knowledge in this way, a CEM summarizes and documents: (1) what is known, with what certainty, and the sources of this information, (2) critical areas of uncertain or conflicting science that demand resolution to better guide management planning and action, (3) crucial attributes to use while monitoring system conditions and predicting the effects of experiments, management actions, and other potential agents of change, and (4) how the characteristics of the resource would likely change as a result of altering its shaping/controlling factors, including those resulting from management actions.

A CEM thus translates existing knowledge into a set of explicit hypotheses. The scientific community may consider some of these hypotheses well tested, but others less so. Through the model, scientists and managers can identify which hypotheses, and the assumptions they express, most strongly influence management actions. The CEM thus helps guide management actions based on the results of monitoring and experimentation. These results indicate whether expectations about the results of management actions – as clearly stated in the CEM – have been met or not. Both expected and unexpected results allow managers to update the model, improving certainty about some aspects of the model while requiring changes to other aspects, to guide the next cycle of management actions and research. The CEM, through its successive iterations, becomes the record of improving knowledge and the ability to manage the system.

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE FOR CRCR

The CEM methodology used here expands on that developed for the Sacramento-San Joaquin River Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al. 2012). The expansion incorporates recommendations of Wildhaber et al. (2007), Wildhaber (2011), Kondolf et al. (2008), and Burke et al. (2009) to provide greater detail on causal linkages and outcomes as well as explicit demographic notation in the characterization of life-stage outcomes (McDonald and Caswell 1993). Attachment 1 provides a detailed description of the methodology. The resulting model is a "life history" model, as is common for CEMs focused on individual species (Wildhaber et al. 2007; Wildhaber 2011). That is, it distinguishes the major life stages or events through which the individuals of a species must pass to complete a full life cycle, including reproducing, and the biologically crucial outcomes of each life stage. These biologically crucial outcomes typically include the number of individuals recruited to the next life stage (e.g., juvenile to adult) or next age class within a single life stage (recruitment rate), or the number of viable offspring produced (fertility rate). It then identifies the factors that shape the rates of these outcomes in the study area and thereby shapes the abundance, distribution, and persistence of the species in that area.

The CRCR conceptual ecological model has five core components as explained further in attachment 1:

- **Life stages** – These consist of the major growth stages and critical events through which the individuals of a species must pass in order to complete a full life cycle.

- **Life-stage outcomes** – These consist of the biologically crucial outcomes of each life stage, including the number of individuals recruited to the next life stage (e.g., juvenile to adult), or the number of offspring produced (fertility rate). The rates of the outcomes for an individual life stage depend on the rates of the critical biological activities and processes for that life stage.

- **Critical biological activities and processes** – These consist of the activities in which the species engages and the biological processes that take place during each life stage that significantly affect its life-stage outcomes rates. Examples of activities and processes for a small mammal species may include dispersal, foraging, maternal care, and avoiding predators. Critical biological activities and processes typically are "rate" variables; the rate (intensity) of the activities and processes, taken together, determine the rate of recruitment of individuals to the next life stage.

- **Habitat elements** – These consist of the specific habitat conditions, the quality, abundance, and spatial and temporal distributions of which significantly affect the rates of the critical biological activities and processes for each life stage. These effects on critical biological activities and processes may be either beneficial or detrimental. Taken together, the suite of natural habitat elements for a life stage is called the "habitat template" for that life stage. Defining the natural habitat template may involve estimating specific thresholds or ranges of suitable values for particular habitat elements, outside of which one or more critical biological activities or processes no longer fully support desired life-stage outcome rates – if the state of the science supports such estimates.

- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the quality, abundance, and spatial and temporal distributions of important habitat elements. Controlling factors are also called "drivers." There may be a hierarchy of such factors affecting the system at different scales of time and space (Burke et al. 2009). For example, the availability of adequate food, cover, and nesting material depends on the presence of suitable herbaceous vegetation, which in turn may depend in part on factors such as the local hydrology, which is affected by water storage-delivery system design and operation coupled with habitat restoration or other management activities.

The CEM identifies these five components and the causal relationships among them that affect life-stage outcome rates. Further, the CEM assesses each causal linkage based on four variables to the extent possible with the available information: (1) the character and direction of the effect, (2) the magnitude of the effect, (3) the predictability (consistency) of the effect, and (4) the status (certainty) of a present scientific understanding of the effect.

The CEM for each life stage thus identifies the causal relationships that most strongly support or limit the rates of its life-stage outcomes, support or limit the rate of each critical biological activity or process, and support or limit the quality, abundance, and distribution of each habitat element (as these affect other habitat elements or affect critical biological activities or processes). In addition, the model for each life stage highlights areas of scientific uncertainty concerning these causal relationships, the effects of specific management actions aimed at these relationships, and the suitability of the methods used to measure habitat and population conditions. Attachment 1 provides further details on the assessment of causal relationships, including the use of diagrams and a spreadsheet tool to record the details of the CEM and summarize the findings.

Chapter 2 – CRCR Life Stage Model

A life stage consists of a biologically distinct portion of the life cycle of a species during which individuals undergo distinct developments in body form and function, engage in distinct behaviors, use distinct sets of habitats, and/or interact with their larger ecosystems in ways that differ from those associated with other life stages. This chapter proposes a life stage model for CRCR along the LCR on which to build the CEM.

INTRODUCTION TO THE CRCR LIFE CYCLE

The CRCR life cycle is typical of many rodents, being one of high fecundity during a short lifespan. Cotton rats become sexually mature at around 40 days and can breed throughout the year, although they usually live 6 months on average. This life history strategy likely enabled cotton rats to adapt to and recolonize riparian habitats periodically disturbed by flooding events (Neiswenter 2011).

CRCR LIFE STAGE 1 – NEST

Little is known about the nests and nesting behavior of the Colorado River cotton rat; however, it is likely similar to the more common hispid cotton rat. In that species, the females build a grass nest in shallow depressions or underground in burrows (Baar et al. 1974 and references therein). There are usually 5–6 pups per litter (Hoffmeister 1986 *in* Reclamation 2008), though sometimes up to 15 pups are born (Cameron and Spencer 1981). The young develop rapidly during this stage, although they are blind at birth and completely dependent on the parent for care. The mother nurses them until weaning, which occurs between 4–7 days (Burt and Grossenheider 1976), 10–15 days (Cameron and Spencer 1981), or 15–25 days as reported in Louisiana populations (Reclamation 2008).

CRCR LIFE STAGE 2 – ADULT

The adult life stage includes both subadults and breeding adults. It begins when the young are weaned and are no longer dependent on maternal care. Hispid cotton rats typically become sexually mature at about 40 days of age (Burt and Grossenheider 1976); however, there is no discernable difference in critical life processes between these subadults (age ≈7–40 days) and sexually mature adults. For this reason, these time periods are considered together to be the adult life stage. Non-migratory, they are active day and night (California Department of

Fish and Game 2005; Zimmerman 1970 *in* Gwinn et al. 2011). The life expectancy for cotton rats can be short, usually averaging 6 months (Cameron and Spencer 1981; Reclamation 2008).

LIFE STAGE MODEL SUMMARY

Based on this information, the CRCR conceptual ecological model distinguishes two life stages and their associated life-stage outcomes as shown in table 1 and figure 1. The life stages are numbered sequentially beginning with the nest life stage.

Table 1.—Outcomes of each of the two life stages of CRCR

Life stage	Life-stage outcome(s)
1. Nest	• Survival
2. Adult	• Survival • Reproduction

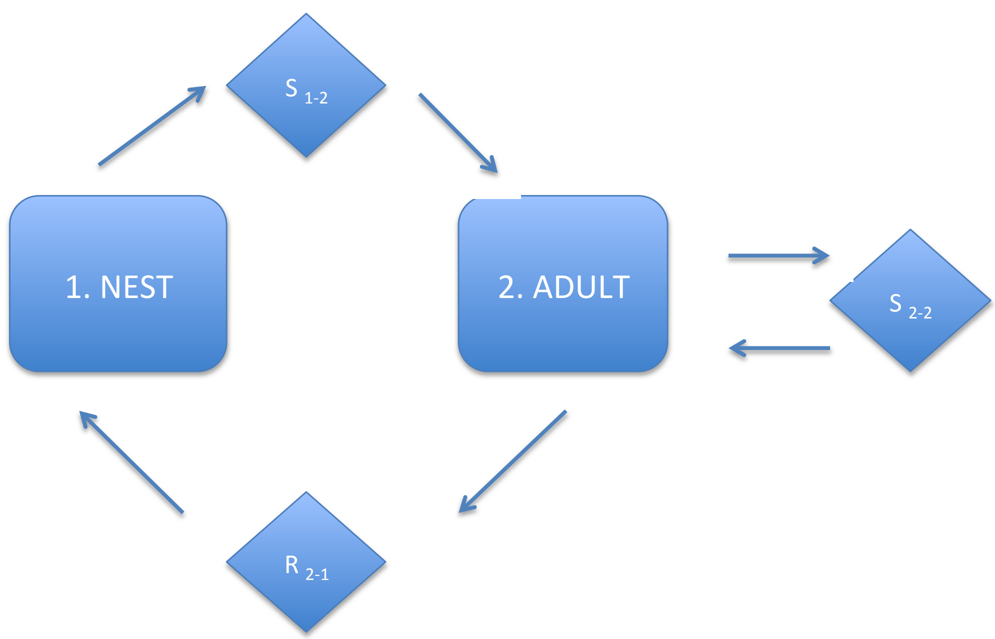

Figure 1.—Proposed CRCR life history model.
Squares indicate the life stages, and diamonds indicate the life stage outcomes. S_{1-2} = survivorship rate from nest; S_{2-2} = survivorship rate of weaned juveniles until breeding and of adults between breeding events; and R_{2-1} = adult cotton rat reproduction rate.

Chapter 3 – Critical Biological Activities and Processes

Critical biological activities and processes consist of activities in which the species engages and biological processes that take place during each life stage that significantly shape the rate(s) of the outcome(s) for that life stage. Critical biological activities and processes are "rate" variables (i.e., the rate [intensity] of these activities and processes, taken together, determine the rate of recruitment of individuals from one life stage to the next).

The CEM identifies eight critical biological activities and processes that affect one or more CRCR life stages. Some of these activities or processes differ in their details between life stages. For example, CRCR of different life stages differ in their ability to forage for food or disperse to new habitats. However, grouping activities or processes across all life stages into broad types makes it easier to compare the individual life stages to each other across the entire life cycle. Table 2 lists the eight critical biological activities and processes and their distribution across life stages.

