Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Desert Pocket Mouse (*Chaetodipus penicillatus sobrinus*) (DPMO) Basic Conceptual Ecological Model for the Lower Colorado River

LCR MSCP website photo gallery

March 2021

Work conducted under LCR MSCP Work Task G6

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Lower Colorado River Multi-Species Conservation Program

Desert Pocket Mouse (*Chaetodipus penicillatus sobrinus*) (DPMO) Basic Conceptual Ecological Model for the Lower Colorado River

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ACRONYMS AND ABBREVIATIONS

CEM	conceptual ecological model
cm	centimeter(s)
DPMO	desert pocket mouse (*Chaetodipus penicillatus sobrinus*)
ERP	Sacramento-San Joaquin Delta Ecosystem Restoration Program
ft	foot/feet
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
Reclamation	Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service

Symbols

°C	degrees Celsius
>	greater than
≥	greater than or equal to
<	less than
%	percent (*aka* parts per hundred)
™	trademark

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.

CONTENTS

Page

Foreword ..... **v**

Executive Summary **ES-1**
Conceptual Ecological Models ES-1
Conceptual Ecological Model Structure ES-3
Results ES-4

Chapter 1 – Introduction **1-1**
Desert Pocket Mouse Reproductive Ecology 1-2
Conceptual Ecological Model Purposes 1-2
Conceptual Ecological Model Structure 1-3

Chapter 2 – DPMO Life-Stage Model **2-1**
Introduction to the DPMO Life Cycle 2-2
DPMO Life Stage 1 – Pups 2-2
DPMO Life Stage 2 – Adults 2-2

Chapter 3 – Critical Biological Activities and Processes **3-1**
Disease 3-2
Dispersal 3-2
Foraging 3-3
Gene Flow 3-4
Nest Attendance 3-4
Nursing 3-4
Predation 3-5
Torpor 3-5

Chapter 4 – Habitat Elements **4-1**
Food Availability 4-2
Habitat Connectivity 4-3
Infectious Agents 4-4
Parental Care 4-4
Predators 4-4
Shrub Density 4-5
Soil Texture 4-5
Temperature 4-6
Vegetation Community Type 4-6

Page

Chapter 5 – Controlling Factors **5-1**
Fire Management 5-2
Grazing 5-3
Habitat Management & Restoration 5-4
Nuisance Species Introduction & Management 5-5
On-Site Vegetation Management 5-6

Chapter 6 – Conceptual Ecological Model by Life Stage **6-1**
DPMO Life Stage 1 – Pups 6-4
DPMO Life Stage 2 – Adults 6-7

Chapter 7 – Causal Relationships Across Life Stages **7-1**
Effects of Critical Biological Activities and Processes on Life-Stage Outcomes 7-1
Effects of Critical Biological Activities and Processes on Each Other 7-3
Effects of Habitat Elements on Critical Biological Activities and Processes 7-4
Effects of Habitat Elements on Each Other 7-6
Effects of Controlling Factors on Habitat Elements 7-7
Causal Relationships with High Understanding 7-9
Potentially Influential Causal Relationships with Low Understanding and/or Unknown Magnitude 7-10

Chapter 8 – Discussion and Conclusions **8-1**

Literature Cited **L-1**

Acknowledgments **A-1**

Tables

Table Page

1 DPMO life stages and life-stage outcomes 2-1
2 DPMO critical biological activities and processes and their distribution among life stages 3-1
3 DPMO habitat elements and the critical biological activities and processes that are proposed to directly affect them across all life stages 4-2
4 DPMO controlling factors and the habitat elements they are proposed to directly affect among the life stages 5-1
5 Direct effects of critical biological activities and processes on DPMO life-stage outcomes 7-2
6 Direct effects of critical biological activities and processes on other critical biological activities and processes 7-3
7 DPMO habitat elements and the critical biological activities and processes they are proposed to directly affect across the two DPMO life stages 7-5
8 Direct effects of habitat elements on each other 7-6
9 Direct effect of controlling factors on habitat elements 7-8
10 Direct effect of controlling factors on other controlling factors 7-9
11 Low-understanding and medium- or unknown-magnitude direct effects of critical biological activity or process on life stage outcomes 7-11

Figures

Figure Page

1 Proposed DPMO life history model. 2-1
2 Diagram conventions for LCR MSCP species conceptual ecological models 6-3
3 CEM master diagram for DPMO life stage 1 – pups life stag controlling factors, habitat elements, critical biological activities and processes, and life-stage outcome. 6-5
4 CEM master diagram for DPMO life stage – adult life stage controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes. 6-11

Attachments

Attachment

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

2 Desert Pocket Mouse (*Chaetodipus penicillatus sobrinus*) (DPMO) Habitat Data

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, documented models are valuable tools, 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 depends on CEMs to 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: https://www.ecologyandsociety.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 the 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 [*Coccyzus americanus occidentalis*]) 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 decision making 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 desert pocket mouse (*Chaetodipus penicillatus sobrinus*) (DPMO). The purpose of this model is to help the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), Bureau of Reclamation (Reclamation), identify areas of scientific uncertainty concerning DPMO ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure DPMO 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 present DPMO population and its distribution within the greater lower Colorado River (LCR) ecosystem. It is considered to be the northernmost subspecies of *C. penicillatus* and is found in northwestern Arizona, southeastern Nevada, and extreme southwestern Utah. Hoffmeister (1986) reported that it not been confirmed south of Hoover Dam; however, it likely occurs in river Reaches 1, 2, and the northern section of Reach 3 (Jezkova et al. 2009)—what are likely DPMO have been trapped in the Big Bend Conservation Area intermittently since 2012 (LCR MSCP 2016; Lyon 2020). The model addresses the landscape as a whole rather than any single managed area.

The research questions and gaps in scientific knowledge identified through the modeling effort serve as examples of topics the larger scientific community could explore to improve the overall understanding of the ecology and conservation of DMPO. These research questions and knowledge gaps 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 DPMO 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 DPMO conceptual ecological model has five core components:

- **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 surviving to the next life stage (e.g., from juvenile to adult), and 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 bird species may include foraging, molt, nest site selection, and temperature regulation. Critical biological activities and processes typically are "rate" variables.

- **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 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 the water storage-delivery system design and operation (dam design, reservoir morphology, and dam operations), which in turn is shaped by climate, land use, vegetation, water demand, and watershed geology.

This 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. Software tools developed specifically for the LCR MSCP's conceptual ecological models allow users to query the CEM spreadsheet for each life stage and generate diagrams that selectively display query results concerning the CEM for each life stage.

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE

The information used to construct the present CEM includes the most recent LCR MSCP species account (LCR MSCP 2016) and Mantooth and Best (2005). The CEM also integrates information from Hill (2017, 2018), Hill and Calvert (2016), Hill and Lyon (2019); Lyon (2020) and Micone (2002) on DPMO and related pocket mice,; general works on the types of habitat in which DPMO can occur; studies and overviews of small mammal biology and ecology in general; and the expert knowledge of LCR MSCP biologists. However, the purpose of the present report is not to provide an updated literature review; rather, its purpose is to integrate the available information and knowledge into a CEM so it can be used for adaptive management.

The DPMO conceptual ecological model identifies two life stages based on the aforementioned sources of information. Further, the CEM identifies one to two life-stage outcomes for each life stage as follows:

- Pups: pup survival
- Adults: adult survival and adult fertility

Chapter 2 defines and discusses these life stages and life-stage outcomes in detail.

The DPMO conceptual ecological model identifies eight critical biological activities and processes that affect one or both of these life-stage outcomes. Chapter 3 defines and discusses these critical biological activities and processes in detail. The eight critical biological activities and processes are as follows, in alphabetical order: disease, dispersal, foraging, gene flow, nest attendance, nursing, predation, and torpor.

The DPMO conceptual ecological model distinguishes nine habitat elements that affect the rates, timing, magnitude, distribution, or other aspects of one or more critical biological activities or processes for one or more life stages. Chapter 4 defines and discusses these habitat elements in detail. The nine habitat elements are as follows, in alphabetical order: food availability, habitat connectivity, infectious agents, parental care, predators, shrub density, soil texture, temperature, and vegetation community type.

Finally, the DPMO conceptual ecological model distinguishes five controlling factors that affect the distribution, quality, composition, abundance, and other features of one or more of these habitat elements. Because the LCR ecosystem is highly regulated, the controlling factors almost exclusively concern human activities. Chapter 5 defines and discusses these controlling factors in detail. The five controlling factors are as follows, in alphabetical order: fire management, grazing, habitat management & restoration, nuisance species introduction & management, and on-site vegetation management.

RESULTS

The CEM identifies the following direct, strong (high-magnitude) causal relationships among these controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes:

- One controlling factor—habitat management & restoration—has a direct, high-magnitude effect on one or more habitat elements relevant to one or more DPMO life stages.

- Two habitat elements—infectious agents and vegetation community type—have direct, high-magnitude effects on one or more critical biological activities and processes in both DPMO life stages.

- No habitat elements have a direct, high-magnitude effect on any other habitat elements.

- No critical biological activities or processes have direct, high-magnitude effects on any life-stage outcomes in either of the two DPMO life stages.

- No critical biological activities or processes have direct, high-magnitude effects on other critical biological activities or processes.

The CEM also identifies a large number of potential causal relationships with low understanding. These include several links for which the available information indicates a likely high or medium-magnitude, but currently poorly understood relationship, and links for which the available information is too scant to rate magnitude at all. The CEM includes links with unknown magnitude based on established ecological principles and knowledge of particular features of pocket mouse biology, and ecology in general, for which there currently is no documentation for DPMO or any closely related species in particular. Specifically:

- The CEM identifies the effects of disease on dispersal, nest attendance, foraging, adult fertility, pup survival, and adult survival as unknown magnitude and low understanding.

Second, the CEM does identify several potentially important causal relationships with medium magnitude and high or medium understanding. These ratings of medium or high for link understanding reflect cumulative knowledge from several detailed studies of DPMO or related species and their habitat. Of these well and moderately well understood, medium-magnitude relationships, 12 out of 20 are related directly or indirectly to the vegetation community type.

Finally, the assessment of causal relationships among controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes also identifies numerous relationships with proposed intermediate (medium) and low magnitude. As knowledge about the species expands, the ratings of link magnitude for these proposed relationships, as well as for those currently assigned a high-magnitude rating, may change.

Chapter 1 – Introduction

This document presents a conceptual ecological model (CEM) for the desert pocket mouse (*Chaetodipus penicillatus sobrinus*) (DPMO). The purpose of this model is to help the Lower Colorado River Multi-Species Conservation Program (LCR MSCP), Bureau of Reclamation (Reclamation), identify areas of scientific uncertainty concerning DPMO ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure DPMO 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 present DPMO population and its distribution within the greater lower Colorado River (LCR) ecosystem. It is considered to be the northernmost subspecies of *C. penicillatus* and is found in northwestern Arizona, southeastern Nevada, and extreme southwestern Utah. Hoffmeister (1986) reported that it not been confirmed south of Hoover Dam; however, it likely occurs in river Reaches 1, 2, and the northern section of reach 3 (Jezkova et al. 2009)—what are likely DPMO have been trapped in the Big Bend Conservation Area intermittently since 2012 (LCR MSCP 2016; Lyon 2020). The model addresses the landscape as a whole rather than any single managed area.

The basic sources of information for the present CEM consist of the most recent LCR MSCP species account (LCR MSCP 2016) and Mantooth and Best (2005). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The CEM also integrates information from Hill (2017, 2018), Hill and Calvert (2016), Hill and Lyon (2019), Lyon (2020), and Micone (2002) on DPMO and related pocket mice; general works on the types of southwestern settings in which DPMO can occur; and the expert knowledge of LCR MSCP biologists. However, the purpose of the present report is not to provide an updated literature review; rather, its purpose is 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 DPMO, describes the purpose of the CEM, and introduces the underlying concepts and structure of the CEM. Succeeding chapters present and explain the CEM for DPMO within the LCR and identify possible implications of this information for management, monitoring, and research needs.

DESERT POCKET MOUSE REPRODUCTIVE ECOLOGY

DPMO (subspecies *sobrinus*) are found in deserts and sandy arid regions with scattered shrubs, typically creosote bush (*Larrea* sp.) and/or mesquite (*Prosopis* sp). The northernmost subspecies of the pocket mouse, DPMO are relatively common along the northern Colorado River into Nevada (Micone 2002; Stephens 1906 *in* Mantooth and Best 2005). They have also been found in grass and shrub habitat in certain LCR riparian conservation areas, including the Big Bend Conservation Area (Lyon 2020). DPMO have small home ranges and do not appear to disperse widely—there is concern that their populations have become fragmented by habitat alteration (LCR MSCP 2016; Micone 2002).