Table 2.—Distribution of CRCR critical biological activities and processes among life stages
(Xs indicate that the critical biological activity or process is applicable to that life stage.)

Life stage ➔ / **Critical biological activity or process ➔**	**Nest**	**Adult**
Disease	X	X
Dispersal		X
Foraging		X
Gene flow		X
Nest attendance		X
Nursing	X	
Predation	X	X
Predator avoidance behavior		X

The most widely used sources of the information used to identify the critical biological activities and processes are BIO-WEST, Inc. (2005), California Department of Fish and Game (2005), Reclamation (2008), and Neiswenter (2011). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The identification also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP mammal biologists. The following paragraphs discuss the eight critical biological activities and processes in alphabetical order.

DISEASE

This process refers to diseases caused by infectious agents. Hispid cotton rats are parasitized by trematodes, cestodes, nematodes, and fleas (Mollhagan 1978), each of which can be disease carriers. In addition, cotton rats are often used in studies of infectious diseases in humans, as they are susceptible to many human pathogens (Niewiesk 2015). Although CRCR populations may, in part, be regulated by disease (Reclamation 2015), there is little or no information available about disease in CRCR specifically, although CRCR in all life stages are conceivably susceptible to disease.

DISPERSAL

Hispid cotton rats will disperse into new habitat patches as conditions become favorable. They may follow corridors of dense vegetation (e.g., moving along unlined canals or mown roadsides and roadside ditches) but also appear capable of dispersing to new habitats across “atypical” habitat (Diffendorfer and Slade 2002).

Research on cotton rats provides differing results on cotton rat dispersal. A paper on the long-distance dispersal of hispid cotton rats that looked at the characteristics of dispersing animals found that most dispersers were subadult males, with a trend toward greater movement during the autumn months (Diffendorfer and Slade 2002). Other researchers found no sex bias in dispersing cotton rats (Joule and Cameron 1975; Stafford and Stout 1983), while work by Diffendorfer et al. (1995) on habitat fragmentation and small mammals showed that it was adult male cotton rats that moved most often among habitat patches. Of the females that did disperse, most were non-reproductive.

These differing results may be due to location (northern versus southern populations), variation in experimental design, or other factors such as distances studied. Although there are no specific data on dispersal of CRCR, dispersal is an important mechanism structuring small mammal populations and allowing for colonization of the ephemeral riparian habitats along the LCR. In fact, mammal biologists have observed colonization of restored LCR habitats within a few years of restoration (A. Calvert 2015, personal communication).

FORAGING

Cotton rats generally are herbivores, feeding on stems, leaves, and seeds of a variety of grasses, occasionally consuming insects and small invertebrates (Martin et al. 1961). Newborn pups are nursed by the female (see "Nest Attendance," below), and foraging is done only by subadults and breeding adults as part of the adult life stage.

GENE FLOW

This refers to the process of transferring genes from one population of cotton rats to another, usually through dispersal of CRCR into new habitat patches. This, in turn, affects genetic diversity (i.e., the genetic homogeneity versus heterogeneity of a population during each life stage). The greater the heterogeneity, the greater the possibility that individuals of a given life stage will have genetically encoded abilities to survive their encounters with the diverse stresses presented by their environment and/or take advantage of the opportunities presented (Allendorf and Leary 1986). Cotton rat populations along the LCR experience boom and bust cycles, with population numbers occasionally being reduced to a small number of individuals (Neiswenter 2011). This may lead to a lack of genetic diversity (genetic bottlenecks) that could make individuals in isolated populations more susceptible to environmental stresses. It has been noted that there are genetic concerns for CRCR populations due to their isolated and spotty distribution along the LCR (Reclamation 2008; Neiswenter 2011). This is in part due to the construction of dams and reservoirs along the river, preventing dispersal among CRCR populations.

NEST ATTENDANCE

Female cotton rats build the nest and care for and nurse their young until weaning. The presence of the mother is critical to the survival of the young, depends in part on her survivorship, and affects the nest life stage.

NURSING

This process only applies to the nest stages because cotton rat pups nurse from mothers to eat and stay alive. A pup's ability to eat is determined by the provisioning rate of its mother.

PREDATION

Predation is a threat to CRCR at all life stages, and it obviously affects subpopulation persistence to varying degrees. Although the most common predators of cotton rats are well known (see the habitat element of "Predator Density"), the depredation rates at any CRCR life stage are not known.

PREDATOR AVOIDANCE BEHAVIOR

Avoiding predation is a major activity of herbivores such as cotton rats. Apart from the outright mortality associated with predation, there are non-lethal costs to the presence of predators in the landscape. For example, research on hispid cotton rats showed that the detection of predators in a habitat by the rats, whether detected visually, by scent, or by listening to alarm call cues from other species such as blue jays (*Cyanocitta cristata*), reduced the time spent foraging for food and the ability of cotton rats to quickly detect optimal foraging patches (Felts and Schmidt 2010). In addition, the perceived presence of predators reduced the home range size for cotton rats (Wiegert 1972). Since CRCR prefer dense vegetation (Neiswenter 2014), the absence of such vegetation also may affect antipredator behaviors.

Chapter 4 – Habitat Elements

Habitat elements consist of specific habitat conditions that ensure, allow, or interfere with critical biological activities and processes.

This chapter identifies six habitat elements that affect one or more critical biological activities or processes across the two CRCR life stages. Some of these habitat elements differ in their details between life stages. For example, CRCR at different life stages may experience different predation risks. However, using the same labels for the same *kinds* of habitat elements across all life stages makes comparison and integration of the CEMs for the individual life stages across the entire life cycle less difficult.

The habitat elements included here were chosen based upon scientific literature demonstrating a direct influence on CRCR, influence on similar species or species in similar habitats, or based upon the experience of the author and reviewers with CRCR or related species.

Table 3 lists the six habitat elements and the critical biological activities and processes that they *directly* affect across all CRCR life stages.

Table 3.—Distribution of CRCR habitat elements and the critical biological activities and processes that they directly affect across all life stages
(Xs indicate that the habitat element is applicable to that critical biological activity or process.)

Critical biological activity or process ➔ / **Habitat element ➔**	**Disease**	**Dispersal**	**Foraging**	**Gene flow**	**Nest attendance**	**Nursing**	**Predation**	**Predator avoidance behavior**
Food availability			X					
Herbaceous vegetation assemblage		X			X		X	X
Infectious agents	X							
Local hydrology		X			X			
Maternal care						X		
Predator density							X	X

Note: Gene flow is affected indirectly by several habitat elements, including herbaceous vegetation assemblage and local hydrology, as they impact dispersal.

The diagrams and other references to habitat elements elsewhere in this document identify the habitat elements by a one-to-three-word short name. However, each short name in fact refers to a longer, complete name. For example, the habitat element label, "food availability," is the short name for "The diversity, sizes, abundance, and spatial and temporal distributions of the species on which CRCR feed." The following paragraphs provide the full name for each habitat element and a detailed definition, addressing the elements in alphabetical order.

The most widely used sources of the information used to identify the habitat elements are BIO-WEST, Inc. (2005), California Department of Fish and Game (2005), Reclamation (2008), and Neiswenter (2011). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The identification also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP biologists.

As with all tabulations of habitat associations, inferences that particular habitat characteristics are critical to a species or life stage require evidence and CEMs for why each association matters to species viability (Rosenfeld 2003; Rosenfeld and Hatfield 2006).

FOOD AVAILABILITY

Full name: **The diversity, sizes, abundance, and spatial and temporal distributions of the species on which CRCR feed**. This element refers to the availability of food resources, whether stems, leaves, or seeds of grasses and other forbs, or invertebrates, that individual CRCR will encounter during each life stage; and the density and spatial and temporal distributions of the food supply in proximity to the nest. Although hispid cotton rats feed mainly on grasses, they may consume other plant materials and even insects from time to time (California Department of Fish and Game 2005). Importantly, research on hispid cotton rats has shown that the food supply for breeding females during pregnancy and during lactation directly influences litter size and survivorship of nursing young (Mattingly and McClure 1982, 1985).

HERBACEOUS VEGETATION ASSEMBLAGE

Full name: **The species diversity, abundance/density, spatial and temporal distributions, and vertical structure of herbaceous vegetation**. Cotton rats require grasses and other low herbaceous vegetation to provide habitat structure and protection from predators, nesting material, and food. CRCR have been found in a variety of mesic habitats (e.g., sloughs, backwater marshes with emergent vegetation, cottonwood/willow riparian areas, and agricultural fields along canals) with wetland vegetation that includes tule (*Scirpus acutus*), wiregrass (*Cynodon dactylon*) in cottonwood-willows (Grinnell 1914 *in* BIO-WEST, Inc. 2005), and cattails (*Typha* sp.) as well as other emergent vegetation such as common reed (*Phragmites australis*)(Zimmerman 1970 *in* BIO-WEST, Inc. 2005), bulrush (*Scirpus* sp.) and arrowweed (*Pluchea sericea*) (BIO-WEST, Inc. 2005). Hoffmeister 1986 (*in* BIO-WEST, Inc. 2005) also reports them in drier grassy areas. CRCR will use habitats with either native or non-native grasses or other vegetation. In fact, much of the habitat used by CRCR along the LCR is currently comprised of mostly non-native vegetation such as Johnsongrass (*Sorghum halepense*) (Neiswenter 2014).

The development of an herbaceous understory is an important factor in determining the presence of Arizona cotton rats (*Sigmodon arizonae*)(Andersen and Nelson 1999 *in* Reclamation 2008). In particular, it is the density of vegetation less than 1 meter in height, rather than the species composition, that appears to be the most important habitat parameter for cotton rats (Neiswenter 2014). In fact, Neiswenter (2011, 2014) found greater vertical vegetation density between 10–120 and 90–100 centimeters at CRCR capture sites, along with higher ground cover of forbs. In addition to dense herbaceous cover, hispid cotton rats appear to select for shrubs at least 1 meter high (Bowne et al. 1999), so CRCR may also rely on different vegetation types to provide optimal vegetation density.

INFECTIOUS AGENTS

Full name: **The types, abundance, and distribution of infectious agents of CRCR individuals**. Infectious agents refer to the spectrum of viruses, bacteria, fungi, and parasites capable of infecting CRCR that individuals are likely to encounter during each life stage. Hispid cotton rats are parasitized by trematodes, cestodes, nematodes, and fleas (Mollhagan 1978), each of which can be disease carriers. In addition, cotton rats are often used in studies of infectious diseases in humans, as they are susceptible to many human pathogens (Niewiesk 2015). However, the effects of disease and other infectious agents are poorly understood.

LOCAL HYDROLOGY

Full name: **The hydrologic regime that maintains sufficient water and flow to support native riparian or wetland vegetation**. CRCR are often found near water, whether natural streams (e.g., alluvial bottoms along the LCR [Goldman 1928]) or manmade irrigation canals, ponds, and agricultural fields (Hoffmeister 1986) (see Gwinn et al. 2011). In Nevada, they were found nesting just above the water line in a cattail marsh (Hall 1946 *in* BIO-WEST, Inc. 2005). Recently, CRCR have been found in grassy areas in restored cottonwood/willow/mesquite riparian habitats along the LCR (Reclamation 2008). CRCR are able to tolerate some stream or irrigation flooding, moving to higher ground until water subsides (A. Calvert and J. Hill 2015, personal communication).

MATERNAL CARE

Full name: **The care and feeding provided by mother cotton rats to their young**. Female cotton rats build the nest and groom, nurse, and otherwise care for the young until weaning. The presence of the mother is critical to the survival of the young, depends in part on her survivorship, and affects the nest life stage.

PREDATOR DENSITY

Full name: **The taxonomic and functional composition, abundance, and spatial and temporal distributions of species that may prey on CRCR during each life stage**. This element refers to a set of closely related variables that affect the likelihood that different kinds of predators will encounter and successfully prey on CRCR during any life stage. The variables of this element include the species and sizes of the fauna that prey on CRCR during different life stages and the density and spatial distribution of these fauna in the habitats used by cotton rats. Nesting on the ground exposes hispid cotton rats and their young to many predators such as raptors (e.g., northern harrier [*Circus cyaneus*], sharp shinned hawk [*Accipiter striatus*], great horned owl [*Bubo virginianus*]), snakes, and mammals (e.g., coyote [*Canis latrans*], bobcat [*Lynx rufus*], fox species, and mustelids) (Schnell 1968; A. Calvert and J. Hill 2015, personal communication). Little is known about depredation rates of CRCR at any life stage. For hispid cotton rats generally, avian predators have been found to be the most important predators regulating population density (Schnell 1968; Wiegert 1972; Neiswenter 2011).

Other potential predators may include imported red fire ants (*Solenopsis invicta*). Although not currently documented from Arizona, an infestation of these fire ants was discovered in Yuma and extirpated (Arizona-Sonoran Desert Museum 2015). They are known to attack newborn rodents in the nest and could become a threat to cotton rats should the ants become established in the LCR region.

Competition among rodent species does occur (e.g., hispid cotton rats compete with other cricetid rodents, especially microtines and *Mus musculus*) (California Department of Fish and Game 2005). However, there are no data as to whether this is a significant issue for CRCR; therefore, it has not been included as a component of this habitat element.

Chapter 5 – Controlling Factors

Controlling factors consist of environmental conditions and dynamics, both natural and anthropogenic, which affect the abundance, spatial and temporal distributions, and quality of critical habitat elements. These may also significantly directly affect some critical biological activities or processes. A hierarchy of such factors exists, with long-term dynamics of climate and geology at the top. However, this CEM focuses on five immediate controlling factors that are within the scope of potential human manipulation. The five controlling factors identified in this CEM do not constitute individual variables; rather, each identifies a category of variables (including human activities) that share specific features, which makes it useful to treat them together. Table 4 lists the five controlling factors and the habitat elements they directly affect. Table 4 shows one habitat element that is not directly affected by any controlling factor. This latter habitat element is directly shaped by the condition of one or more other habitat elements rather than by any of the controlling factors.

Table 4.—Habitat elements directly affected by controlling factors

Controlling factor ➔ / Habitat element 🡻	Fire management	Grazing	Habitat management and restoration	Nuisance species introduction and management	Water storage-delivery system design and operation
Food availability					
Herbaceous vegetation assemblage	X	X	X	X	
Infectious agents			X	X	
Local hydrology					X
Maternal care					
Predator density			X	X	

Note: Food availability is affected indirectly by fire management, grazing, habitat management and restoration, and nuisance species introduction and management through their effects on the herbaceous vegetation assemblage. Maternal care is affected indirectly by controlling factors that affect the herbaceous vegetation assemblage, local hydrology, and predator density.

FIRE MANAGEMENT

This factor addresses any fire management, whether prescribed fire or fire suppression, which may occur along the LCR and could affect CRCR or their habitat. Effects may include creation of habitat that supports or excludes cotton rats (e.g., roadside disking of vegetation used by CRCR), reduction in the food supply, or support of species that pose threats to cotton rats such as predators, competitors, or carriers of infectious agents. Although typically not a major threat in most riparian habitats, severe wildfires have affected cottonwood-willow riparian habitat in the past decade (Graber et al. 2007) and could pose a threat to any cotton rat populations in similar habitats in part by removing the dense cover on which they depend.

In addition, the presence of flammable native or exotic grasses may increase fire frequency and/or intensity in desert systems and associated riparian habitats. Climate change is also projected to affect fire frequency along the LCR (U.S. Fish and Wildlife Service [USFWS] 2013). Following a fire, studies have documented decreases in local abundances of several rodent species, including *Sigmodon* sp. that require dense vegetation (Simons 1991; Litt 2007).

GRAZING

This factor addresses the grazing activity on riparian habitats along the LCR and in surrounding areas that could affect cotton rats or their habitat. Grazing by cattle, burros, or mule deer across the arid Southwestern United States has substantially degraded riparian habitat (see Appendix G *in* USFWS 2002) (Note: Reclamation staff and researchers have observed mule deer browsing on LCR sites, and their impacts may become an issue if populations are not managed). Over-grazing may thin the understory, prevent the establishment of cottonwood and willow seedlings, and remove the herbaceous cover (Kauffman et al. 1997), possibly affecting foraging and nesting habitats for cotton rats. Although not discussed in background papers for CRCR, grazing is a factor that affects riparian habitat generally and may affect animals that rely on a dense herbaceous layer.

HABITAT MANAGEMENT AND RESTORATION

This factor addresses the active management and restoration activities to restore grasslands in riparian habitats as well as marshes and backwater areas within the LCR and includes not only mechanical or chemical clearing of existing vegetation but also the vegetation community planted and the pattern in which it is planted within restoration areas.

Cotton rats are known to use marsh vegetation, including cattails and tule (*Scirpus* sp.), and use grassy habitats that occur naturally in restored cottonwood and willow riparian areas. Yuma hispid cotton rats (*Sigmodon hispidus eremicus*) have been found using dense sacaton (*Sporobolus* sp.) areas near Yuma, and CRCR have been found frequenting habitats with the native shrub *Chlorocantha*, so plantings of these species could be incorporated into future habitat restoration plans (Neiswenter 2011, 2014; A. Calvert 2015, personal communication).

NUISANCE SPECIES INTRODUCTION AND MANAGEMENT

This factor addresses the intentional or unintentional introduction of nuisance species (animals and plants as well as microbes) and/or their control that affect cotton rat survival and reproduction. The nuisance species may poison, infect, prey on, compete with, or present alternative food resources for CRCR during one or more life stages; cause other alterations to the riparian food web that affect CRCR; or affect physical habitat features such as vegetation cover. Exotic grasses have increased wildfire frequency and intensity (see "Fire Management," above). The presence of dense stands of invasive salt cedar (*Tamarix* sp.) in riparian areas where the hydrology has been severely altered may affect the germination and establishment of cottonwood and willow and the growth of the dense grass cover required by cotton rats. The use of herbicides to control invasive plants such as salt cedar or common reed may alter riparian and marsh vegetation structure, especially if non-target herbicides are broadly applied.

WATER STORAGE-DELIVERY SYSTEM DESIGN AND OPERATION

Much of the habitat used by CRCR is along regulated waterways. The water moving through these systems is highly managed to allow for storage and delivery (diversion) to numerous international, Federal, State, Tribal, and municipal users and for hydropower generation. This factor includes river and off-channel water management, including pumping of groundwater and diversion of river water to manage water levels in refuge ponds as well as dewatering and flushing of marsh habitats. The amount of water, flooding frequency, water depth and stability, etc., each affect the species composition and density of the moist herbaceous plant community required by cotton rats for food, shelter, and nesting. The construction of reservoirs and associated dams along the main stem of the river also impedes gene flow by preventing dispersal of cotton rats among sites.

Chapter 6 – Conceptual Ecological Model by Life Stage

This chapter contains two sections, each presenting the CEM for a single CRCR life stage. The text and diagrams identify the critical biological activities and processes for each life stage, the habitat elements that support or limit the success of these critical biological activities and processes, the controlling factors that determine the abundance and quality of these habitat elements, and the causal links among them. The CEM sections specifically refer to conservation and other protected areas managed as CRCR habitat and thus address the landscape as a whole rather than any single reach or managed area.

The CEM for each life stage assesses the character and direction, magnitude, predictability, and scientific understanding of each causal link based on the following definitions (see attachment 1 for further details):

- **Character and direction** categorizes a causal relationship as positive, negative, or complex. "Positive" means that an increase in the causal node results in an increase in the affected node, while a decrease in the causal node results in a decrease in the affected node. "Negative" means that an increase in the causal node results in a decrease in the affected element, while a decrease in the causal node results in an increase in the affected node. Thus, "positive" or "negative" here do ***not*** mean that a relationship is beneficial or detrimental. The terms instead provide information analogous to the sign of a correlation coefficient. "Complex" means that there is more going on than a simple positive or negative relationship. Positive and negative relationships are further categorized based on whether they involve any response threshold in which the causal agent must cross some value before producing an effect. In addition, the "character and direction" attribute categorizes a causal relationship as uni- or bi-directional. Bi-directional relationships involve a reciprocal relationship in which each node affects the other.

- **Magnitude** refers to "…the degree to which a linkage controls the outcome *relative to other drivers*" (DiGennaro et al. 2012). Magnitude takes into account the spatial and temporal scale of the causal relationship as well as the strength (intensity) of the relationship at any single place and time. The present methodology separately rates the intensity, spatial scale, and temporal scale of each link on a three-part scale from "Low" to "High" and assesses overall link magnitude by averaging the ratings for these three. If it is not possible to estimate the intensity, spatial scale, or temporal scale of a link, the subattribute is rated as "Unknown" and ignored in the averaging. If all three subattributes are "Unknown," however, the overall link magnitude is rated as "Unknown." Just as the terms for link character provide information analogous to the sign of a correlation coefficient, the terms for link magnitude provide information analogous to the size of a correlation coefficient.