Female DPMO build grass nests in underground burrows. The breeding season lasts from April through August (LCR MSCP 2016; Mantooth and Best 2005; Micone 2002), with peak activity in June. Females give birth to 3 to 4 young after a 26-day gestation period. DPMO live 12 to 16 months, with 87–90% turnover each year (Micone 2002). The reproductive age for DPMO is not known, but related species reach maturity by 6 months of age (e.g., Pacific pocket mice [*Perognathus longimembreis pacificus*] generally mature at 2 to 5 months, with some as soon as around 41 days [Center for Biological Diversity 2020; U.S. Fish and Wildlife Service [USFWS] 2010]; San Diego pocket mice [*Chaetodipus fallax*] mature at 5 to 6 months of age [Chebes 2002]). In a study by Kenagy and Bartholomew (1985), young of the related *C. formosus* did not reproduce in the calendar year they were born.

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 (DiGennaro et al. 2012; Fischenich 2008). The CEM methodology followed here is a crucial foundation for carrying out effects analyses, as described by Murphy and Weiland (2011, 2014) and illustrated by Jacobson et al. (2016).

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. A 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. A CEM, through its successive iterations, becomes the record of improving knowledge and the ability to manage the system.

Conceptual Ecological Model Structure

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 Burke et al. (2009), Kondolf et al. (2008), and Wildhaber et al. (2007, 2011) to provide greater detail on causal linkages and outcomes, and 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 and their population dynamics (Wildhaber et al. 2007, 2011).

That is, the CEM 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 minimally include the number of individuals recruited to the next life stage (e.g., juvenile to adult) or to the next age class within a single life stage, termed the recruitment rate; and the number of viable offspring produced, termed the fertility rate. A CEM 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 DPMO 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 surviving to the next life stage (e.g., from juvenile to adult), and 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 bird species may include foraging, molt, nest site selection, and temperature regulation. Critical biological activities and processes typically are "rate" variables.

- **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 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 the water storage-delivery system design and operation (dam design, reservoir morphology, and dam operations), which in turn is shaped by climate, land use, vegetation, water demand, and watershed geology.

The process of identifying the life stages, life-stage outcomes, critical biological activities and processes, habitat elements, and controlling factors for a CEM begins with a review of the LCR MSCP and other major accounts for the species of interest, accounts for better known but closely related or ecologically similar species, and LCR MSCP management concerns as expressed in the LCR MSCP Habitat Conservation Plan (LCR MSCP 2004) and annual work plans (LCR MSCP 2018). The process also follows conventions for life history CEMs focused on individual species and their population dynamics in the relevant branch of zoology for the species of interest. Further, the process is guided by an overarching need to ensure that the CEM helps the LCR MSCP identify areas of scientific uncertainty concerning the ecology and specific habitat requirements of the species it has been charged with conserving, the effects of specific stressors on these species, the effects of specific management actions aimed at habitat and species conservation, and the appropriate methods with which to monitor species and habitat conditions. Each CEM is developed in consultation with experts in the LCR MSCP, and submitted in draft form for review by the LCR MSCP, to ensure that the CEM meets management needs. Terminology for life stages, life-stage outcomes, critical biological activities and processes, habitat elements, and controlling factors is standardized across CEMs where feasible and appropriate.

The process of identifying the life stages for a CEM recognizes that the life cycle of any species can be divided into multiple life stages. There is no rule for how many life stages a CEM must include, and different scientists may lump together or divide up the life cycle into a different set of life stages. The process of identifying the life stages for the LCR MSCP conceptual ecological models takes into account the following two criteria for lumping versus splitting life stages. First, knowledge of the species in the LCR valley prior to river regulation and the general ecological literature for similar species indicates that there could be differences in habitat requirements, threats, behaviors, or management requirements for individuals in different portions of the life cycle. Second, a single life stage may encompass several age classes. However, unless there are strong ecological reasons to distinguish individual age classes or groups of age classes as separate life stages, the LCR MSCP conceptual ecological models combine different age classes into the fewest life stages that make good ecological sense.

The process of identifying the life-stage outcomes for a CEM follows the conventions for life history CEMs focused on individual species and their population dynamics in the relevant branch of zoology for the species of interest, as noted above. These conventions recognize three possibilities: (1) The outcomes for an individual life stage may consist exclusively of survival. For example, the outcome of a juvenile life stage may consist only of survival to become an adult. (2) The outcomes for an individual life stage may consist of both survival and participation in reproduction when participation in reproduction constitutes a distinct life stage for the species. (3) Alternatively, the outcomes for an individual life stage may consist of both survival and fertility, the latter of which concerns the production of viable fertilized eggs in the absence of parental care or the production of viable newborn in the presence of parental care. This third possibility pertains either to a life stage in which all individuals participate in reproduction, or to a life stage that focuses only on some subset of adults that engages in reproduction in a single year, such as "Breeding Adults." Several of the species of concern to the LCR MSCP are subject to management goals concerning their genetic integrity; however, the present CEMs focus only on demographic outcomes unless the LCR MSCP Adaptive Management Program specifically requests that it also includes outcomes related to genetic integrity.

The process of identifying the critical biological activities and processes for a CEM focuses on identifying three possibilities in the literature: (1) activities necessary to achieve one or more life-stage outcomes, such as feeding, mating, migrating, avoiding or escaping hazards, or resting in (relatively) safe settings, (2) biological processes that individuals must undergo to achieve one or more life-stage outcomes, such as maturing sexually, developing adult morphology and strength, or mating, and (3) biological processes that individuals will experience during the life stage that affect their fitness or survival, such as encounters with predators and/or competitors, or experiences with physical or physiological stress that reduces fitness. Critical biological activities and processes thus may be either beneficial or detrimental to fitness, survival, or reproduction. Critical biological activities and processes may affect life-stage outcomes directly, or they may affect them only indirectly through their effects on other critical biological activities or processes. For example, disease may not always result in death (i.e., may not always directly affect survivorship), but it may make an individual weaker or disoriented and therefore less able to forage or be more vulnerable to depredation.

Ordinarily, only the life-stage outcomes of an individual life stage—survival and fertility—affect demographic dynamics in the next life stage. However, in some circumstances, critical activities or processes for one life stage also may affect dynamics in the next life stage. Most commonly, such transgenerational dynamics involve patterns of parental investment in raising offspring. For example, preparing a nest for eggs, protecting the eggs during incubation, and caring for the nestlings after the eggs hatch are all critical activities for breeding

adult birds that have energetic and other costs for these adults. At the same time, these activities constitute crucial features of the environment (i.e., habitat elements) for the eggs and nestlings that affect their access to food and vulnerability to predators.

The process of identifying the critical biological activities and processes for a CEM recognizes that the critical biological activities and processes for any species can be combined or split into different categories in different ways. A single critical biological activity or process may encompass several more specific variables, behaviors, or changes. There is no rule for how many critical biological activities and processes a CEM must include or for determining which specific variables, behaviors, or changes to lump together under the heading of a single critical biological activity or process and which to split under separate headings. As with the process of identifying the life stages for the LCR MSCP conceptual ecological models, the process of identifying the critical biological activities and processes for a CEM looks for information on the species within its historic range and information in the general ecological literature for similar species indicating that there could be differences in habitat requirements, threats, or management requirements for different possible critical biological activities or processes.

The process of identifying the habitat elements for each life stage in a CEM focuses on identifying physical or biological environmental conditions that: (1) are necessary or beneficial for the successful participation of individuals of a life stage in particular beneficial critical biological activities or processes, (2) may limit or prevent the successful participation of individuals of a life stage in particular beneficial critical biological activities or processes, or (3) may result in the participation of individuals of a life stage in particular detrimental critical biological activities or processes. Habitat elements thus shape the rates of beneficial or detrimental critical biological activities or processes. Further, habitat elements may affect critical biological activities or processes directly, indirectly through their effects on other habitat elements, or both. For example, the herbaceous vegetation in a marsh may benefit an aquatic species directly by providing protective cover and plant litter on which the aquatic species may feed or indirectly by helping maintain cooler water temperatures, stabilizing the marsh substrate, and providing habitat for insects on which the aquatic species also may feed. However, the same marsh vegetation may also provide habitat for invertebrate or vertebrate species that may prey on the aquatic species of interest.

The process of identifying the habitat elements for each life stage in a CEM also recognizes that the key physical or biological environmental conditions affecting the individuals of a life stage can be combined or split into different categories in different ways. A single habitat element may encompass several more specific variables or properties of the physical or biological environment. There is no rule for how many habitat elements a CEM must include or for determining which specific properties of the physical or biological environment to lump together

under the heading of a habitat element and which to split under separate headings. The process of identifying the habitat elements for each life stage in a CEM lumps together properties of the physical or biological environment that closely covary with each other over space and time along the LCR because these properties are shaped by the same controlling factors and laws of physics or chemistry and/or because these properties strongly interact with each other and, therefore, are not independent. A CEM also may lump together properties of the physical or biological environment when there is not sufficient knowledge to split these properties into separate habitat elements in ways that would help the LCR MSCP manage the species of concern. Finally, the CEMs lump together properties of the physical or biological environment that have similar effects or management implications across multiple life stages, even if these effects or implications differ in their details between life stages. Lumping together such closely related properties under the heading for a single habitat element across all life stages makes comparison and integration of the CEMs for the individual life stages across the entire life cycle less difficult. On the other hand, a CEM may split properties of the physical or biological environment into separate habitat elements if they do not meet any of these criteria.

Finally, the process of identifying the controlling factors for each life stage in a CEM focuses on environmental conditions and dynamics—including human actions—that (1) determine the quality, abundance, and spatial and temporal distributions of important habitat elements and (2) are within the scope of potential human manipulation, most particularly manipulation by the LCR MSCP and its conservation partners along the LCR valley. The specific or "immediate" controlling factors identified in a CEM necessarily exist and vary in a larger context of human institutions and policies and both short- and long-term dynamics of climate and geology. However, a CEM does not address this larger context. The process of identifying the controlling factors for each life stage in a CEM also recognizes that a controlling factor may affect a habitat element directly or may do so indirectly through its effects on either another controlling factor or another habitat element.

The process of identifying the controlling factors for each life stage in a CEM also recognizes that the key drivers affecting the habitat elements for that life stage can be combined or split into different categories in different ways. A single controlling factor may encompass several more specific variables or human activities. There is no rule for how many controlling factors a CEM must include. The process of identifying the controlling factors for each life stage in a CEM lumps together types of human activities in particular that closely covary with each other over space and time along the LCR, because of the institutions and policies driving them, and/or because these activities strongly interact with each other and, therefore, are not independent. A CEM also may lump together human activities when there is not sufficient knowledge to split them into separate categories in ways that would help the LCR MSCP manage the species of

concern. Finally, CEMs lump together human activities as controlling factors when these activities have similar effects or management implications across multiple life stages and across multiple species of concern to the LCR MSCP, even if these effects or implications differ in their details between life stages and species. Lumping together such closely related activities under the heading for a single controlling factor across multiple species and multiple life stages of these species makes comparison and integration of CEMs across the LCR MSCP less difficult.

Each CEM not only identifies these five components (life stages, life-stage outcomes, critical biological activities and processes, habitat elements, and controlling factors) for each species, it also identifies the causal relationships among them that affect life-stage outcome rates. Further, a 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. Attachment 1 provides detailed definitions and criteria for assessing these four variables for each causal link. Each CEM attempts to include all possible "significant" causal linkages among controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes for each life stage. "Significant" here means that, based on the available literature and knowledge of experts in the LCR MSCP, the linkage has been proposed to exist, or appears reasonably likely to exist, and to have the potential to affect management of the species.

A 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. Software tools developed in association with these CEMs allow users to query the CEM spreadsheet for each life stage and generate diagrams that selectively display query results concerning the CEM for each life stage. For example, a query may selectively identify all links with high magnitude but low understanding or identify the critical biological activities or processes for a life stage with the greatest number of poorly understood drivers or effects.

Chapter 2 – DPMO Life-Stage Model

A life stage consists of a biologically distinct portion of the life history 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 DPMO within the LCR on which to build the CEM. Table 1 and figure 1 summarize the proposed DPMO life stage model.

Table 1.—DPMO life stages and life-stage outcomes

Life stage	Life-stage outcomes
1. Pups	• Pup survival
2. Adults	• Adult survival • Adult fertility

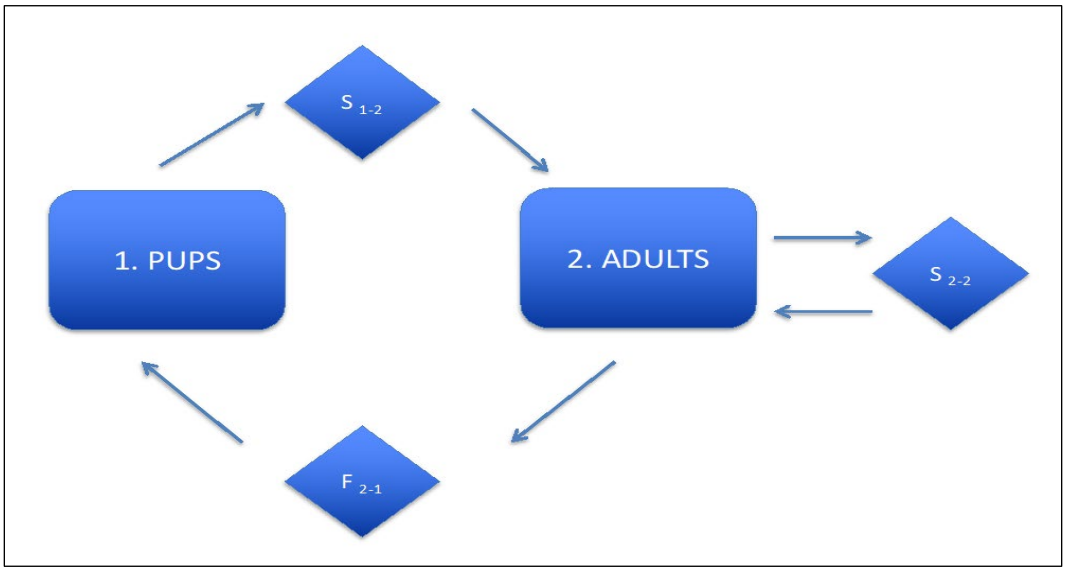

Figure 1.—Proposed DPMO life history model.
Squares indicate the life stages, and diamonds indicate the life-stage outcomes. S_{1-2} = survival of pups, S_{2-2} = survival of weaned juveniles until breeding and of adults between breeding events, and F_{2-1} = adult DPMO fertility.

INTRODUCTION TO THE DPMO LIFE CYCLE

The DPMO life cycle is typical of many rodents, being one of relatively short duration with emphasis on reproduction. Depending on species, pocket mice become sexually mature from 2 to 6 months (LCR MSCP 2016) (actual time to maturity in DPMO is not known) and usually breed during the late spring and summer months, since they typically undergo a time of prolonged torpor over winter. DPMO live a year to 16 months on average (Micone 2002).

DPMO LIFE STAGE 1 – PUPS

Female DPMO build a sphere-shaped grass nest 18 centimeters deep in shallow depressions or underground in burrows (Micone 2002). *C. penicillatus* and closely related *C. eremicus* usually give birth to three to four pups per litter (Micone 2002; Schmidly and Bradley 2016; Van De Graaff 1975 *in* Mantooth and Best 2005). The young develop rapidly during this stage—blind at birth, they are completely dependent on the parent for care. The mother nurses them until weaning, which in similar heteromyid rodents occurs at about 21 days (Kenagy and Bartholomew 1985). In related pocket mice (i.e., *Perognathus longimembris* and *C. formosus*), late in the lactation period, the mother brings food to the burrow to feed young to start the weaning process. In these species, pups do not appear above ground until completely weaned (Kenagy and Bartholomew 1985).

DPMO LIFE STAGE 2 – ADULTS

The adults life stage includes both subadults and breeding adults. It begins when the young are weaned and are no longer dependent on maternal care. Kenagy and Bartholomew (1985) observed in closely related *C. formosus* that young emerged from their burrows about a week after they had ceased nursing. Depending on species, pocket mice become sexually mature at an age of 2 to 6 months (actual time to maturity in DPMO is not known); however, there is no discernable difference in critical life processes between subadults and sexually mature adults. For this reason, these time periods are considered together to be the adults life stage. Non-migratory with small home ranges, DPMO are nocturnal. Most enter prolonged states of torpor during the winter months, especially those in the northern parts of the range (Micone 2002). The life expectancy for DPMO is short, usually averaging 12 to 16 months (LCR MSCP 2016; Schmidly and Bradley 2016). Solitary animals, closely related *C. penicillatus* usually

have nonoverlapping home ranges (Jones 1985 *in* Mantooth and Best 2005), with territory sizes of similar species *C. p. pricei* and *C. p. baileyi* averaging 1,214–2,430 square meters (Reynolds and Haskel 1949).

DPMO usually excavate their burrows under bushes, typically mesquite or creosote bush, but they occasionally will use areas bare of vegetation (Bailey 1931; Ingles 1959 *in* Mantooth and Best 2005). Substrate is usually fine sand or light gravelly soil (Bailey 1931; Mantooth and Best 2005 and references therein). In addition to nesting under shrubs, DPMO often forage under large bushes or in dense grass, although dense vegetation is not a requirement for this species (Caire 1978 *in* Mantooth and Best 2005; Reynolds and Haskell 1949).

In the Big Bend region of Texas, R. Porter (Schmidly and Bradley 2016) observed that the breeding season of related *C. eremicus* (formerly considered a subspecies of *C. penicillatus*) began in late February, with peak pregnancies in April and births in May. In the LCR, partly because DPMO enter into a winter torpor, most reproductive activity occurs a little later, during the late spring and summer, with young born between June and October. Average litter size in the wild for *C. penicillatus* (including *C. eremicus* and *C. p. sobrinus*) is three to four young (Micone 2002; Schmidly and Bradley 2016; Van De Graaff 1975 *in* Mantooth and Best 2005).

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 DPMO conceptual ecological model identifies eight critical biological activities and processes that affect one or more DPMO life stages. Some of these activities or processes differ in their details among life stages; 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.—DPMO critical biological activities and processes and their distribution 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 🡻**	Pups	Adults
Disease	**X**	**X**
Dispersal		**X**
Foraging		**X**
Gene flow		**X**
Nest attendance		**X**
Nursing	**X**	
Predation	**X**	**X**
Torpor		**X**

Except where noted, the sources for the following information are LCR MSCP (2016) and Mantooth and Best (2005). These publications summarize all earlier studies. Where appropriate and accessible, those earlier studies are directly cited.

The identification also integrates information from both older and more recent works including Micone (2002) as well as the expert knowledge of LCR MSCP biologists. In addition, where appropriate, the discussions of individual critical biological activities and processes draw upon literature concerning other species of pocket mice of the Southwestern United States. The following paragraphs discuss the eight critical biological activities and processes in alphabetical order.

DISEASE

This process refers to diseases caused either by lack of genetic diversity or by infectious agents. Although there is little information available about DPMO in relation to disease susceptibility, DPMO in all life stages are conceivably susceptible to diseases. DPMO are parasitized by protozoans (Ivens et al. 1958), nematodes, mites, chiggers, a species of flea, and sucking louse (Mantooth and Best 2005 and references therein), each of which can be disease vectors. Additionally, two species of fungi have been found on DPMO (Ashburn and Emmons 1942; Emmons 1942; Emmons and Ashburn 1942).

DISPERSAL

Dispersal is an important mechanism structuring small mammal populations, allowing for colonization of isolated or ephemeral habitats and helping to maintain genetic diversity. Micone (2002) found that in one Nevada DPMO population there was no sex-biased dispersal—adult or subadult males were no more likely to move than females. In addition, there was no movement into new habitat types; rather, mice in this study remained within one habitat type although they moved throughout it. This may have been due in part to the fact that this particular population was constrained by inhospitable habitats, surrounded by a storm drain channel with near continuous flow and a sizeable detention basin. In contrast, for many small mammals such as cotton rats (Diffendorfer and Slade 2002; Diffendorfer et al. 1995) and several heteromyid species (French 1968), males are often the main dispersers and may travel longer distances. However, other studies have found no sex bias in dispersal activity in small rodents (e.g., cotton rats [Joule and Cameron 1975; Stafford and Stout 1983] and *P. formosus* [Allred and Beck 1963]).

Micone (2002) observed the greatest distance moved by a DPMO (a single male) to be 132.7 meters (m) (435.4 feet [ft]). Apart from Micone's research, home range sizes and dispersal distances are not known for DPMO.

FORAGING

DPMO are granivores, feeding on seeds of grasses, forbs, and shrubs (Mantooth and Best [2005] and references therein) in addition to an occasional insect (e.g., beetles, bees) (Arnold 1942). (See chapter 4, "Food Availability," for lists of plant species that comprise the DPMO diet.) Newborn pups are nursed by the mother (see below, "Nest Attendance" and "Nursing"), and foraging is done only by subadults and breeding adults as part of the adults life stage.

DPMO use olfaction to locate seeds on or just beneath the soil surface and, once gathered, place the seeds in external fur-lined cheek pouches and carry them back to their burrows for use in times of seed scarcity (larder hoarding) (Price and Heinz 1984; Reichman 1983). Some pocket mice species also scatter hoard-foraged seeds in caches in the surrounding habitat (Jenkins and Breck 1998). Typically, these scatter hoards are found in the same microhabitat used for foraging; for related pocket mice, this is under small shrubs (Swartz et al. 2010). Scatter hoards, and sometimes larder hoards ,are prone to pilfering by a variety of rodent species (Jenkins and Breck 1998). There is no information about whether DPMO use scatter caches as well as burrow caches.

Price (1978) observed that *C. penicillatus* preferentially foraged under large shrubs and trees growing where the soil was sandy rather than coarse. Pocket mice (*Chaetodiplus* spp. and *Perognathus* spp.) usually forage on the ground but occasionally will climb into vegetation to gather seeds (Reichman 1983; Reichman and Price 1993; Rosenzweig et al. 1975 *in* Mantooth and Best 2005). The foraging (harvest) rate is related to the density of seeds encountered (a greater density improves the success of foraging activity) and to the size of soil particles in relation to seed size. Larger soil particles make it more difficult for pocket mice to separate and collect seeds (Price and Heinz 1984).

DPMO are nocturnal, and all foraging activity occurs at night (Price and Heinz 1984). Schmidly and Bradley (2016) noted that burrow entrances of closely related *C. eremicus* in Texas populations were closed during the day. All pocket mice species may reduce foraging activity on nights when there is a full moon, possibly to lessen predation risk, as do many small rodents (Meyer and Valone 1999; Price et al. 1984). Rosenzweig (1973) found that *C. penicillatus* foraged in open areas less than 4 m (13 ft) in radius but not greater than 8 m (26 ft) in radius, another way to reduce predation risk.

Bowers (1982) observed foraging in related *C. formosus* and found that peak nocturnal foraging activity occurred between 2200 and 0100 Mountain Daylight Time. Foraging behavior consisted of short movements of 3–4 m (9.8–13 ft),

followed by digging and pouching of gathered seeds before moving to another location. Most of their time was spent moving, and they collected a wide range of seed species.

Foraging behaviors of *C. penicillatus* and other pocket mice may change depending on the composition of the small rodent community and whether and how species are competing for resources (Kotler 1984). No information is available about foraging and competition for resources in DPMO.

GENE FLOW

This refers to the process of transferring genes from one population of DPMO to another, usually through dispersal of DPMO into new habitat patches. This, in turn, affects genetic diversity with larger panmictic populations typically having greater diversity. The greater the heterogeneity, the greater the possibility that individuals within a subpopulation 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). Jezkova et al. (2009) proposed that speciation and the resulting distribution of the *sobrinus* subspecies occurred during the last glacial period, when pocket mouse populations became separated into refugia. More recently, it has been noted that many DPMO populations along the LCR are isolated. However, since they are found on both sides of the river the water may not be a factor restricting distribution (Jezkova et al. 2009; LCR MSCP 2016, 2020); rather, their current isolation has been attributed to habitat loss and fragmentation (Micone 2002).

NEST ATTENDANCE

Female DPMO build the nest and care for and nurse their young until weaning. Nesting occurs in underground burrows, typically excavated near the base of a shrub. Nests are small domelike structures made of grasses. The presence of the mother is critical to the survival of the young, depends in part on her survival, and affects the pups life stage.

NURSING

This process only applies to the pups life stage because DPMO pups nurse from mothers and are entirely dependent on their mother prior to weaning. A pup's ability to eat is determined by the provisioning rate of its mother.

PREDATION

Predation is a threat to DPMO during both life stages, and it obviously affects subpopulation persistence to varying degrees. Although the most common predators of DPMO have been identified (see chapter 4, "Predators"), the depredation rates at any DPMO life stage are not known.

DPMO have several mechanisms to help them avoid predators, including erratic leaping, bounding and running straightaway, and acute hearing (Bleicher et al. 2018; Price and Brown 1983). Rosenzweig (1973) observed that "Indeed, never pausing, a released *P. penicillatus* always ricochets from cover to cover." They will also reduce foraging activity or may hide by climbing into dense vegetation in the presence of certain predators such as sidewinder rattlesnakes (*Crotalus cerastes*) (Bleicher et al. 2018).

On nights with a full moon, there is a higher risk of depredation, so pocket mice (*C. penicillatus*) typically do not forage during that time (Meyer and Valone 1999; Price et al. 1984). However, even foraging during the darker moon phases can be dangerous, as sidewinder rattlesnakes will forage at night during the hotter summer months; they have heat-sensing pits and are not in need of illumination to find prey (Bleicher et al. 2018). *C. penicillatus* may have an ability to use chemosensory cues to detect snake predators (Punzo 2005).

TORPOR

Torpor is a "state of lowered physiological activity typically characterized by reduced metabolism, heart rate, respiration, and body temperature" (Merriam-Webster 2019). Torpor can be triggered by temperatures outside the range of tolerance, or if food resources are scarce, and is used to conserve limited energy reserves.