- **Predictability** refers to "…the degree to which current understanding of the system can be used to predict the role of the driver in influencing the outcome. Predictability … captures variability… [and recognizes that] effects may vary so much that properly measuring and statistically characterizing inputs to the model are difficult" (DiGennaro et al. 2012). A causal relationship may be unpredictable because of natural variability in the system or because its effects depend on the interaction of other factors with independent sources for their own variability. Just as the terms for link character provide information analogous to the sign of a correlation coefficient, the terms for link predictability provide information analogous to the size of the range of error for a correlation coefficient. The present methodology rates the predictability of each link on a three-part scale from "Low" to "High." If it is not possible to rate predictability due to a lack of information, then the link is given a rating of "Unknown" for predictability.

- **Scientific understanding** refers to the degree of agreement represented in the scientific literature and among experts in understanding how each causal relationship works—its character, magnitude, and predictability. Link predictability and understanding are independent attributes. A link may be highly predictable but poorly understood or poorly predictable but well understood. The present methodology rates the state of scientific understanding of each link on a three-part scale from "Low" to "High."

The CEM for each life stage thus identifies the causal relationships that most strongly support or limit life-stage outcomes, support or limit the rate of each critical biological activity or process, and support or limit the quality of each habitat element, as that element affects other habitat elements or affects critical biological activities or processes.

A separate spreadsheet is used to record the assessment of the character and direction, magnitude, predictability, and scientific understanding for each causal link along with the underlying rationale and citations for each life stage. The CEM for each life stage, as cataloged in its spreadsheet, is illustrated with diagrams showing the controlling factors, habitat elements, critical biological activities and processes, and causal links identified for that life stage. A diagram may also visually display information on the character and direction, magnitude, predictability, and/or scientific understanding of every link. The diagrams use a common set of conventions for identifying the controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes as well as for displaying information about the causal links. Figure 2 illustrates these conventions.

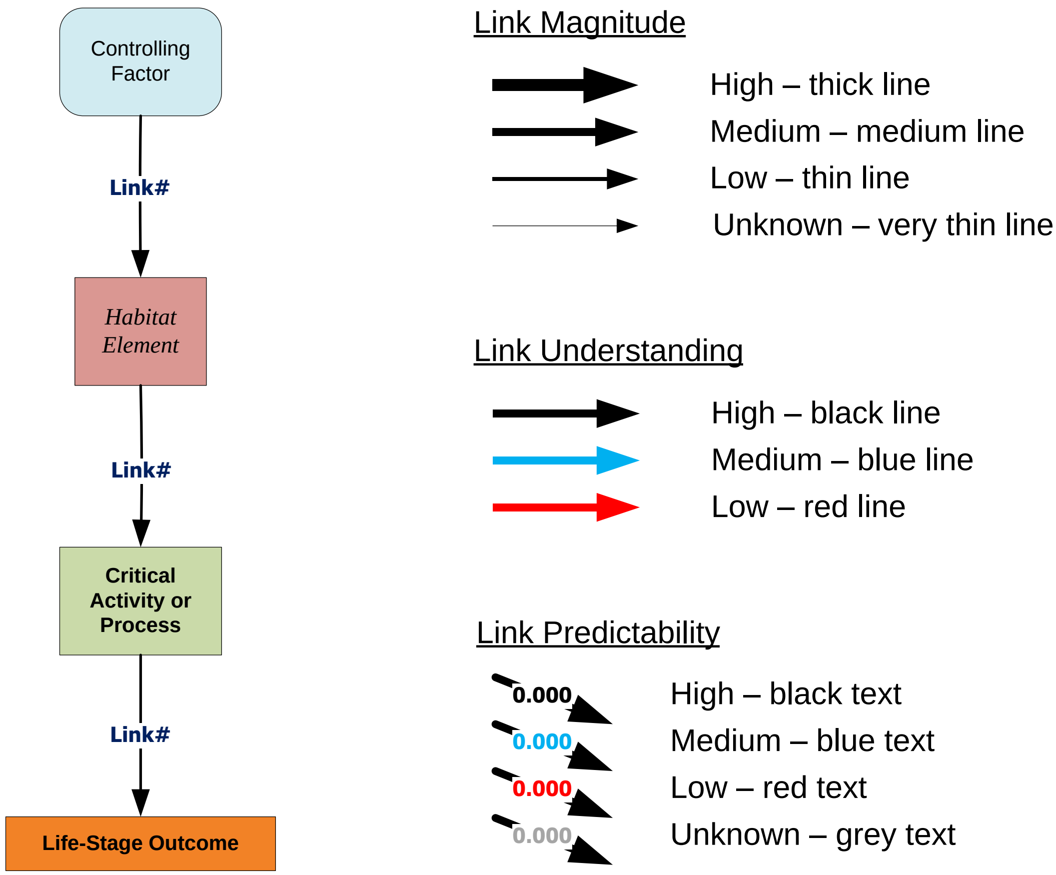

Figure 2.—Diagram conventions for LCR MSCP conceptual ecological models.

The discussion of each life stage includes an analysis of the information contained in the spreadsheet. The analyses highlight causal chains that strongly affect survivorship, identify important causal relationships with different levels of predictability, and identify important causal relationships with high scientific uncertainty. The latter constitutes topics of potential importance for adaptive management investigation.

The causal relationships between controlling factors and habitat elements are essentially identical across all three life stages. For this reason, the discussion of controlling factor-habitat element linkages across all three life stages appears in a subsequent chapter.

CRCR Life Stage 1 – Nest

The CRCR conceptual ecological model addresses the time spent in the nest as the first life stage in the overall CRCR life cycle. It begins when the pup is born and ends when the young are weaned and no longer need maternal care. Success during this life stage – successful transition to the next stage – involves survival of the young cotton rats to weaning. The organisms actively interact with their environment. Critical biological activities and processes therefore consist of both activities and processes.

The CEM (figure 3) recognizes three (of eight) critical biological activities and processes for this life stage. Dispersal, foraging, gene flow, nest attendance, and predator avoidance behavior are not included, as they are activities of the adult life stage. The critical biological activities and processes are presented here, ordered as they appear on the following figure:

1. **Disease** – Although the literature does not emphasize disease as affecting population levels of CRCR, we still feel that disease bears mentioning. Disease may affect a pup's ability to nurse, but because it has been so little studied, there is no information on the magnitude of the effect. Disease also directly affects survival. The habitat element that directly and strongly affects disease transmission is infectious agents.

2. **Predation** – Predation affects survival of the young and is directly affected by the habitat elements of herbaceous vegetation assemblage and predator density.

3. **Nursing** – The young pup must eat to grow and survive. Disease is the critical biological activity and process that directly affects nursing. The habitat element that affects nursing directly is maternal care, which is indirectly affected by food availability, the herbaceous vegetation assemblage, local hydrology, and predator density. Nursing directly affects survival.

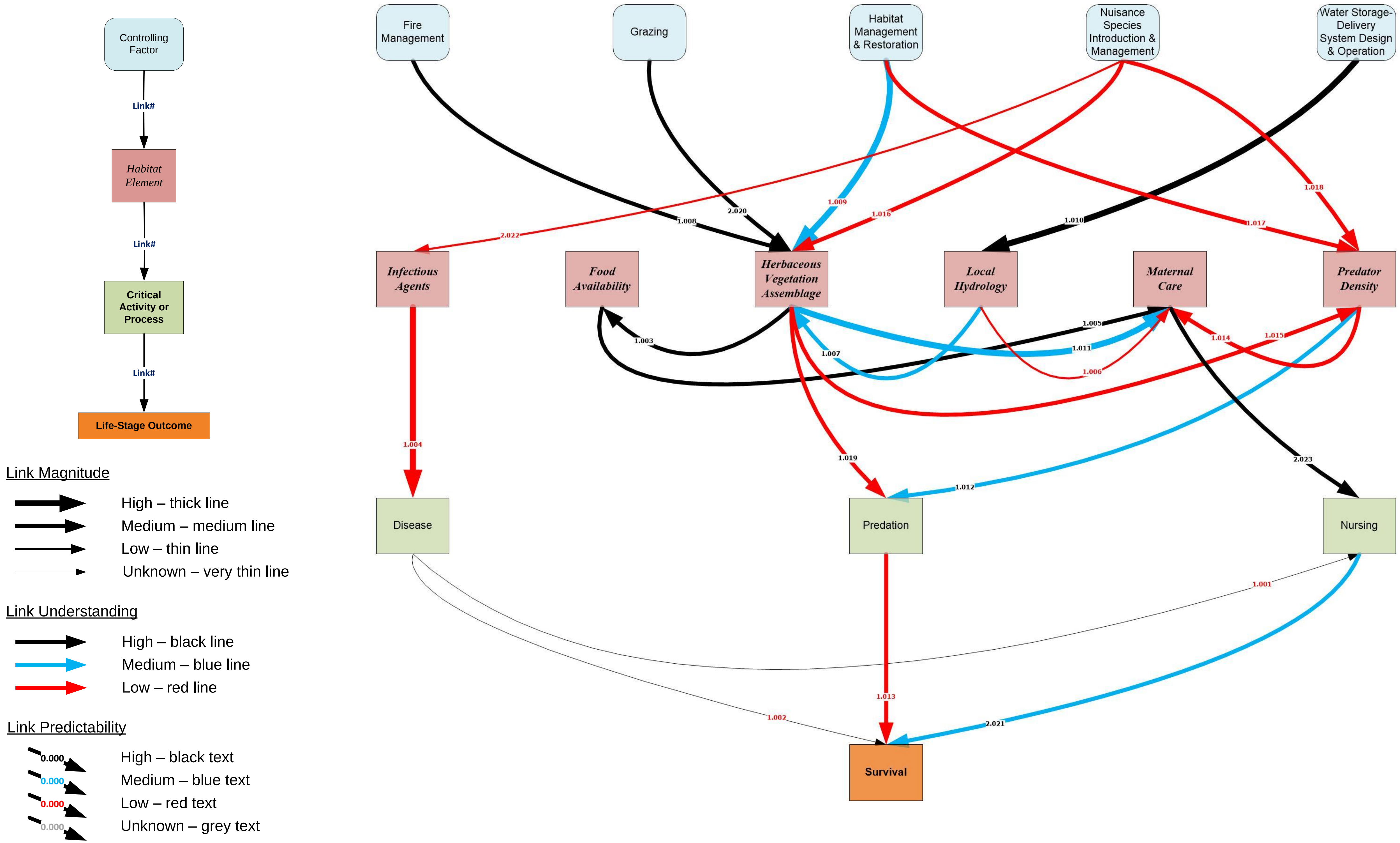

Figure 3.—CRCR life stage 1 – nest, basic CEM diagram.