Research by Brower (1970 and references therein) in the lab demonstrated that pocket mice (*C. penicillatus*) undergo short periods of spontaneous daily torpor in times of food limitation, perhaps as a way to conserve energy and/or to extend the length of time their cached stores of food last until an aboveground foraging supply is again available.

Seasonal torpor (similar to hibernation) occurs when ambient temperatures drop below a certain threshold. Bartholomew and Cade (1957, *in* Mantooth and Best 2005) observed that captive animals entered spontaneous torpor at 10–15 degrees Celsius (°C), with death reported at 5 °C. In the northern part of their range, the activity level of DPMO slows during the late fall and winter months. DPMO

observed in the Las Vegas Valley in Nevada entered a state of dormancy during winter (Micone 2002). Micone suggests that mice that do not become dormant during this time are in less than optimal conditions—they do not have sufficient fat stores to survive dormancy (LCR MSCP 2016; Micone 2002). In related *C. formosus*, Kenagy and Bartholomew (1985) hypothesize that harsh environmental conditions during late winter can extend the length of seasonal torpor, increasing the likelihood of survival but delaying or reducing reproductive success in certain years. Torpor affects adult survival; however, for the purposes of this model, we have not included a link between torpor triggered by temperature or food supply and adult fertility, as there is insufficient information.

Chapter 4 – Habitat Elements

Habitat elements consist of specific conditions in the physical or biotic environment; the quality, abundance, spatial and temporal distributions; or other properties of which significantly affect the rates of critical activities and biological processes for one or more life stages.

This chapter identifies nine habitat elements that may affect one or more critical biological activities or processes among the two DPMO life stages. Some of these habitat elements differ in their details among life stages. For example, different species may prey on different life stages of DPMO. However, using the same labels for the same *kinds* of habitat elements across all life stages makes it possible to compare the CEMs for individual life stages across the entire life cycle.

The DPMO conceptual ecological model includes habitat elements identified in species accounts and scientific studies demonstrating or positing a direct effect on one or more critical biological activities or processes for one or more DPMO life stages or for similar or related species in similar habitats. Table 3 lists the nine habitat elements and the critical biological activities or processes that they may *directly* affect across all DPMO life stages. Habitat elements may also directly affect each other.

Except where noted, the sources for the information in this chapter are LCR MSCP (2016) and Mantooth and Best (2005). These publications summarize earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The identification also integrates information from the expert knowledge of LCR MSCP biologists and from more recent studies, including investigations by Micone (2002). The results are hypotheses that make the best use of the available information.

The following paragraphs discuss the nine habitat elements in alphabetical order. As with all such tabulations of habitat associations, inferences that particular habitat characteristics may be 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).

Table 3.—DPMO habitat elements and the critical biological activities and processes that are proposed to directly affect them across all life stages

(Xs indicate that the habitat element is applicable to that critical biological activity or process.)

Affected critical biological activity or process ➔ / **Causal habitat element ⬇**	Disease	Dispersal	Foraging	Gene flow	Nest attendance	Nursing	Predation	Torpor
Food availability			X					X
Habitat connectivity		X						
Infectious agents	X							
Parental care						X		
Predators			X				X	
Shrub density			X				X	
Soil texture			X					
Temperature								X
Vegetation community type					X		X	

Note: Vegetation community type affects foraging indirectly via food availability, predation via predators, and dispersal via habitat connectivity. Food availability affects nursing via parental care (habitat element). Predators affect nest attendance via predation.

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, "food availability" is the short name for "The diversity, sizes, abundance, and spatial and temporal distributions of the species on which DPMO feed." The following paragraphs provide both the short and full names for each habitat element and a detailed definition, addressing the elements in alphabetical order.

FOOD AVAILABILITY

Full name: **The diversity, sizes, abundance, and spatial and temporal distributions of the species on which DPMO feed**. This element refers to the availability of food resources, whether seeds of grasses, forbs, or shrubs, or

invertebrates that individual DPMO will encounter during each life stage, and the density and spatial and temporal distributions of the food supply in proximity to the burrow. Pocket mice (*C. penicillatus* and other *Chaetodipus* species) feed mainly on seeds. Most are dietary generalists, selecting from the seeds that are most available in their surrounding habitat. Arnold (1942) found the following species in mouse cheek pouches: catclaw (*Senegalia greggii*), creosote bush, dates (*Zizyphus*), and mesquite (*Prosopis juliflora*). Other seed species consumed by pocket mice include weedy naturalized species, including red-stemmed filaree (*Erodium cicutarium*) and Engelmann prickly pear (*Opuntia engelmannii*); annual and perennial grasses such as sixweeks threeawn (*Aristida adscencionis*), needle grama (*Bouteloua aristidoides*), spider grass (*Aristida ternipes*), and tanglehead (*Heteropogon contortus*); annual and perennial forbs, including *Euphorbia* sp., Arizona poppy (*Kallstroemia grandiflora*), and Torrey's spiderling (*Boerhavia torreyana*); and shrubs, including jumping jholla (*Opuntia = Cylindropuntia fulgida*) (Inouye 1981; M'Closkey 1983; Reynolds and Haskell 1949).

C. penicillatus may consume insects from time to time, as Arnold (1942) reported that beetle and bees were found in immature mouse cheek pouches. According to Reichman (1975), seeds found in cheek pouches can provide a general idea of diet; however, what pocket mice collect often doesn't match stomach content analyses of what was actually consumed.

In a lab study by Price (1983), heteromyids (including *C. penicillatus*) preferred seeds that were larger than the average soil particle size, presumably to make seed collecting (separating seeds from soil before placing in cheek pouch) more efficient.

HABITAT CONNECTIVITY

Full name: **The capacity of a suitable habitat network to support or inhibit movement of organisms, as determined by the spatial distribution of natural and artificial barriers that may prevent or inhibit such movement**. Although little information is available for DPMO, research by Micone (2002) found that animals in the Nevada population did not disperse long distances. The fact that the population at that site was surrounded by habitats inhospitable to movement, notably a large storm drain channel with near continuous flow during the active season and a sizeable detention basin, may have been a contributing factor.

Habitat connectivity affects the taxonomic and genetic composition of DPMO populations in different reaches of the Colorado River. The severity of fragmentation (loss of connectivity) depends on the number and spatial extent of barriers, their relative placement, and their permeability (ability to allow some

passage of the subject fauna). It has been noted that there are concerns about the isolation of DPMO populations due to fragmentation of their habitat along the LCR (LCR MSCP 2020; Micone 2002).

INFECTIOUS AGENTS

Full name: **The types, abundance, and distribution of infectious agents of DPMO individuals and their vectors**. Infectious agents refer to the spectrum of viruses, bacteria, fungi, and parasites capable of infecting DPMO that individuals are likely to encounter during each life stage. Although there is some information about infectious agents that afflict cotton rats with which DPMO share habitat in the LCR (See Johnson and Unnasch [2015a, 2015b] CRCR and YHCR reports), little is known about the effects of disease and other infectious agents on DPMO.

PARENTAL CARE

Full name: **The care and feeding provided by mother DPMO to their young**. Female DPMO 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; their survival depends, in part, on her survival; and presence affects the pups life stage.

PREDATORS

Full name: **The abundance and distribution of species that depredate DPMO 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 DPMO during any life stage. The variables of this element include the species and sizes of the fauna that prey on DPMO during different life stages and the density and spatial distribution of these fauna in the habitats used by pocket mice.

Small rodents are extremely vulnerable to predation, and the fact that DPMO are ground nesters increases the exposure of adults and their young. In addition to coyotes (*Canis latrans*) (Short 1979 *in* Mantooth and Best 2005), mammalian predators likely include bobcats [*Lynx rufus*], foxes (likely *Urocyon cinereoargenteus*), and mustelids. Additional predators include the sidewinder

rattlesnake (Faulkner 2018) and other snakes and raptors such as great horned owls (*Bubo virginianus*). Because DPMO are nocturnal, diurnal raptors are not primary predators. Little is known about depredation rates of DPMO at any life stage.

Red fire ants (*Solenopsis invicta*) may be considered a potential future predator. Although not currently documented from Arizona, an infestation of these exotic fire ants was discovered in Yuma in 1999 and extirpated (Pest Control Technology 1999). Five infestations were found and destroyed in southern Nevada in 2000 (Clemens 2000), and the species does not appear to have become established since then. In California, red fire ants were first reported and intercepted at the California border in 1984, with periodic outbreaks in various counties since that time. Since the ending of a Statewide eradication effort in 2003, localized eradication efforts continue in Orange, Los Angeles, and San Diego Counties and in the Central Valley (Center for Invasive Species Research 2020). Red fire ants are known to attack newborn rodents in the nest and could become a threat to DPMO should the ants become established in the LCR region.

SHRUB DENSITY

Full name: **The density of shrubs in the habitat patch of DPMO**. DPMO habitat typically consists of dry sandy washes characterized by scattered large shrubs or trees, particularly creosote bush and/or mesquite. Bateman (1967) found *C. penicillatus* at Arizona sites where there was "a fairly dense overgrowth of mesquite and other trees." Reynolds and Haskell (1949) also found *C. penicillatus* in dense grass where cacti and mesquite were common. Similarly, Rosenzweig and Winakur (1969) found this species with shrubs, which they defined as "foliage growing higher than 2 ft (61 cm)." Foraging pocket mice usually avoid open areas, preferring to gather seeds under these shrubs; however, pocket mice have been found foraging at a distance of 4 m (13 ft) from cover (LCR MSCP 2016). *C. penicillatus* typically nest in burrows or depressions under bushes such as creosote or mesquite and feed on seeds from shrubs in addition to grasses and forbs (Bailey 1931 and Ingles 1959 *in* Mantooth and Best 2005). In addition, they rely on shrubs to provide protective cover from predators.

SOIL TEXTURE

Full name**: The composition of the surface soil within the DPMO habitat patch**. The qualities of soil—texture and density, among other factors—can affect burrow construction and the rate at which pocket mice forage for seeds, with looser, sandy soils often preferred by DPMO, as it is easier for them to locate

and separate seeds from soil particles (Price 1983; Price and Heinz 1984). Bateman (1967) reports that *C. penicillatus* occur in "friable" soils. Micone (2002) observed that Nevada DPMO selected coarse sandy soils associated with scattered shrubs and avoided microhabitats with low soil bulk density and percent coarse gravel (particle size > 2 millimeters).

TEMPERATURE

Full name: **The maximum or minimum temperatures in a habitat patch**. The maximum air temperature will also affect soil temperatures, in turn affecting conditions in the burrow (i.e., for nesting, and resting during times of torpor). DPMO avoid the hottest daytime temperatures by being nocturnal; however, most become dormant during times of cooler temperatures during late fall and winter months in the northern parts of their range (Micone 2002). In the southern reaches of the LCR, *C. penicillatus* may remain active all year (LCR MSCP 2016; Micone 2002).

VEGETATION COMMUNITY TYPE

Full name: **The species composition of vegetation in the DPMO habitat patch**. DPMO require grasses and other low herbaceous vegetation with scattered shrubs to provide food, nesting material, habitat structure, and protection from predators. They are found mostly in drier desert areas of the Southwestern United States, usually in association with creosote bush or mesquite. Other associated species include saltbush (*Atriplex* spp.), grama grass (*Bouteloua* spp.), tarwort (*Flourensia* spp.), and succulents such as *Fouquieria* spp., *Opuntia* spp., and *Yucca* spp. (Mantooth and Best 2005 and references therein).

DPMO also have been found in a variety of restored LCR riparian habitats. The *sobrinus* subspecies (DPMO) occurs along the northern reaches of the river, possibly as far south as Laughlin, Nevada (the uppermost section of Reach 3) (Jezkova et al. 2009; Lyon 2020). What are likely DPMO have been trapped at the Big Bend Conservation area in grassy areas of dallisgrass (*Paspalum dilatum*) and bushy bluestem (*Andropogon glomeratus*) adjacent to a more shrubby area with scattered *Baccharis* sp. and arroweed (*Pluchea sericea*) (Hill 2017, 2018; Hill and Calvert 2016; Lyon 2020). *C. penicillatus* have been trapped on the Havasu National Wildlife Refuge at the Beal Lake Conservation Area in patches of arrowweed (Hill 2018) and at Pintail Slough in dense patches of Johnsongrass (*Sorghum halepense*), mule-fat (*Baccharis salicifolia*), and Mexican devil weed (*Chlorocantha spinosa*) (Hill 2017). The subspecies at the Havasu National

Wildlife Refuge has not been determined. DPMO have been trapped at other conservation areas (e.g., Palo Verde Ecological Reserve, Cibola Valley Conservation Area, Laguna Division Conservation Area, Imperial Ponds Conservation Area), but these are likely *C. penicillatus* and not *sobrinus*.

Chapter 5 – Controlling Factors

Controlling factors consist of environmental conditions and dynamics, both natural and anthropogenic, that affect the abundance, spatial and temporal distributions, and quality of habitat elements. Controlling factors may also significantly directly affect some critical biological activities or processes. A hierarchy of controlling 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, particularly manipulation by the LCR MSCP and its conservation partners.

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 that make it useful to treat them together. In particular, each controlling factor covers activities with similar effects or management implications across multiple life stages and across multiple species of concern to the LCR MSCP. Categorizing such activities together across multiple species and multiple life stages of these species makes it easier to compare and integrate the CEMs across the LCR MSCP.

Table 4 lists the five controlling factors included in the DPMO conceptual ecological model and the habitat elements they directly affect. Controlling factors affect habitat elements indirectly, as well, through their effects on other controlling factors or through the cascading effects of habitat elements on each other.

Table 4.—DPMO controlling factors and the habitat elements they are proposed to directly affect among the life stages

Habitat element ➔ / **Controlling factor 🡻**	Food availability	Habitat connectivity	Infectious agents	Parental care	Predators	Shrub density	Soil texture	Temperature	Vegetation community type
Fire management									**X**
Grazing						**X**			**X**
Habitat management & restoration					**X**		**X**		**X**
Nuisance species introduction & management			**X**		**X**				**X**
On-site vegetation management									**X**

Note: All controlling factors affect food availability, habitat connectivity, and parental care indirectly via vegetation community type. Parental care is also affected by habitat management & restoration and nuisance species introduction & management indirectly via predators. No controlling factor directly affects ambient temperature.

FIRE MANAGEMENT

Full name: **Any fire management, whether prescribed fire or fire suppression, which may occur along the LCR and could affect DPMO or their habitat**. The LCR MSCP and other land management agencies along the LCR and Bill Williams River valleys may use prescribed fire as a management tool and actively manage wildfires through fire suppression and the construction of fire control breaks. Wildfire is a natural type of disturbance in the riparian plant communities of the LCR valley, and wildfires today also occur through human accidents (Meyer 2005 and references therein; LCR MSCP 2018).

Effects of fire management may include creation of habitat that supports or excludes DPMO (e.g., roadside disking of vegetation used by DPMO to create firebreaks—see below, "On-Site Vegetation Management"), reduction in the food supply, or support of species that pose threats to DPMO, including predators, competitors, and carriers of infectious agents. Although typically not a major threat in most riparian habitats, severe wildfires have affected Fremont cottonwood-Goodding's willow (*Populus fremontii-Salix gooddingii*) riparian habitat in the past decade (Graber et al. 2007) and could pose a threat to any DPMO populations in similar habitats in part by removing grasses and/or the shrub cover on which they depend.

Wildfires have occurred recently at LCR MSCP restoration sites (Hunters Hole and Yuma East Wetlands) and in riparian habitat at the Cibola National Wildlife Refuge (J. Hill and C. Ronning 2018, personal communications), which likely support *C. p. penicillatus* populations. Fires have also occurred at the Havasu National Wildlife Refuge and at a 224-acre (90.6-hectare) site just north of the Big Bend Conservation Area on Big Bend of the Colorado State Recreation Area (August 2019), which the LCR MSCP considers possible DPMO habitat for management purposes, as it is in Reach 3 near the subspecies boundary identified in Lee et al. (1996) in an area that was not sampled (C. Ronning 2020, personal communication).

In dry upland habitats that experience fire, studies have documented decreases in local abundances of *Chaetodipus* spp. that require either grasses or some shrub cover for foraging (Litt 2007; Simons 1991). Responses of these small mammals to fire depends on the amount of cover removed; often, the effects are short-lived, as with *C. penicillatus,* which rebounded as habitat recovered 2 years post-fire (Litt 2007). Direct mortality from fire is not typically an issue for small mammals living in underground burrows, as they are buffered from fire, depending on the thickness of the litter layer (Simons 1991).

Sharp Bowman et al. (2017) looked at the effects of applied fire at sites in Utah's Great Basin and Mojave Desert. In those habitats, fire resulted in a decreased abundance of silky desert pocket mice (*P. flavus*), with little effect on kangaroo rats (*Dipodomys* spp.). The authors concluded that quadrupedal species like pocket mice were more affected by fire's changes to habitat than were bipedal species like kangaroo rats perhaps due to differences in foraging behavior. Pocket mice will forage more under or near shrubs as compared to kangaroo rats, which forage most often in open areas. In this study, the effects of fire decreased over time.

Monasmith et al. (2010) studied fire effects in desert habitat in New Mexico dominated by creosote bush. In that short-term study, three species of pocket mice responded differently after a burn: *P. flavesence* were equally abundant on burned and control plots, *C. eremicus* were more abundant on control plots, and *P. flavus* were more abundant on burned plots. The authors did not explain the differing results; however, *C. eremicus* are most closely related to DPMO.

The effects of fire on the rodent community are variable, dependent in part on the plant community being burned, the seasonality and intensity of the fire, the species of rodent and its life history characteristics, and other factors. But, the potential for the removal of shrub foraging cover after a fire may be a challenge to some pocket mice species such as DPMO until vegetation recovers.

In addition, the presence of flammable native or exotic grasses (e.g., cheatgrass [*Bromus tectorum*], buffelgrass [*Cenchrus ciliaris*]) may increase fire frequency and/or intensity in desert systems (Brooks et al. 2004; Sharp Bowman et al. 2017) and associated riparian habitats used by DPMO. Climate change is also projected to affect fire frequency along the LCR (USFWS 2013).

GRAZING

Full name: **The grazing activity on riparian habitats along the LCR and in surrounding areas that could affect DPMO using riparian habitat**. Overgrazing by cattle (Bovidae), burros (*Equus asinus*), or mule deer (*Odocoileus hemionus*) across the arid Southwestern United States has substantially degraded riparian habitat in many areas (see Appendix G *in* USFWS 2002). (*Note*: Reclamation staff and researchers have observed mule deer and burros browsing on some LCR sites, which may affect vegetation communities if population numbers increase to the point that overgrazing occurs.) Overgrazing may thin the understory, prevent the establishment of cottonwood and willow seedlings, and remove the herbaceous cover (Kauffman et al. 1997), possibly affecting foraging for DPMO using riparian areas. Krueper (1993) and

Krueper et al. (2003) report that fencing cattle out of sensitive riparian habitats in the San Pedro Riparian National Conservation Area led to improved habitat quality for riparian birds, which would likely benefit other species inhabiting the same location.

Cattle, wild horses, and burros do occur at various locations in Reaches 1 to 3 of the LCR where DPMO can be found. Specifically, in Reach 1, cattle are grazed around Gold Butte National Monument, Grand Canyon-Parashant National Monument, Mormon Mesa, Muddy River, and the Virgin River; wild horses occur in the Muddy Mountains Herd Management Area; and burros occur in the Gold Butte and Black Mountain Herd Management Areas near Reaches 2 and 3. The herd management area do not include the Lake Mead National Recreation Area National Park Service lands, but the boundary is not fenced, so animals likely graze parts of it (C. Ronning 2020, personal communication). More information is needed to determine whether overgrazing by any of these species affects DPMO habitats directly and significantly.

HABITAT MANAGEMENT & RESTORATION

Full name: **The active management and restoration activities to restore riparian habitats, as well as marshes and backwater areas within the LCR, including 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**. Specifically, the conservation measures for DPMO include: "Conduct surveys to locate desert pocket mouse habitat that could be affected by LCR MSCP habitat creation–related activities to determine whether the habitat is occupied. If the habitat is occupied, design habitat creation-related activities to avoid the habitat. If the habitat cannot be avoided, to the extent practicable, restore the disturbed habitat area on-site following completion of the activities and protect and incorporate the habitat into the conservation area. If the habitat cannot be restored on-site, create amount of habitat at least equal to the extent of disturbed habitat elsewhere in the conservation area. Restoring disturbed habitat will ensure that covered activities do not adversely affect the existing or potential future enhanced distribution, abundance, or population viability of the desert pocket mouse in the LCR MSCP planning area" (LCR MSCP 2004).

Although DPMO mainly frequent dry sandy habitats, they will use grassy habitats that occur naturally in adjacent restored cottonwood and willow riparian areas and upland areas around marshes. Habitat restoration plantings for cotton rats have been successful at attracting *C. p. penicillatus* at a number of conservation areas along the LCR, and with DPMO, which are likely *C. p. sobrinus* found in

restored areas in the uplands near the marsh vegetation edge at the Big Bend Conservation Area (Hill 2017, 2018; Hill and Lyon 2019; C. Ronning 2020, personal communication). However, nesting in close proximity to these managed wetlands may have an impact on DPMO if burrows are inundated too long or often or if grasses die off where water is reduced (C. Ronning 2020, personal communication).

NUISANCE SPECIES INTRODUCTION & MANAGEMENT

Full name: **The intentional or unintentional introduction of nuisance species (animals and plants as well as microbes) and/or their control or management that affects DPMO survival and reproduction**. The nuisance species may poison, infect, prey on, compete with, or present alternative food resources for DPMO during one or more life stages, or they may affect physical habitat features such as shrub cover and soil substrate.

Many non-native invasive plant species (e.g., cheatgrass and buffelgrass) have invaded desert and grassland habitats in the West, altering natural fire regimes (see above, "Fire Management"). In addition, the increasing presence of non-native grasses in a natural community alters the rodent community. Litt (2007) found that with increased cover of Lehmann's lovegrass (*Eragrostis lehmanniana*), *C. penicillatus* numbers declined, possibly responding to the reduction in abundance and diversity of native species on which they feed. Where cheatgrass has become widespread, it has crowded out native grasses. However, despite the increase in seed production due to the presence of cheatgrass, its seeds are selected against by native rodents (including the related pocket mouse *P. parvus*). Kelrick and MacMahon (1985 *in* Lucero and Calloway 2018) and Lucero et al. (2015) demonstrated that "cheatgrass seeds are relatively poor in calories and other nutrients."

Non-native mammals such as feral pigs may degrade habitat and also depredate nests of pocket mice (including DPMO if present at the Beal Lake Conservation Area where feral pigs are found and regularly managed [Neskey 2018; USDOI 2016; C. Ronning 2020, personal communication]). Feral cats may affect populations of pocket mice in areas near the Las Vegas Valley in the northern part of the range, although cats are generally not a problem in LCR conservation areas (C. Ronning 2020, personal communication).

ON-SITE VEGETATION MANAGEMENT

Full name: **The types, frequencies, and durations of actions taken to manage the taxonomic composition, abundance, condition, and spatial distribution of vegetation at locations with or potentially suitable for DPMO habitat within the LCR ecosystem**. This factor addresses vegetation management at the scale of individual sites managed to achieve specific habitat or hydrologic goals. The LCR MSCP and other land managers along the LCR and Bill Williams River valleys use a range of methods to manage vegetation on lands under their authorities, including prescribed fire, surface irrigation and subirrigation, planting, fertilizing, thinning or hand removal of dead or downed vegetation, or the application of herbicides, disking and plowing, mowing, or the use of any associated vehicles (LCR MSCP 2014, 2018; C. Ronning 2020, personal communication). Agencies and irrigation and drainage districts may remove vegetation to maintain roads and canals under their authorities (this includes roadside mowing or disking to create or maintain firebreaks – see above, "Fire Management").

Chapter 6 – Conceptual Ecological Model by Life Stage

This chapter contains three sections, each presenting the CEM for a single DPMO life stage. For each life stage, the text and diagrams identify its life-stage outcomes; its critical biological activities and processes; the habitat elements that support or limit the success of its critical biological activities and processes; the controlling factors that determine the abundance, distribution, and other important qualities of these habitat elements; and the causal links among them.

The model 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."

Constructing the CEM for each life stage involves identifying, assembling, and rating each causal link one at a time. Analyses of the resulting information for each life stage can then help identify 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. Analyses also can help identify which, among these potentially high-impact relationships, are not well understood.

All potential causal links—among controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes—affecting each life stage are recorded on a spreadsheet. This spreadsheet is then used to record information on the character and direction, magnitude, predictability, and scientific understanding for each causal link, along with the underlying rationale and citations, for each life stage. Software tools developed in association with these CEMs then allow users to generate a "master" diagram for each life stage from the data in the spreadsheet—or, more usefully, to query the CEM spreadsheet for each life stage and generate diagrams that selectively display query results concerning that life stage.

This report includes the master diagram for each life stage. The master diagrams display all causal links, of all character types and directions, magnitudes, predictabilities, and levels of understanding. The results can be visually complex but are included to give the reader an overall sense of the CEM for each life stage.

The master CEM diagram for each life stage shows the controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes for that life stage. The diagram displays information on the character and direction, magnitude, predictability, and 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.