CRCR LIFE STAGE 2 – ADULT

The adult life stage includes both subadults and breeding adults. It begins when the young are weaned (at about 7 days) and are no longer dependent on maternal care. Success during this life stage – successful transition to the next stage – involves organism survival and includes mating, nesting, and rearing young. The organisms actively interact with their environment. Critical biological activities and processes therefore again consist of both activities and processes.

The CEM (figure 4) recognizes seven (of eight) critical biological activities and processes for this life stage. Nursing is not included, as it is an activity of the nest life stage. The critical biological activities and processes are presented here, ordered as they appear on the following figure:

1. **Disease** – Although the literature does not emphasize disease as affecting population levels of CRCR, we still feel that disease bears mentioning. Susceptibility to disease is directly affected by gene flow and may affect dispersal, foraging, and nest attendance. Because it has been so little studied, there is no information on the magnitude of the effect. Disease also affects survival and may affect reproduction. The habitat element that directly and strongly affects disease transmission is infectious agents.

2. **Foraging** – Juveniles and adults must forage on their own to find food. Foraging directly affects nest attendance and survival, as well as reproductive output, and is affected by disease and predator avoidance behavior. Habitat elements that directly affect foraging include food availability, with the herbaceous vegetation assemblage an indirect link through effects on food availability.

3. **Predation** – Predation directly affects survival and is directly affected by the critical biological activity and process of predator avoidance behavior. The habitat elements of herbaceous vegetation assemblage and predator density directly affect predation.

4. **Dispersal** – The ability of an individual cotton rat to disperse to new habitats is affected by disease and predator avoidance behavior. Habitat elements that directly affect dispersal include the herbaceous vegetation structure along movement corridors and at new habitats, as well as local hydrology, which may affect dispersal by flooding events.

5. **Gene Flow** – Gene flow is directly affected by dispersal of subadult or adult cotton rats into new habitats, and in turn, affects disease. Indirectly, it is affected by the habitat elements and critical biological activities and processes that affect dispersal.

6. **Nest Attendance** – The survival of a young cotton rat pup to weaning depends on the care and feeding that the mother provides. Critical biological activities and processes that directly affect nest attendance include disease, foraging, and predator avoidance behavior. The habitat element of herbaceous vegetation assemblage directly affects nest attendance, as the female constructs the nest of grasses. Local hydrology can also directly affect nest attendance via flooding events that destroy a nest and indirectly through its effects on the herbaceous vegetation assemblage. Other habitat elements that indirectly affect nest attendance include predator density, through effects on predation and predator avoidance behavior, and infectious agents that affect disease (which, in turn, may affect nest attendance).

7. **Predator Avoidance Behavior** – Engaging in predator avoidance through altered behavior directly affects dispersal, foraging, nest attendance, and predation rates and indirectly affects gene flow (via dispersal). Habitat elements that directly affect such behaviors are the herbaceous vegetation assemblage and predator density.

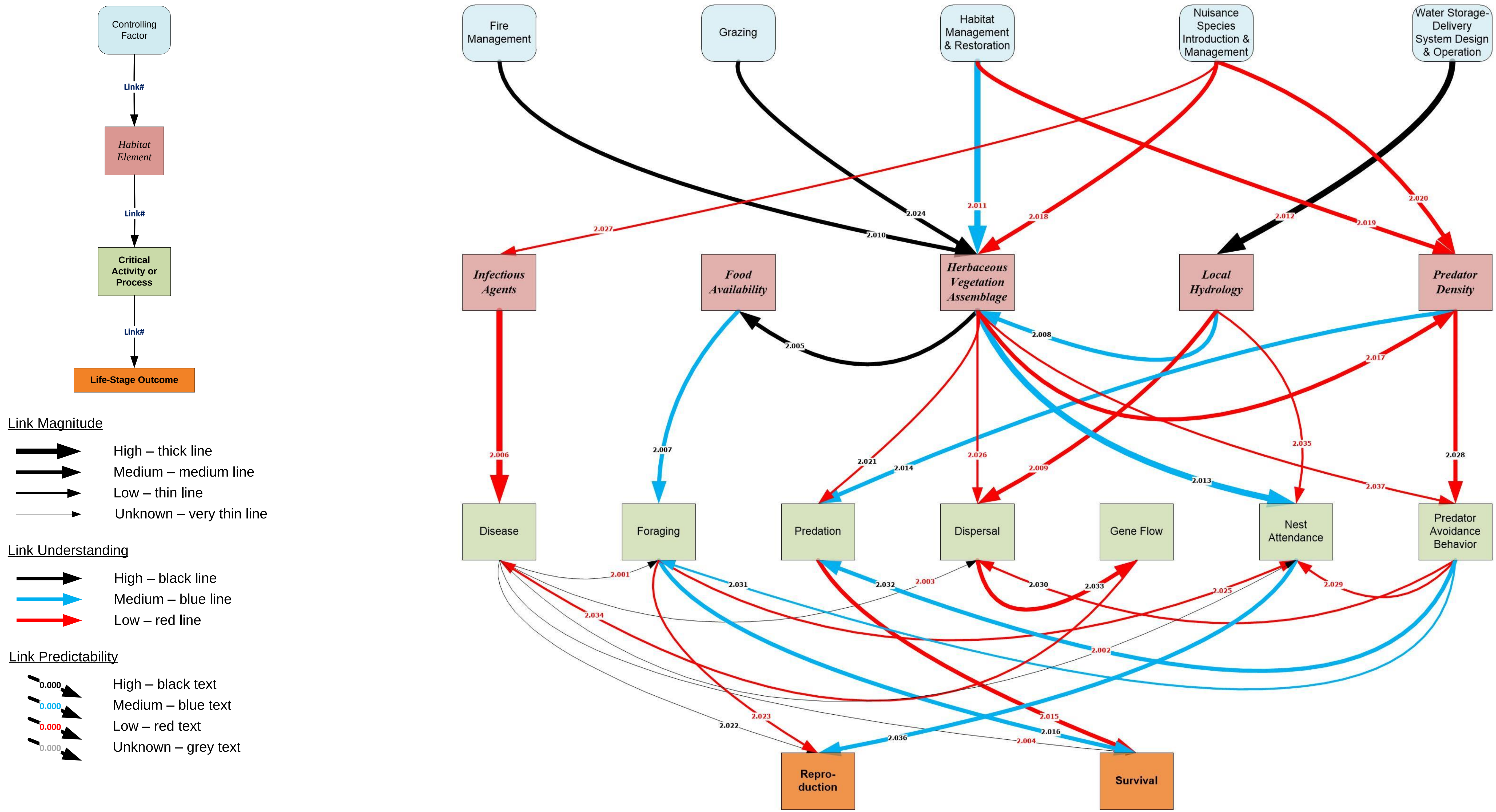

Figure 4.—CRCR life stage 2 – adult, basic CEM diagram.

Chapter 7 – Causal Relationships Across All Life Stages

The five controlling factors discussed in chapter 5 have the same influence on the same habitat elements for all life stages for which those habitat elements matter. Table 5 shows the magnitudes of *direct* influence of the five controlling factors on the six habitat elements. The structure of table 5 is the same as for table 4, but table 5 shows the magnitudes of the relationships instead of just their presence/absence. The paragraphs following the table discuss the relative effects of the different controlling factors on each habitat element. The magnitudes of direct influences of controlling factors on habitat elements is color coded in the table as follows:

High = H, Medium = M, Low = L

Table 5.—Magnitude of influence of controlling factors on habitat elements

Controlling factor ➔ / Habitat element affected 🡻	Fire management	Grazing	Habitat management and restoration	Nuisance species introduction and management	delivery system design and
Food availability					
Herbaceous vegetation assemblage	M	M	H	M	
Infectious agents				L	
Local hydrology					H
Maternal care					
Predator density			M	M	

FOOD AVAILABILITY

No controlling factors directly affect food availability. Instead, fire management, grazing, habitat management and restoration, and nuisance species introduction and management affect the food supply through their effects on the herbaceous vegetation assemblage. Water storage-delivery system design and operation also indirectly affects food availability, depending on how modifications alter local hydrology (hence, the herbaceous vegetation assemblage). Depending on the controlling factor and the types of changes to the herbaceous vegetation assembly, effects on food availability can be minor, lasting just a season, or can cover extensive areas and alter habitat for the long term.

HERBACEOUS VEGETATION ASSEMBLAGE

The herbaceous vegetation assemblage is directly affected by fire management, grazing, and habitat management and restoration as well as by nuisance species introduction and management. It is indirectly affected by water storage-delivery system design and operation, as it affects the local hydrology. Effects of these controlling factors on the herbaceous vegetation assemblage can be localized, at the patch size, or in the case of habitat management and restoration, and possibly nuisance species introduction and management, can cover extensive areas and last for decades.

INFECTIOUS AGENTS

Nuisance species introduction and management can directly affect the presence of infectious agents (and disease) in the habitat, depending on the species involved. Effects can last if introduced species and infectious agents become established; however, little is known about the likelihood of this occurring and the potential magnitude of the effects.

LOCAL HYDROLOGY

Local hydrology is directly and strongly affected by water storage-delivery system design and operation. In turn, local hydrology affects the herbaceous vegetation assemblage. Effects can be widespread and long term if flooding or drought persists such that the herbaceous vegetation assemblage is significantly altered.

MATERNAL CARE

No controlling factors directly affect maternal care; rather, they affect maternal care indirectly by their effects on other habitat elements such as food availability, the herbaceous vegetation assemblage, local hydrology, and predator density. Effects will be at the nest scale during the reproductive period.

PREDATOR DENSITY

Predator density is affected directly by habitat management and restoration as well as nuisance species introduction and management. It is indirectly affected by fire management and grazing through their alterations to the herbaceous vegetation assemblage at a site and indirectly by water storage-delivery system design and operation via the local hydrology's effects on the herbaceous vegetation assemblage. Effects of habitat management and restoration and nuisance species introduction and management can be local but last for the long term if new species become established or if habitat management activities are ongoing.