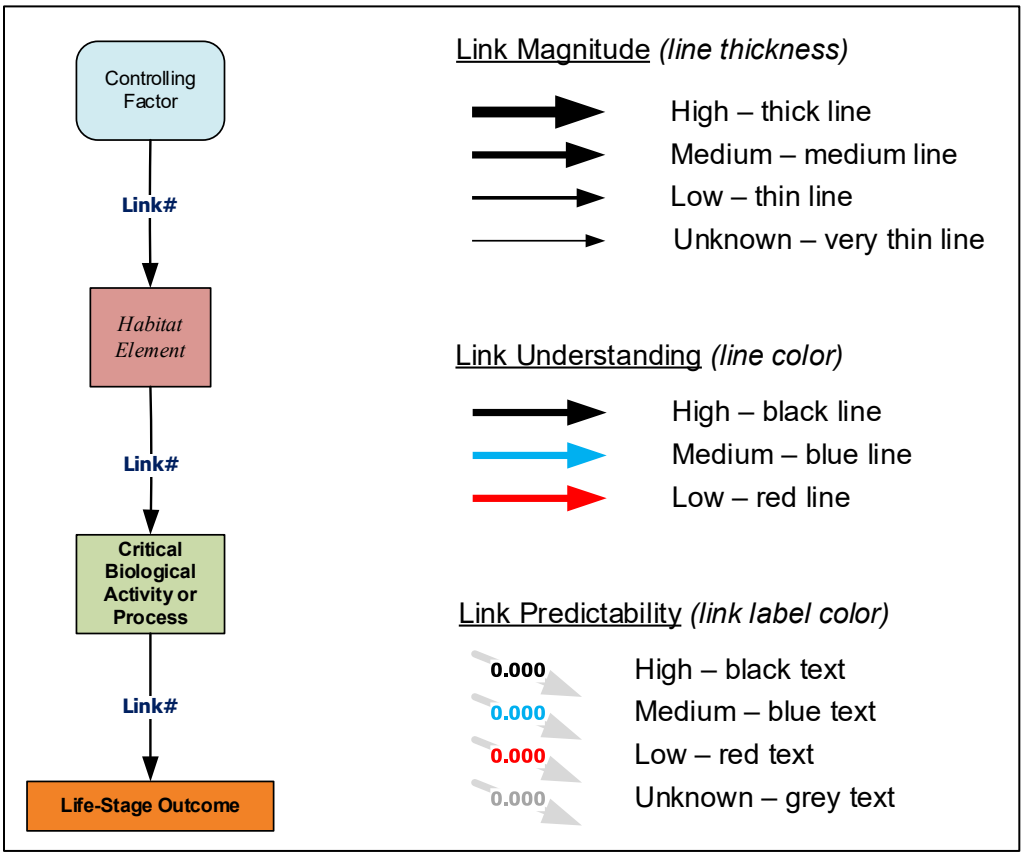

Figure 2.—Diagram conventions for LCR MSCP species conceptual ecological models.

The conventions for displaying information about the causal links are as follows: Links are represented by arrows, the point of which indicates the direction of causation. Bi-directional causal links are represented by arrows with points at

both ends. The thickness of the arrow represents link magnitude, and the color of the arrow represents link understanding. Each arrow has a label that uniquely identifies the link. The number to the left of the decimal place indicates the life stage (1…N), while the number to the right of the decimal place provides a unique index value for each link. The color of the label represents link predictability.

The discussions of each life stage in this chapter and of all three life stages considered together in chapter 7 include analyses of the information contained in the spreadsheet. The analyses highlight causal chains that strongly affect the outcomes for each life stage and identify important causal relationships with high scientific uncertainty. The latter constitutes topics of potential importance for adaptive management investigation.

DPMO Life Stage 1 – Pups

The CEM identifies three critical biological activities or processes affecting one survival outcome for this life stage as shown on figure 3. Two of these processes, predation and nursing, directly affect pup survival with a medium-magnitude effect. Predation is the most commonly proposed cause of mortality among DPMO in both life stages. The literature does not address how predation rates differ specifically between the DPMO life stages. As a result, link understanding is rated as low. The nursing process is well understood and is rated at medium magnitude.

In contrast, the effect of disease on pup survival is considered of unknown magnitude, with low understanding, due to a lack of studies of possible effects on DPMO or closely related species (see figure 3).

The CEM identifies one habitat element, Infectious Agents, with a high-magnitude effect on disease in DPMO, and two habitat elements (Parental Care affecting nursing of DPMO pups and Predators affecting predation) with medium-magnitude effects. The CEM rates the understanding of infectious agents on disease as low due to the absence of reported information on these topics for DPMO or any closely related species. However, the effect of parental care on nursing is well understood and is rated at high magnitude. Without parental care from their mother, the young will be unable to nurse, and they will die. Predator effects on predation are ranked medium understanding, as it is difficult to predict which predators may be at a site at any one time.

Lastly, the effect of vegetation community type on predation is considered low magnitude and low understanding, as effects of predation are at the individual scale, and the predator community can change.

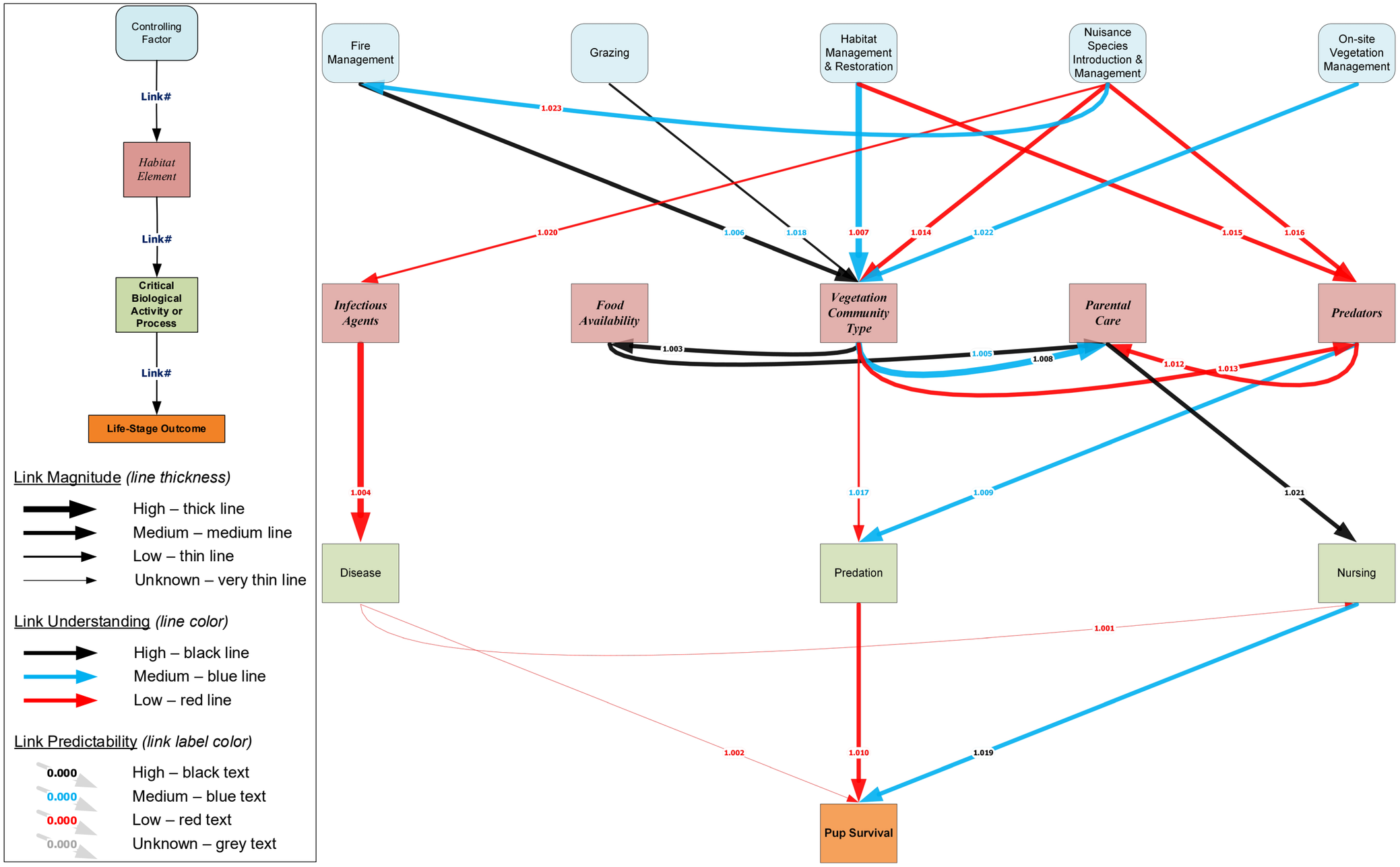

Figure 3.—CEM master diagram for DPMO life stage 1 – pups life stage controlling factors, habitat elements, critical biological activities and processes, and life-stage outcome.

DPMO Life Stage 2 – Adults

This life stage has two life-stage outcomes (see figure 1): adult survival and adult fertility. Figure 4 presents the complete CEM for this life stage, showing all controlling factors, habitat elements, critical biological activities and processes, life-stage outcomes, and their linkages.

The CEM identifies four critical activities or processes that directly affect adult DPMO survival. However, only two of these, predation and foraging, are proposed to have significant effects on this life-stage outcome; both are proposed to have a medium-magnitude effect overall because they are acting at the level of an individual and only over a short lifespan.

Predation is the most likely cause of premature mortality among adult pocket mice. The predators commonly mentioned are coyotes, sidewinder rattlesnakes, and owls; however, predation of DPMO has not been studied in the LCR, and understanding is low.

The two other critical activities or processes that affect adult DPMO survival are torpor and disease. Torpor is proposed to have a low-magnitude effect with medium understanding, and disease is proposed to have an unknown magnitude effect on survival with low understanding due to a lack of information specific to DPMO.

The CEM identifies three critical biological activities or processes that directly affect DPMO adult fertility: nest attendance by the mother, disease, and foraging. Disease has an effect of unknown magnitude on fertility, with low understanding. Nest attendance has a proposed medium effect on fertility, with medium understanding. Foraging has a proposed low-magnitude effect on fertility, with low understanding (food resources contribute to fertility while maternal care is critical to the likelihood of offspring surviving to adulthood); however, these effects are at the individual level, and only during the short life of the pocket mouse, and they have not been studied in DPMO in the LCR.

The CEM proposes that several critical biological activities and processes affect each other, compounding their effects on DPMO life-stage outcomes. The CEM specifically identifies five links between critical biological activities and processes. Dispersal directly affects gene flow, and this relationship has a medium-magnitude effect, with low understanding. Disease affects dispersal, nest attendance, and foraging with interactions of unknown magnitude and low understanding; the effects of disease have not been studied for DPMO in the LCR. Gene flow affects disease with a proposed low-magnitude effect, with low understanding. Foraging directly affects nest attendance, with a proposed low-magnitude effect, with low understanding.

The CEM identifies two habitat elements with high-magnitude direct effects on one or more critical biological activities or processes for DPMO adults as follows:

- The CEM proposes that infectious agents strongly affect disease; however, there is little evidence that disease is a strong factor in the survival of pocket mice – although they are afflicted as a species with numerous parasites. Link understanding is low.

- The CEM proposes that the vegetation community type has a strong (high-magnitude) effect on nest attendance. DPMO build domed grass nests in burrows or depressions, often under shrubs; good nest placement may increase the likelihood of successful maternal care. DPMO live in the same plant community year round and are dependent on the vegetation community.

The CEM identifies several habitat elements with medium-magnitude effects on one or more critical biological activities or processes for DPMO adults as follows:

- The CEM proposes that temperature, or its pattern of variation, has a medium-magnitude effect on DPMO entering into torpor during the winter months in the LCR. This link is of medium understanding (other factors are at play [e.g., food availability]).

- The CEM proposes that the link from habitat connectivity to dispersal is of medium intensity, with medium understanding.

- The CEM proposes that the link from food availability to torpor and foraging are both of medium intensity, with medium understanding.

- The CEM proposes that predators and their assemblage affect the rate of predation on DPMO adults as well as foraging activity. The effect on predation is proposed to be of medium intensity, with medium understanding.

- The CEM proposes that soil texture affects foraging activity. This interaction is proposed to be of medium magnitude, with medium understanding. (Link intensity is medium and acts only during the short life of the pocket mouse.)

- The CEM proposes that vegetation community type has a medium-magnitude effect on food availability, with high understanding.

Lastly, the remainder of the interactions between habitat elements and critical biological activities or processes are of low magnitude and include the following:

- Vegetation community type is proposed to have a low-magnitude effect on predation, with low understanding.

- Shrub density has a low intensity effect on predation and on foraging, with medium understanding for both. Shrubs may serve as perches for some predators, yet at the same time provide escape from other predators, so many factors are at play. Foraging activity may occur under shrubs and on shrub seeds, yet is also affected by other factors such as seed type and size, soil texture, and presence of predators. These interactions and relationships have not been studied for DPMO in the LCR.

- Predators affect nest attendance and foraging, although these interactions are proposed to be of low intensity given the lack of study on DPMO. There is little information available about predators of DPMO, other than what the most common predators of rodents are, generally. However, it is known that many nocturnal rodents minimize foraging activity on moonlit nights to avoid predation, which may increase time spent at the nest with young.

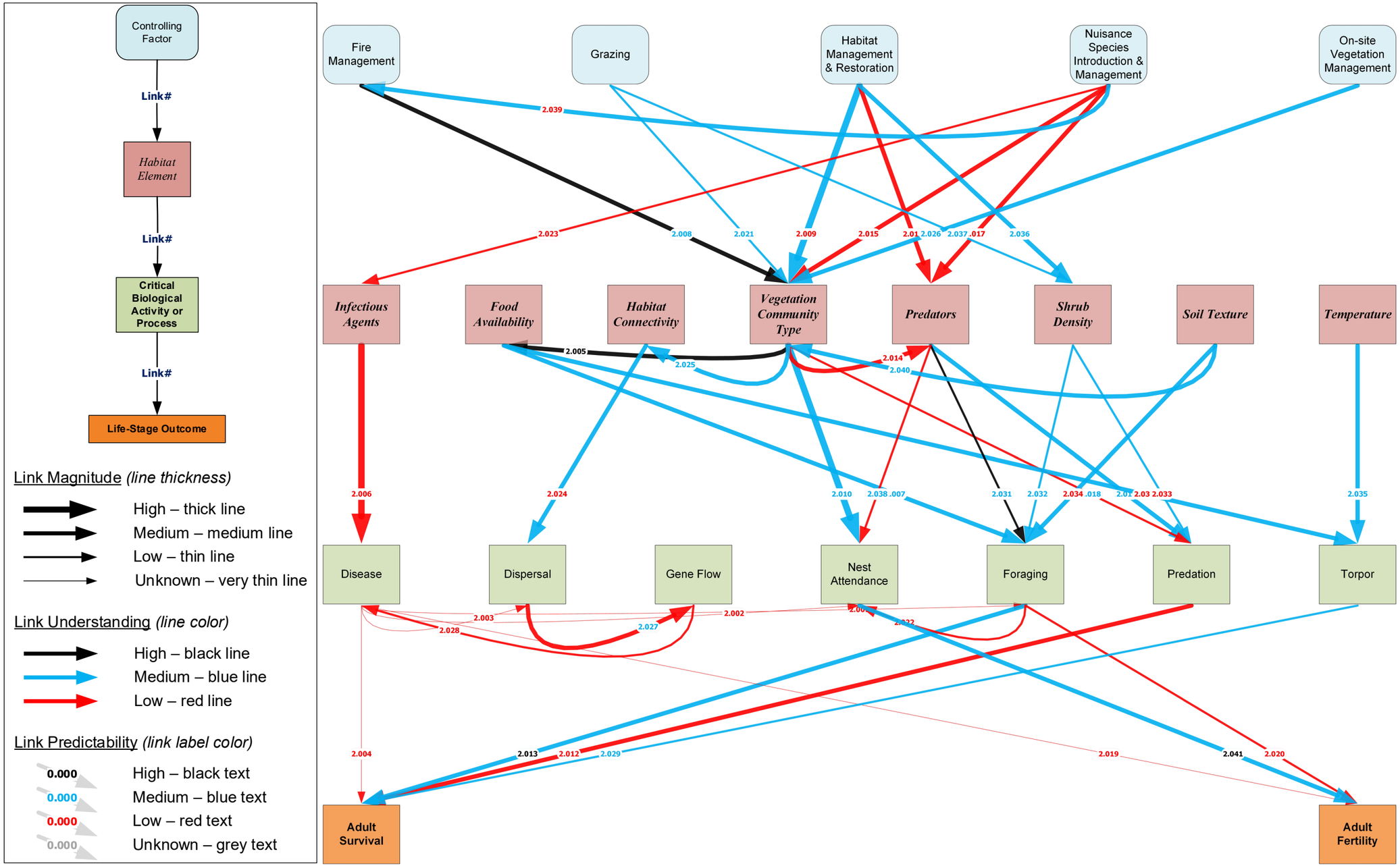

Figure 4.—CEM master diagram for DPMO life stage – adult life stage controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes.

Chapter 7 – Causal Relationships Across Life Stages

This chapter examines the information assembled for a CEM across all life stages to assess the following:

- Which critical biological activities and processes most strongly affect the life-stage outcomes across all life stages?
- Which critical biological activities and processes strongly affect other critical biological activities and processes across all life stages?
- Which habitat elements, through their abundance, distribution, and/or quality, most strongly affect the most influential activities and processes across all life stages?
- Which habitat elements, through their abundance, distribution, and/or quality, most strongly affect the abundance, distribution, and/or quality of other habitat elements across all life stages?
- Which controlling factors most strongly affect the most influential habitat elements across all life stages?
- Which of the most influential causal relationships appear to be the least understood in ways that could affect their management?

EFFECTS OF CRITICAL BIOLOGICAL ACTIVITIES AND PROCESSES ON LIFE-STAGE OUTCOMES

Table 5 shows which critical biological activities and processes directly affect each life-stage outcome, the estimated magnitude of each effect, and the estimated level of understanding of the effect. Two critical biological activities or processes—disease and predation—directly affect at least one life-stage outcome in each life stage. Five critical biological activities or processes—dispersal, gene flow, nest attendance, foraging, and torpor—only affect one life stage, adults. And one critical biological activity or process—nursing—only affects one life stage, pups.

Table 5.—Direct effects of critical biological activities and processes on DPMO life-stage outcomes

(Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown. Letter color indicates the level of understanding of the effect: High = **X,** medium = **X,** and low = **X**.)

Life-stage outcome ➔ / **Critical biological activity or process ➓**	Pup survival	Adult fertility	Adult survival
Disease	*U*	*U*	*U*
Foraging		L	**M**
Nursing	**M**		
Nest attendance		**M**	
Predation	**M**		**M**
Torpor			L

Table 5 shows that no critical biological activities or processes are proposed to have high-magnitude effects on any life-stage outcome in a life stage. The CEM assigns a rating of low for link understanding (red letters in table) to many of the interactions in table 5, indicating a lack of knowledge about most aspects of DPMO biology.

Table 5 also indicates that four critical biological activities or processes are proposed to have medium-magnitude effects on any life-stage outcome in either life stage. Foraging is proposed to have a medium-magnitude effect on individual adult survival; nursing is proposed to have a medium-magnitude effect on individual pup survival; nest attendance is proposed to have a medium-magnitude effect on adult fertility; and predation is proposed to have medium-magnitude effects on both pup and adult survival. All other links shown in table 5 are proposed to be of low or unknown magnitude.

Looked at another way, table 5 indicates that the CEM identifies nursing and predation as the most important critical biological activities or processes shaping pup survival, foraging and predation as the most important critical biological activities or processes shaping adult survival, and nest attendance as the most important critical biological activity or process shaping adult fertility.

EFFECTS OF CRITICAL BIOLOGICAL ACTIVITIES AND PROCESSES ON EACH OTHER

Table 6 shows which critical biological activities and processes directly affect other critical biological activities and processes, thereby influencing life-stage outcomes indirectly across the two DPMO life stages, the estimated magnitude of these effects, and the estimated level of understanding of the effects. Four critical biological activities or processes directly affect at least one other critical biological activity or process in at least one life stage. However, only one critical biological activity or process—disease—is proposed to affect one or more other critical biological activities or processes in both life stages. Four critical biological activities or processes—dispersal, foraging, gene flow, and nest attendance—only pertain to the adult life stage and, therefore, are affected by other critical biological activities or processes only in this life stage. And four critical biological activities or processes— nest attendance, nursing, predation, and torpor—do not affect any other critical biological activities or processes in any life stage.

The CEM proposes that most of the effects of critical biological activities and processes on each other are of low or unknown magnitude, and all are of low understanding (see paragraphs below and table 6):

Table 6.—Direct effects of critical biological activities and processes on other critical biological activities and processes

(Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown. Letter color indicates the level of understanding of the effect: High = **X,** medium = **X,** and low = **X.**)

Affected critical biological activity or process ➔ / **Causal critical biological activity or process 🡻**	Disease	Dispersal	Foraging	Gene flow	Nest attendance	Nursing	Predation	Torpor
Disease		*U*	*U*		*U*	*U*		
Dispersal				**M**				
Foraging					L			
Gene flow	L							
Nest attendance								
Nursing								
Predation								
Torpor								

- Dispersal is proposed to have medium-magnitude effects on gene flow in the adults life stage, with low understanding.

- Gene flow is proposed to have low-magnitude effects on disease in the adults life stage, with low understanding.

- The effects of disease on nursing in the pups life stage and on dispersal, foraging, and nest attendance in the adults life stage are unknown, with low understanding, for each interaction in either life stage.

- Foraging is proposed to have a low-magnitude effect on nest attendance for the adults life stage, with low understanding.

EFFECTS OF HABITAT ELEMENTS ON CRITICAL BIOLOGICAL ACTIVITIES AND PROCESSES

Table 3 (see chapter 4) identifies which habitat elements affect which critical biological activities and processes across all DPMO life stages. These relationships are in fact largely identical across both life stages in the CEM. However, a small number of critical biological activities and processes—and therefore a small number of habitat elements—only come into play for one life stages. Table 7 shows which habitat elements directly affect which critical biological activities and processes, as in table 3, and also indicates the proposed magnitude and level of understanding of these effects among the two DPMO life stages.

Close to half the entries in table 7 indicate effects of habitat elements on critical biological activities and processes with low magnitude. Conversely, table 7 indicates several effects of habitat elements on critical biological activities and processes with high or medium magnitude as follows. Specifically, the CEM proposes that:

- Infectious agents have high-magnitude effects on disease in both life stages, but the level of understanding of these relationships is low for both.

- The vegetation community type directly affects nest attendance in the adults life stage, with a high-magnitude effect. Without suitable vegetation, DPMO will not nest and cannot raise young. This relationship has medium understanding. (Vegetation community type also affects predation in both life stages with a low-magnitude effect and low understanding.)

- Temperature directly affects torpor during the adults life stage with a medium-magnitude effect of medium understanding.
- Parental care has a medium-magnitude effect on nursing during the pups life stage, and this relationship is well understood.
- Food availability has a medium-magnitude effect on torpor and foraging by DPMO adults. Both relationships are fairly well understood.
- Predators also affect predation in both life stages with a medium-magnitude effect that is fairly well understood.
- Soil texture affects adult DPMO foraging activity with a medium-magnitude effect that is moderately well understood.
- Predators affect foraging in the adults life stage with a low-magnitude effect of high understanding.

Table 7.—DPMO habitat elements and the critical biological activities and processes they are proposed to directly affect across the two DPMO life stages
(Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown. Letter color indicates the level of understanding of the effect: High = **X,** medium = **X,** and low = **X**.)

Affected critical biological activity or process ➔ **Causal habitat elements 🡻**	Disease	Dispersal	Foraging	Nest attendance	Nursing	Predation	Torpor
Food availability			**M**				**M**
Habitat connectivity		**M**					
Infectious agents	*H* *H*						
Parental care					**M**		
Predators			L L			**M** **M**	
Shrub density			L			L	
Soil texture			**M**				
Temperature							**M**
Vegetation community type				***H***		L L	

EFFECTS OF HABITAT ELEMENTS ON EACH OTHER

Table 8 shows which habitat elements directly affect which other habitat elements, as in table 4, and also indicates the proposed magnitude and level of understanding of these effects between the two life stages. These relationships are identical across both DPMO life stages.

Table 8.—Direct effects of habitat elements on each other
Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown.
Letter color indicates the level of understanding of the effect: High = **X,** medium = **X,** and low = **X**.)

Affected habitat element ➔ / **Causal habitat elements ➓**	Food availability	Habitat connectivity	Infectious agents	Parental care	Predators	Shrub density	Soil texture	Temperature	Vegetation community type
Food availability				**M**					
Habitat connectivity									
Infectious agents									
Parental care									
Predators				**M**					
Shrub density									
Soil texture									**M**
Temperature									
Vegetation community type	**M**		**M**	***H***	**M**				

Table 8 shows that five habitat elements—habitat connectivity, infectious agents, parental care, shrub density, and temperature—have no direct effects on any others. Further, three habitat elements—(food availability, predators, and soil texture—only affect one other habitat element; only one habitat element—vegetation community type—affects multiple other habitat elements. There is only one high-magnitude effect of one habitat element on other habitat element (i.e., vegetation community type effect on parental care). Specifically, the CEM proposes that:

- In the pups life stage, food availability and predators directly affect parental care with medium-magnitude effects. The effect of food availability is of high understanding, whereas the effect of predators on parental care is of low understanding.

- In the adults life stage, soil texture directly affects the vegetation community type with medium-magnitude effects and is of medium understanding.

- The vegetation community type influences the highest number of other habitat elements, directly affecting food availability, habitat connectivity, parental care (in the pups life stage), and predators. Of these, the effect of vegetation community type on parental care is considered to be of high-magnitude with medium understanding. The other relationships are proposed to be of medium magnitude, with varying degrees of understanding (low for predators, medium for habitat connectivity, and high for food availability).