Chapter 8 – Discussion and Conclusions

This chapter summarizes the findings of the assessment in three ways by posing three questions: (1) which critical biological activities and processes most strongly affect the individual across all life stages, (2) which habitat elements, in terms of their abundance, distribution, and quality, most strongly affect the most influential activities and processes, and (3) which of these causal relationships appear to be the least understood in ways that could affect their management?

MOST INFLUENTIAL ACTIVITIES AND PROCESSES ACROSS ALL LIFE STAGES

The critical biological activities and processes that the assessment found most strongly directly or indirectly affect the success of CRCR at each life stage (high or medium magnitude) may be summarized as follows:

- Nest attendance (adult stage)/maternal care (nest stage) is the main factor that determines whether or not a young rat will survive the nest stage to become an adult.

- Predation is a major determinant of individual survival in each life stage. Some researchers (Schnell 1968; Wiegert 1972) identify avian predators as the main predator group that determines cotton rat population structure, but other predators (e.g., snakes and mammals) are also important.

- Foraging not only directly affects survival of adult rats, foraging by female rats has a direct influence on fecundity, playing an important role in reproductive output.

POTENTIALLY PIVOTAL ALTERATIONS TO HABITAT ELEMENTS

The habitat elements that the assessment indicates most strongly directly or indirectly affect the critical biological activities and processes identified across all life stages (high or medium magnitude) may be summarized as follows:

- The herbaceous vegetation assemblage is the most important habitat component for CRCR, affecting the most critical biological activities and processes and influencing other habitat elements. Vegetation provides not only cover from predators, but nesting material and a food supply, directly affecting nest attendance/maternal care (hence, survival) in both life stages.

- Predator density directly affects the predation rate at a site, with direct effects on the long-term survival of these small mammals. At the adult life stage, predator density effects on predator avoidance behavior also indirectly affect other critical biological processes of dispersal, foraging, and nest attendance.

- Local hydrology directly affects the herbaceous vegetation assemblage and may also affect nest attendance/maternal care and dispersal (and indirectly, gene flow) of CRCR, depending on habitat flooding that destroys nests or prevents dispersal and/or the construction of dams and reservoirs.

- The presence of infectious agents is an important habitat element that, in part, determines susceptibility to disease and survival. However, there is a lack of information specifically about which diseases are present onsite.

GAPS IN UNDERSTANDING

Figures 3 and 4 use the conventional color coding of individual causal relationships to identify relationships that the CEM identifies as having high, intermediate, or low levels of scientific confirmation. As noted in the attachment 1, "Low" scientific understanding of a relationship means that it is "… subject to wide disagreement or uncertainty in peer-reviewed studies from within the ecosystem of concern and in scientific reasoning among experts familiar with the ecosystem." In many cases, the scientific principles are well understood, but the factual details are insufficiently understood within the LCR. The two figures show large numbers of red arrows, indicating relationships that the assessment identifies as having a low level of scientific understanding. Each of these red arrows identifies a causal relationship that may warrant further field, laboratory, or literature investigation. The following paragraphs highlight some potentially important areas of low understanding.

Although there is much literature about the Arizona cotton rat and the hispid cotton rat, there is very little information about the subspecies under consideration. The following paragraphs highlight some potentially important areas of low understanding based on BIO-WEST, Inc. (2005), Reclamation (2008), and Neiswenter (2011, 2014).

- Recent work by Neiswenter (2011, 2014) has improved the understanding of basic vegetation characteristics such as height and species diversity; however, more detailed research is still needed, particularly on addressing stem density measurements and optimal structural components.

- More information is needed about CRCR habitat substrate and hydrology – soil type, quality, soil moisture, water depth, and proximity to water. How does water fluctuation affect nesting activity and habitat use (BIO-WEST, Inc. 2005)?

- How much habitat does a viable CRCR subpopulation require? Are there seasonal habitat requirements? Is there a minimal patch size? Is a network of connected patches sufficient? Is there an optimal habitat matrix that includes both adjacent upland and riparian habitat (BIO-WEST, Inc. 2005)? What habitat configuration will lessen the effects of a catastrophic event at a single site (Neiswenter 2014)?

- How important is dispersal in maintaining CRCR populations and in colonizing new habitats? Is landscape connectivity critical? What distances can a CRCR move? What type of habitat is used by dispersing animals? Who moves? Males, females? Young? And when?

- What are the population density estimates for CRCR in occupied habitats along the LCR, and how do these numbers fluctuate over time (Reclamation 2008)?

- What are the limiting factors that influence habitat selection (i.e., availability of certain food types, soil moisture, and vegetation density) (Reclamation 2008)?

- How important are agricultural fields and vegetated irrigation canals to CRCR persistence and dispersal (BIO-WEST, Inc. 2005)? If they are important, what characteristics make these habitats beneficial? Are CRCR considered a pest in agricultural systems? If CRCR are using irrigation canals, are agricultural practices harmful to them?

This list of uncertainties is not meant to be exhaustive but only to highlight topics the literature identifies as potentially pivotal to CRCR recruitment along the LCR and to identify important knowledge gaps in these publications. They are not in any way to be considered guidance for Reclamation or LCR MSCP, nor are these knowledge gaps expected to be addressed under the program.

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ATTACHMENT 1

Species Conceptual Ecological Model Methodology for the Lower Colorado River Multi-Species Conservation Program

OVERVIEW OF METHODOLOGY

The conceptual ecological models (CEMs) for species covered by the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) Habitat Conservation Plan expand on a methodology developed by the Sacramento-San Joaquin Delta Ecosystem Restoration Program (ERP): https://www.dfg.ca.gov/ERP/conceptual_models.asp. The ERP is jointly implemented by the California Department of Fish and Wildlife, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. The Bureau of Reclamation participates in this program.

The ERP methodology incorporates common best practices for constructing CEMs for individual species (Wildhaber et al. 2007; Fischenich 2008; DiGennaro et al. 2012). It has the following key features:

- It focuses on the *major life stages or events* through which each species passes and the *output(s)* of each life stage or event. Outputs typically consist of survivorship or the production of offspring.

- It identifies the *major drivers* that affect the likelihood (rate) of each output. Drivers are physical, chemical, or biological factors – both natural and anthropogenic – that affect output rates and therefore control the viability of the species in a given ecosystem.

- It characterizes these interrelationships using a "*driver-linkage-outcomes*" approach. Outcomes are the output rates. Linkages are cause-effect relationships between drivers and outcomes.

- It *characterizes each causal linkage* along four dimensions: (1) the character and direction of the effect, (2) the magnitude of the effect, (3) the predictability (consistency) of the effect, and (4) the certainty of present scientific understanding of the effect (DiGennaro et al. 2012).

The CEM methodology used for species covered by the LCR MSCP Habitat Conservation Plan species expands this ERP methodology. Specifically, the present methodology incorporates the recommendations and examples of Wildhaber et al. (2007), Wildhaber (2011), Kondolf et al. (2008), and Burke et al. (2009) for a more hierarchical approach and adds explicit demographic notation for the characterization of life-stage outcomes (McDonald and Caswell 1993). This expanded approach provides greater detail on causal linkages and outcomes. The expansion specifically calls for identifying **four** types of model components for each life stage, and the causal linkages among them, as follows:

- **Life-stage outcomes** are outcomes of an individual life stage, including the recruitment of individuals to the next succeeding life stage (e.g., juvenile to adult). For some life stages, the outcomes, alternatively or additionally, may include the survival of individuals to an older age class within the same life stage or the production of offspring. The rates of life-stage outcomes depend on the rates of the critical biological activities and processes for that life stage.

- **Critical biological activities and processes** are activities in which a species engages and the biological processes that must take place during each life stage that significantly affect life-stage outcomes. They include activities and processes that may benefit or degrade life-stage outcomes. Examples of critical activities and processes include mating, foraging, avoiding predators, avoiding other specific hazards, gamete production, egg maturation, leaf production, and seed germination. Critical activities and processes are "rate" variables. Taken together, the rate (intensity) of these activities and processes determine the rates of different life-stage outcomes.

- **Habitat elements** are specific habitat conditions that significantly ensure, allow, or interfere with critical biological activities and processes. The full suite of natural habitat elements constitutes the natural habitat template for a given life stage. Human activities may introduce habitat elements not present in the natural habitat template. Defining a habitat element may involve estimating the specific ranges of quantifiable properties of that element *whenever the state of knowledge supports such estimates*. These properties concern the abundance, spatial and temporal distributions, and other qualities of the habitat element that significantly affect the ways in which it ensures, allows, or interferes with critical biological activities and processes.

- **Controlling factors** are environmental conditions and dynamics – both natural and anthropogenic – that determine the quality, abundance, and spatial and temporal distributions of one or more habitat elements. In some instances, a controlling factor alternatively or additionally may directly affect a critical biological activity or process. Controlling factors are also called "drivers." A hierarchy of controlling factors will exist, affecting the system at different temporal and spatial scales. Long-term dynamics of climate and geology define the domain of this hierarchy (Burke et al. 2009). For example, the availability of suitable nest sites for a riparian nesting bird may depend on factors such as canopy closure, community type, humidity, and intermediate structure which, in turn, may depend on factors such as water storage-delivery system design and operation (dam design, reservoir morphology, and dam operations) which, in turn, is shaped by watershed geology, vegetation, climate, land use, and water demand. *The LCR MSCP conceptual ecological models focus* *on controlling factors that are within the scope of potential human manipulation, including management actions directed toward the species of interest.*

The present CEM methodology also explicitly defines a “life stage” as a biologically distinct portion of the life cycle of a species. The individuals in each life stage undergo distinct developments in body form and function; engage in distinct types behaviors, including reproduction; use different sets of habitats or the same habitats in different ways; interact differently with their larger ecosystems; and/or experience different types and sources of stress. A single life stage may include multiple age classes. A CEM focused on life stages is not a demographic model per se (McDonald and Caswell 1993). Instead, it is a complementary model focused on the ecological factors (drivers) that shape population dynamics.