EFFECTS OF CONTROLLING FACTORS ON HABITAT ELEMENTS

Table 4 (chapter 5) identifies which controlling factors affect which habitat elements in the DPMO conceptual ecological model. These relationships are identical across all life stages in the CEM. Table 9 also presents this information but adds information on the magnitude and level of understanding of these effects.

Table 9 shows that only one of the five controlling factors—habitat management & restoration—has a high-magnitude effect on at least one habitat element. This high-magnitude effect and the medium-magnitude effects of controlling factors on other habitat elements are as follows. Specifically, the CEM proposes that:

- Habitat management & restoration by definition has a high-magnitude effect on vegetation community type. This relationship is fairly well understood. Habitat management & restoration's effects are proposed to be of medium magnitude on the habitat elements of predators and shrub density, with low and medium understanding, respectively.

- Fire management affects the vegetation community type with proposed medium-magnitude intensity. This relationship is proposed to have high understanding in the greater LCR ecosystem.

- Nuisance species introduction & management has medium magnitude but poorly understood effects on predators and vegetation community type. Effects on infectious agents are proposed to be of low magnitude and poorly understood.

- On-site vegetation management has medium-magnitude, moderately well understood effects on the vegetation community type.

Table 9.—Direct effect of controlling factors on habitat elements
(Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown.
Letter color indicates the level of understanding of the effect: High = **X,**
medium = **X,** and low = **X**.)

Habitat elements ➔ / **Controlling factors ⬇**	Food availability	Infectious agents	Parental care	Predators	Shrub density	Soil texture	Temperature	Vegetation community type
Fire management								**M**
Grazing								L
Habitat management & restoration				**M**	**M**			***H***
Nuisance species introduction & management		L		**M**				**M**
On-site vegetation management								**M**

The CEM also recognizes that several controlling factors directly affect other controlling factors. Table 10 shows which controlling factors affect others, with what proposed magnitude, and with what proposed level of understanding. Table 10 shows that only one controlling factor has any effect on other controlling factors as follows. Specifically, the CEM proposes that:

- Nuisance species introduction & management has medium-magnitude, moderately well understood effects on fire management.

Table 10.—Direct effect of controlling factors on other controlling factors (Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown. Letter color indicates the level of understanding of the effect: High = **X,** medium = **X,** and low = **X**.)

Affected controlling factor ➔ / **Causal controlling factor 🡻**	Fire management	Grazing	Habitat management & restoration	Nuisance species introduction & management	On-site vegetation management
Fire management					
Grazing					
Habitat management & restoration					
Nuisance species introduction & management	**M**				
On-site vegetation management					

CAUSAL RELATIONSHIPS WITH HIGH UNDERSTANDING

Some causal relationships proposed in the CEM (see chapter 6 and above, this chapter) are rated as having high understanding. The CEM proposes these relationships based on established ecological principles, knowledge of heteromyid rodent biology and ecology in general, published information on the regulated LCR ecosystem overall and various management practices, and detailed studies of DPMO.

The CEM identifies one causal relationship between individual controlling factors. This relationship applies to both DPMO life stages. The CEM does not rate this relationship as having high understanding.

The CEM identifies nine causal relationships between controlling factors and habitat elements, which apply to both DPMO life stages. The CEM considers one

of these, the effect of fire management on vegetation community type, as having high understanding based on general ecological principles and publications concerning resource conditions and management along the LCR valley.

Of the causal relationships between habitat elements and other habitat elements or with critical biological activities or processes, the CEM rates three of these as having high understanding. Chapters 3–6 provide detailed explanations.

Specifically:

- The CEM identifies four causal relationships between habitat elements and other habitat elements. Two of these, food availability's effect on parental care (pups life stage) and vegetation community type's effect on food availability (both life stages), are considered to have high understanding.

- The CEM identifies 11 causal relationships between habitat elements and critical biological activities and processes for the adults life stage and identifies 4 for the pups life stage. Only two (predator link to foraging in the adults life stage and parental care link to nursing in the pups life stage) are considered to be of high understanding.

Potentially Influential Causal Relationships with Low Understanding and/or Unknown Magnitude

Many causal relationships proposed in the CEM (see chapter 6 and above, this chapter) are rated as having low understanding. The CEM proposes these relationships based on established ecological principles, knowledge of heteromyid biology and ecology in general, and suggestions in the literature on DPMO or on closely related species. However, few or no studies provide actual evidence concerning these relationships specifically for DPMO, or any closely related species, or concerning relevant habitat element conditions and dynamics in the greater LCR ecosystem.

In some instances—for example, the effect of disease on adult fertility, adult survival, dispersal, foraging, nest attendance, nursing, and pup survival—the gaps in knowledge are so large that the CEM assigns a rating of unknown for link magnitude as well. The CEM includes links with unknown magnitude based on established ecological principles and knowledge of heteromyid biology and ecology in general for which there is no documentation specifically for DPMO or

any closely related species. Links rated as having low understanding appear in the DPMO life-stage diagrams in chapter 6 (figures 3 and 4) as red arrows; links with unknown magnitude appear in these diagrams as extremely thin red arrows.

Table 11 indicates that the aspect of DPMO biology that is least known is the effect of disease on survival of pups and adults as well as on adult fertility.

Table 11.—Low-understanding and medium- or unknown-magnitude direct effects of critical biological activity or process on life stage outcomes
(Letter in cell indicates: ***H*** = high, **M** = medium, L = low, and *U* = unknown. Letter color indicates the level of understanding of the effect: High = **X,** medium = **X,** and low = **X**.)

Affected life-stage outcome ➔ **Causal critical biological activity or process 🡻**	Pup survival	Adult survival	Adult fertility
Disease	*U*	*U*	
Foraging		**M**	
Nest attendance			**M**
Nursing	**M**		
Predation		**M**	
Torpor		L	

Links that are rated as low for understanding and either high or unknown for magnitude would identify potentially significant gaps in knowledge concerning DPMO in general or in the LCR ecosystem in particular. In the DPMO model, there are no links that fit this combination of categories; however, there are many links that are of low understanding overall, and these may warrant a closer look in future years.

Chapter 8 – Discussion and Conclusions

The DPMO conceptual ecological model has several notable features. First, the assessment of the causal relationships among controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes indicates the following about strong (high-magnitude) causal relationships:

- Only two habitat elements have direct, high-magnitude effects on one or more other critical biological activities or processes—the vegetation community type effect on nest attendance and the effect of infectious agents on disease.

- Only one controlling factor has a direct, high-magnitude effect on any habitat elements—habitat management & restoration effect on vegetation community type.

- No critical biological activities or processes have direct, high-magnitude effects on any life-stage outcomes in either of the two DPMO life stages.

Second, the CEM does identify several potentially important causal relationships with medium magnitude and high or medium understanding. These ratings of medium or high for link understanding reflect cumulative knowledge from several detailed studies of DPMO or related species and their habitat. Of these well and moderately-well understood, medium-magnitude relationships, 12 out of 20 are related directly or indirectly to the vegetation community type.

Finally, the assessment of causal relationships among controlling factors, habitat elements, critical biological activities and processes, and life-stage outcomes also identifies numerous relationships with proposed intermediate (medium) and low magnitude. As knowledge about the species expands, the ratings of link magnitude for these proposed relationships, as well as for those currently assigned a high-magnitude rating, may change.

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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 (DiGennaro et al. 2012; Fischenich 2008; Wildhaber et al. 2007, 2011). 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 Burke et al. (2009), Kondolf et al. (2008), and Wildhaber et al. (2007, 2011) for a more hierarchical approach and adds an 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 & 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 inform 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 floodplain, 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** – This attribute 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. This linkage between the two applications, supported by software scripts developed in association with these CEMs, allow users to generate a "master" diagram for each life stage from the data in the spreadsheet and, crucially, to query the CEM spreadsheet for each life stage and generate diagrams that selectively display query results concerning that life stage.

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.

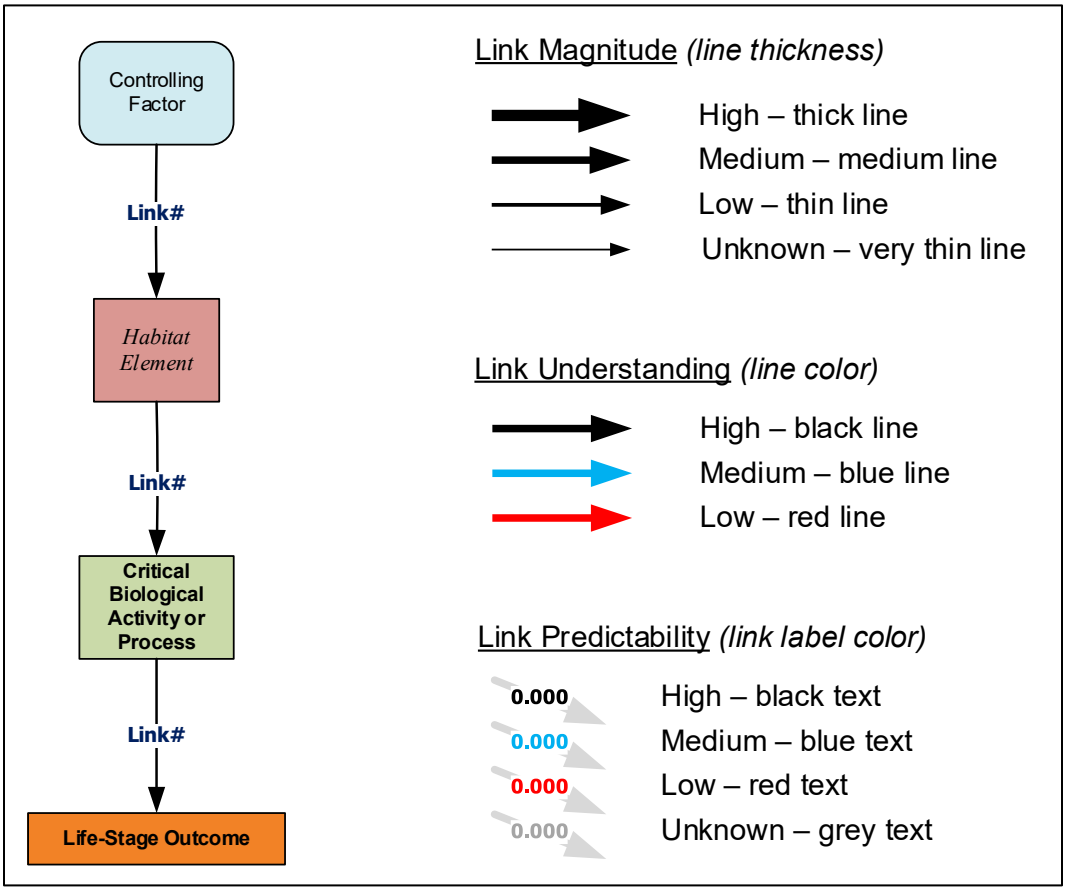

Figure 1-1.—Conventions for displaying cause and effect nodes, linkages, link magnitude, link understanding, and link predictability.

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ATTACHMENT 2

Desert Pocket Mouse (*Chaetodipus penicillatus sobrinus*) (DPMO) Habitat Data

Table 2-1.—Desert pocket mouse (*Chaetodipus penicillatus sobrinus*) (DPMO) habitat data

Habitat element	Value or range	Location	Reference
Food availability	No values or ranges in the literature, just species lists. *Chaetodipus penicillatus* feed mainly on seeds, are dietary generalists selecting seeds most available in the habitat.	Range-wide	Mantooth and Best 2005 and references therein.
Habitat connectivity	DPMO do not disperse long distances; maximum in this study 133 meters (436 feet).	Nevada	Micone 2002
Infectious agents	No values or ranges in the literature.		
Parental care	No values or ranges in the literature.		
Predators	No values or ranges in the literature, just species lists. For *C. penicillatus*, may include nocturnal raptors (owls), sidewinder rattlesnakes (*Crotalus cerastes*), and coyotes.	Range-wide	Faulkner 2018; Mantooth and Best 2005; Short 1979
Shrub density	No values in the literature, described as scattered shrubs.	Nevada	Micone 2002
Soil texture	*C. penicillatus* prefer soil particles that are significantly smaller than seed size.	Laboratory studies	Price 1983
	DPMO prefer loose, sandy soil with low percent of particles > 2 millimeters in size.	Nevada	Micone 2002
Temperature	Related pocket mice (*Perognathus longimembris*) enter torpor between temperatures of 10–15 degrees Celsius (50–60 degrees Fahrenheit).	Laboratory studies	Bartholomew and Cade 1957 *in* Mantooth and Best 2005
Vegetation community type	*C. penicillatus* associated with creosote bush (*Larrea* sp.), and mesquite (*Prosopis* sp.)	Range-wide	Mantooth and Best 2005
	What are likely DPMO found with dallisgrass (*Paspalum dilatum*) and bushy bluestem (*Andropogon glomeratus*) near scattered *Baccharus* sp. and *Pluchea sericea* shrubs.	Lower Colorado River	Hill 2017, 2018; Hill and Calvert 2016; Lyon 2020

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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