This expanded approach permits the consideration of **six** possible types of causal relationships, on which management actions may focus, for each life stage of a species:

(1) The effect of one controlling factor on another

(2) The effect of a controlling factor on the abundance, spatial and temporal distributions, and other qualities of a habitat element

(3) The effect of the abundance, spatial and temporal distributions, and other qualities of one habitat element on those of another

(4) The effect of the abundance, spatial and temporal distributions, and other qualities of a habitat element on a critical biological activity or process

(5) The effect of one critical biological activity or process on another

(6) The effect of a critical biological activity or process on a specific life-stage outcome

Each controlling factor may affect the abundance, spatial and temporal distributions, and other qualities of more than one habitat element and several controlling factors may affect the abundance, spatial or temporal distributions, or other qualities of each habitat element. Similarly, the abundance, spatial and temporal distributions, and other qualities of each habitat element may affect more than one biological activity or process, and the abundances, spatial or temporal distributions, or other qualities of several habitat elements may affect each biological activity or process. Finally, the rate of each critical biological activity or process may contribute to the rates of more than one life-stage outcome.

Integrating this information across all life stages for a species provides a detailed picture of: (1) what is known, with what certainty, and the sources of this information; (2) critical areas of uncertain or conflicting science that demand resolution to better guide LCR MSCP management planning and action; (3) crucial attributes to use to monitor system conditions and predict the effects of experiments, management actions, and other potential agents of change; and (4) how managers may expect the characteristics of a resource to change as a result of changes to controlling factors, including changes in management actions.

Conceptual Ecological Models as Hypotheses

The CEM for each species produced with this methodology constitutes a collection of hypotheses for that species. These hypotheses concern: (1) the species' life history; (2) the species' habitat requirements and constraints; (3) the factors that control the quality, abundance, and spatial and temporal distributions of these habitat conditions; and (4) the causal relationships among these. Knowledge about these model components and relationships may vary, ranging from well settled to very tentative. Such variation in the certainty of current knowledge always arises as a consequence of variation in the types and amount of evidence available and in the ecological assumptions applied by different experts.

Wherever possible, the information assembled for the LCR MSCP species CEMs documents the degree of certainty of current knowledge concerning each component and linkage in the model. This certainty is indicated by the quality, abundance, and consistency of the available evidence and by the degree of agreement/disagreement among the experts. Differences in the interpretations or arguments offered by different experts may be represented as alternative hypotheses. Categorizing the degree of agreement/disagreement concerning the components and linkages in a CEM makes it easier to identify topics of greater uncertainty or controversy.

Characterizing Causal Relationships

A causal relationship exists when a change in one condition or property of a system results in a change in some other condition or property. A change in the first condition is said to cause a change in the second condition. The present CEM methodology includes methods for assessing causal relationships (links) along four dimensions (attributes) adapted from the ERP methodology (DiGennaro et al. 2012):

(1) The character and direction of the effect

(2) The magnitude of the effect

(3) The predictability (consistency) of the effect

(4) The certainty of present scientific understanding of the effect

The present and ERP methodologies for assessing causal linkages differ in three ways. First, the ERP methodology assesses these four attributes for the *cumulative* effect of the entire causal chain leading up to each outcome. However, the LCR MSCP methodology recognizes six different types of causal linkages as described above. This added level of detail and complexity makes it difficult in a single step to assess the cumulative effects of all causal relationships that lead up to any one individual causal link. For example, in the present methodology, the effect of a given critical biological activity or process on a particular life-stage outcome may depend on the effects of several habitat elements on that critical biological activity or process which, in turn, may depend on the effects of several controlling factors. For this reason, the present methodology assesses the four attributes separately for each causal link *by itself* rather than attempting to assess cumulative effects of all causal linkages leading to the linkage of interest. The present methodology assesses cumulative effects instead through analyses of the data assembled on all individual linkages. The analyses are made possible by assembling the data on all individual linkages in a spreadsheet as described below.

Second, the present CEM methodology explicitly divides link magnitude into three separate subattributes and provides a specific methodology for integrating their rankings into an overall ranking for link magnitude: (1) link intensity, (2) link spatial scale, and (3) link temporal scale. In contrast, the ERP methodology treats spatial and temporal scale together and does not separately evaluate link intensity. The present methodology defines link intensity as the relative strength of the effect of the causal node on the affected node *at the places and times where the effect occurs*. Link spatial scale is the relative spatial extent of the effect of the causal node on the affected node. Link temporal scale is the relative temporal extent of the effect of the causal node on the affected node. The present methodology defines link magnitude as the average of the separate rankings of link intensity, spatial scale, and temporal scale as described below.

Third, the ERP methodology addresses a single, large landscape, while the present methodology needed the flexibility to generate models applicable to a variety of spatial scopes. For example, the present methodology needed to support modeling of a single restoration site, the LCR main stem and flood plain, or the entire Lower Colorado River Basin. Consequently, the present methodology assesses the spatial scale of cause-effect relationships only relative to the spatial scope of the model.

The LCR MSCP conceptual ecological model methodology thus defines the four attributes for a causal link as follows:

- **Link character** – This attribute categorizes a causal relationship as positive, negative, involving a threshold response, or "complex." "Positive" means that an increase in the causal node results in an increase in the affected node, while a decrease in the causal node results in a decrease in the affected node. "Negative" means that an increase in the causal node results in a decrease in the affected element, while a decrease in the causal node results in an increase in the affected node. Thus, "positive" or "negative" here do ***not*** mean that a relationship is beneficial or detrimental. The terms instead provide information analogous to the sign of a correlation coefficient. "Threshold" means that a change in the causal agent must cross some value before producing an effect. "Complex" means that there is more going on than a simple positive, negative, or threshold effect. In addition, this attribute categorizes a causal relationship as uni- or bi-directional. Bi-directional relationships involve a reciprocal relationship in which each node affects the other.

- **Link magnitude** – This attribute refers to "… the degree to which a linkage controls the outcome *relative to other drivers*" (DiGennaro et al. 2012). Magnitude takes into account the spatial and temporal scale of the causal relationship as well as the strength (intensity) of the relationship in individual locations. The present methodology provides separate ratings for the intensity, spatial scale, and temporal scale of each link, as defined above, and assesses overall link magnitude by averaging these three elements. Just as the terms for link character provide information analogous to the sign of a correlation coefficient, the terms for link magnitude provide information analogous to the size of a correlation coefficient. Tables 1-1 through 1-4 present the rating framework for link magnitude.

- **Link predictability** – This attribute refers to "… the degree to which the current understanding of the system can be used to predict the role of the driver in influencing the outcome. Predictability … captures variability … [and recognizes that] effects may vary so much that properly measuring and statistically characterizing inputs to the model are difficult" (DiGennaro et al. 2012). A causal relationship may be unpredictable because of natural variability in the system or because its effects depend on the interaction of other factors with independent sources for their own variability. Just as the terms for link character provide information analogous to the sign of a correlation coefficient, the terms for link predictability provide information analogous to the size of the range of error for a correlation coefficient. Table 1-5 presents the scoring framework for link predictability.

- **Link understanding** refers to the degree of agreement represented in the scientific literature and among experts in understanding how each driver is linked to each outcome. Table 1-6 presents the scoring framework for understanding. Link predictability and understanding are independent attributes. A link may be considered highly predictable but poorly understood or poorly predictable but well understood.

Conceptual Ecological Model Documentation

The documentation for each CEM provides information in three forms: (1) a narrative report, (2) causal diagrams showing the model components and their causal linkages for each life stage, and (3) a spreadsheet that is used to record the detailed information (e.g., linkage attribute ratings) for each causal linkage. The spreadsheet and diagrams, built using Microsoft Excel™ and Microsoft Visio™, respectively, are linked so that the diagrams provide a fully synchronized summary of the information in the spreadsheet.

The narrative report for each species presents the definitions and rationales for the life stages/events and their outcomes identified for the species' life history; the critical biological activities and processes identified for each life stage; the habitat elements identified as supporting or impeding each critical biological activity or process for each life stage; the controlling factors identified as affecting the abundance, spatial and temporal distributions, and other qualities of the habitat elements for each life stage; and the causal linkages among these model components.

The narrative report includes causal diagrams (*aka* "influence diagrams") for each life stage. These diagrams show the individual components or nodes of the model for that stage (life-stage outcomes, critical biological activities and processes, habitat elements, and controlling factors) and their causal relationships. The causal relationships (causal links) are represented by arrows indicating which nodes are linked and the directions of the causal relationships. The attributes of each causal link are represented by varying line thickness, line color, and other visual properties as shown on figure 1-1. The diagram conventions mostly follow those in the ERP methodology (DiGennaro et al. 2012).

The spreadsheet for each CEM contains a separate worksheet for each life stage. Each row in the worksheet for a life stage represents a single causal link. Table 1-7 lists the fields (columns) recorded for each causal link.

Link Attribute Ratings, Spreadsheet Fields, and Diagram Conventions

Table 1-1.—Criteria for rating the relative intensity of a causal relationship – one of three variables in the rating of link magnitude (after DiGennaro et al. 2012, Table 2)

Link intensity – the relative strength of the effect of the causal node on the affected node *at the places and times where the effect occurs*.	
High	Even a relatively small change in the causal node will result in a relatively large change in the affected node *at the places and times where the effect occurs*.
Medium	A relatively large change in the causal node will result in a relatively large change in the affected node; a relatively moderate change in the causal node will result in no more than a relatively moderate change in the affected node; and a relatively small change in the causal node will result in no more than a relatively small change in the affected node *at the places and times where the effect occurs*.
Low	Even a relatively large change in the causal node will result in only a relatively small change in the affected node *at the places and times where the effect occurs*.
Unknown	Insufficient information exists to rate link intensity.

Table 1-2.—Criteria for rating the relative spatial scale of a cause-effect relationship – one of three variables in the rating of link magnitude (after DiGennaro et al. 2012, Table 1)

Link spatial scale – the relative spatial extent of the effect of the causal node on the affected node. The rating takes into account the spatial scale of the cause and its effect.	
Large	Even a relatively small change in the causal node will result in a change in the affected node across a large fraction of the spatial scope of the model.
Medium	A relatively large change in the causal node will result in a change in the affected node across a large fraction of the spatial scope of the model; a relatively moderate change in the causal node will result in a change in the affected node across no more than a moderate fraction of the spatial scope of the model; and a relatively small change in the causal node will result in a change in the affected node across no more than a small fraction of the spatial scope of the model.
Small	Even a relatively large change in the causal node will result in a change in the affected node across only a small fraction of the spatial scope of the model.
Unknown	Insufficient information exists to rate link spatial scale.

Table 1-3.—Criteria for rating the relative temporal scale of a cause-effect relationship – one of three variables in the rating of link magnitude (after DiGennaro et al. 2012, Table 1)

Link temporal scale – the relative temporal extent of the effect of the causal node on the affected node. The rating takes into account the temporal scale of the cause and its effect.	
Large	Even a relatively small change in the causal node will result in a change in the affected node that persists or recurs over a relatively large span of time – decades or longer – even without specific intervention to sustain the effect.
Medium	A relatively large change in the causal node will result in a change in the affected node that persists or recurs over a relatively large span of time – decades or longer – even without specific intervention to sustain the effect; a relatively moderate change in the causal node will result in a change in the affected node that persists or recurs over only a relatively moderate span of time – one or two decades – without specific intervention to sustain the effect; a relatively small change in the causal node will result in a change in the affected node that persists or recurs over only a relatively short span of time – less than a decade – without specific intervention to sustain the effect.
Small	Even a relatively large change in the causal node will result in a change in the affected node that persists or recurs over only a relatively short span of time – less than a decade – without specific intervention to sustain the effect.
Unknown	Insufficient information exists to rate link temporal scale.

Table 1-4.—Criteria for rating the overall relative link magnitude of a cause-effect relationship based on link intensity, spatial scale, and temporal scale

Link magnitude – the overall relative magnitude of the effect of the causal node on the affected node based on the numerical average for link intensity, spatial scale, and temporal scale. (Calculated by assigning a numerical value of 3 to “High” or “Large,” 2 to “Medium,” 1 to “Low” or “Small,” and not counting missing or “Unknown” ratings.)	
High	Numerical average ≥ 2.67
Medium	Numerical average ≥ 1.67 but < 2.67
Low	Numerical average < 1.67
Unknown	No subattribute is rated High/Large, Medium, or Low/Small, but at least one subattribute is rated Unknown.

Table 1-5.—Criteria for rating the relative predictability of a cause-effect relationship (after DiGennaro et al. 2012, Table 3)

Link predictability – the statistical likelihood that a given causal agent will produce the effect of interest.	
High	Magnitude of effect is largely unaffected by random variation or by variability in other ecosystem dynamics or external factors.
Medium	Magnitude of effect is moderately affected by random variation or by variability in other ecosystem processes or external factors.
Low	Magnitude of effect is strongly affected by random variation or by variability in other ecosystem processes or external factors.
Unknown	Insufficient information exists to rate link predictability.

Table 1-6.—Criteria for rating the relative understanding of a cause-effect relationship (after DiGennaro et al. 2012, Table 3)

Understanding – the degree of agreement in the literature and among experts on the magnitude and predictability of the cause-effect relationship of interest.	
High	Understanding of the relationship is subject to little or no disagreement or uncertainty in peer-reviewed studies from within the ecosystem of concern or in scientific reasoning among experts familiar with the ecosystem. Understanding may also rest on well-accepted scientific principles and/or studies in highly analogous systems.
Medium	Understanding of the relationship is subject to moderate disagreement or uncertainty in peer-reviewed studies from within the ecosystem of concern and in scientific reasoning among experts familiar with the ecosystem.
Low	Understanding of the relationship is subject to wide disagreement, uncertainty, or lack of evidence in peer-reviewed studies from within the ecosystem of concern and in scientific reasoning among experts familiar with the ecosystem.
Unknown	(*The "Low" rank includes this condition*).

Table 1-7.—Organization of the worksheet for each life stage

Col.	Label	Content
A	Species	Identifies the species being modeled by four-letter code.
B	Link#	Contains a unique identification number for each causal link.
C	Life Stage	Identifies the life stage affected by the link.
D	Causal Node Type	Identifies whether the causal node for the link is a controlling factor, habitat element, critical biological activity or process, or life-stage outcome.
E	Causal Node	Identifies the causal node in the link.
F	Effect Node Type	Identifies whether the effect node for the link is a controlling factor, habitat element, critical biological activity or process, or life-stage outcome.
G	Effect Node	Identifies the effect node in the link.
H	Link Reason	States the rationale for including the link in the conceptual ecological model, including citations as appropriate.
I	Link Character Type	Identifies the character of the link based on standard definitions.
J	Link Character Direction	Identifies whether the link is uni- or bi-directional.
K	Link Character Reason	States the rationale for the entries for Link Character Type and Link Character Direction, including citations as appropriate.
L	Link Intensity	Shows the rating of link intensity based on the definitions in table 1-1.
M	Link Spatial Scale	Shows the rating of link spatial scale based on the definitions in table 1-2.
N	Link Temporal Scale	Shows the rating of link temporal scale based on the definitions in table 1-3.
O	Link Average Magnitude	Shows the numerical average rating of link intensity, spatial scale, and temporal scale based on the definitions in table 1-4.
P	Link Magnitude Rank	Shows the overall rating of link magnitude based on the Link Average Magnitude, grouped following the criteria in table 1-4.
Q	Link Magnitude Reason	States the rationale for the ratings for link intensity, spatial scale, and temporal scale, with citations as appropriate.
R	Link Predictability Rank	Shows the rating of link predictability based on the definitions in table 1-5.
S	Link Predictability Reason	States the rationale for the rating of link predictability, with citations as appropriate.
T	Link Understanding Rank	Shows the rating of link understanding based on the definitions in table 1-6.
U	Link Understanding Reason	States the rationale for the rating of link predictability, including comments on alternative interpretations and publications/experts associated with different interpretations when feasible, with citations as appropriate.
V	Management Questions	Briefly notes questions that appear to arise from the preceding entries for the link, focused on critical gaps or uncertainties in knowledge concerning *management actions and options*, with reasoning, including the estimate of relative importance when possible.
W	Research Questions	Brief notes that appear to arise from the preceding entries for the link, focused on critical gaps or uncertainties in *basic scientific knowledge*, with reasoning, including the estimate of relative importance when possible.
X	Other Comments	Provides additional notes on investigator concerns, uncertainties, and questions.
Y	Update Status	Provides information on the history of editing the information on this link for updates carried out after completion of an initial version.

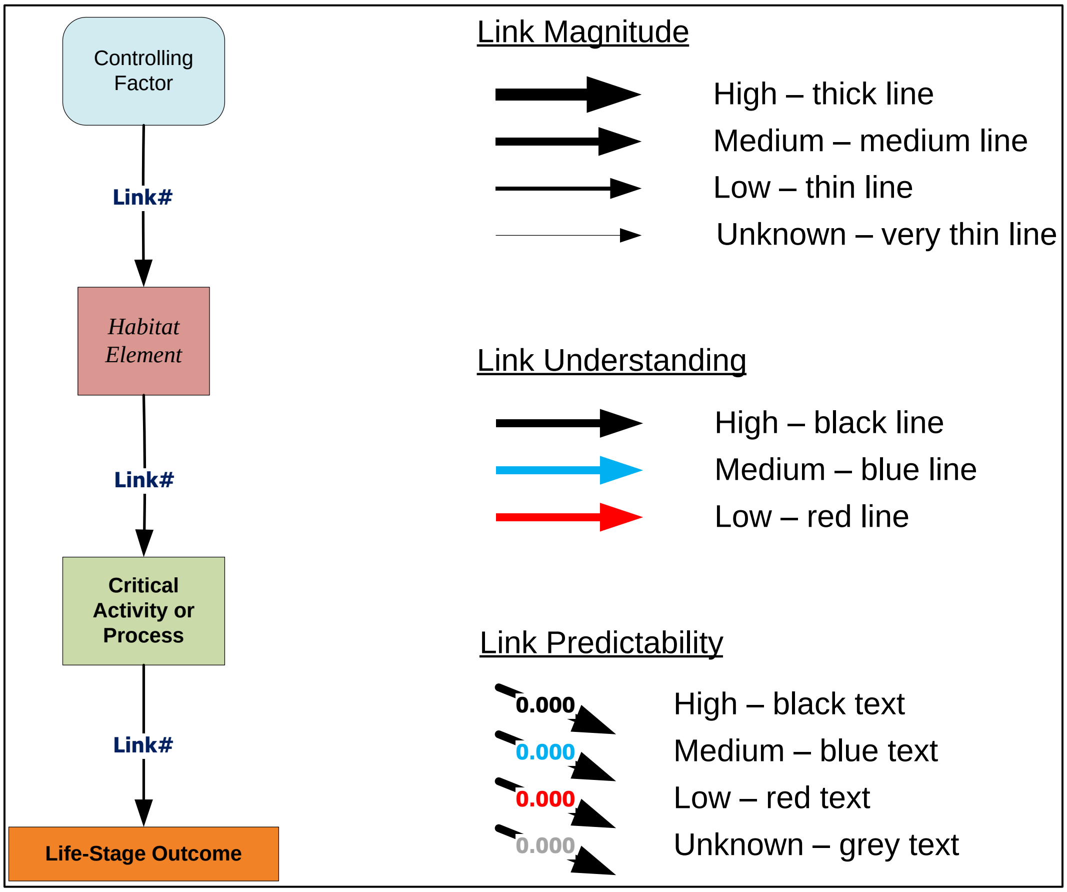

Figure 1-1.—Conventions for displaying cause and effect nodes, linkages, link magnitude, link understanding, and link predictability.

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ATTACHMENT 2

Colorado River Cotton Rat Habitat Data

Table 2-1.—Colorado River cotton rat habitat data

Habitat element	Value or range	Location	Reference
Food availability	No values or ranges in the literature, just species lists.		
Herbaceous vegetation assemblage	Species composition variable, native or non-native.	Lower Colorado River	Neiswenter 2014
	Density of vegetation within 1 meter of ground most important.	Lower Colorado River	Neiswenter 2014
	Greatest density between 10–120 and 90–100 centimeters above ground.	Lower Colorado River	Neiswenter 2014
Infectious agents	No values or ranges in the literature, just species lists.		
Local hydrology	Found near water, natural streams or human-made irrigation canals, ponds, or agricultural fields.	Lower Colorado River	Allen 1895; Burt 1933; Goldman 1928; Hoffmeister 1986 *in* Gwinn 2011
	Found in restored cottonwood/ willow/mesquite riparian habitat	Lower Colorado River	Bureau of Reclamation 2008
	Nested just above water line in cattail marsh.	Nevada	Hall 1946 *in* BIO-WEST, Inc. 2005
Predator density	No values or ranges in the literature, just species lists.		

Note: The data presented in this table reflect those available in the literature at the time this model was developed. These data have not been validated.

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