Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

Yuma Clapper Rail (*Rallus longirostris yumanensis* Dickey) (CLRA) Basic Conceptual Ecological Model for the Lower Colorado River

Photo courtesy of the Bureau of Reclamation

U.S. Department of the Interior
Bureau of Reclamation

August 2015

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Lower Colorado River
Multi-Species Conservation Program

Yuma Clapper Rail
(*Rallus longirostris yumanensis* Dickey) (CLRA)
Basic Conceptual Ecological Model for the
Lower Colorado River

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Multi-Species Conservation Program
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ACRONYMS AND ABBREVIATIONS

AGFD	Arizona Game and Fish Department
CEM	conceptual ecological model
CLRA	Yuma clapper rail (*Rallus longirostris yumanensis* Dickey)
ha	hectare(s)
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
Reclamation	Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service

Symbols

≥	greater than or equal to
<	less than

Definitions

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

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

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

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

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

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Foreword

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

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

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

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

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

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

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

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

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

- A means of identifying appropriate monitoring indicators and metrics.

- A basis for implementing adaptive management strategies.

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

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

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

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

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

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

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

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

How to Use the Models

There are three important elements to each CEM:

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

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

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

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

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

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

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

Executive Summary

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

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

CONCEPTUAL ECOLOGICAL MODELS

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

The CEM applied to the CLRA 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 CLRA conceptual ecological model has five core components:

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

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

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

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

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

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

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE

The CLRA conceptual ecological model addresses the CLRA population along the river and lakes of the lower Colorado River (LCR) and other protected areas. The model does not specifically address the biology of migratory CLRA. The basic sources of information for the CLRA conceptual ecological model are

Eddleman (1989), U.S. Fish and Wildlife Service (2010), Nadeau et al. (2011), Dudek and ICF (2012), Reclamation (2008), and Rush et al. (2012). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The model also integrates numerous additional sources, particularly reports and articles completed since these publications; information on current research projects; and the expert knowledge of LCR MSCP biologists. Our purpose is not to provide an updated literature review but to integrate the available information and knowledge into a CEM so it can be used for adaptive management.

The CLRA conceptual ecological model distinguishes and assesses three life stages as follows (table ES-1):

Table ES-1.—Outcomes of each of the three life stages of CLRA

Life stage	Life-stage outcome(s)
1. Nest	• Survival
2. Juvenile	• Survival
3. Breeding adult	• Survival • Reproduction

The model distinguishes 8 critical biological activities or processes relevant to 1 or more of these 3 life stages and their outcomes, 14 habitat elements relevant to 1 or more of these 8 critical biological activities or processes for 1 or more life stages, and 6 controlling factors that affect 1 or more of these 14 habitat elements. Because the LCR and its protected areas comprise a highly regulated system, the controlling factors almost exclusively concern human activities.

The eight critical biological activities and processes identified across all life stages are: chemical stress, disease, eating, foraging, molt, nest attendance, nest site selection, and predation. The 14 habitat elements identified across all life stages are: anthropogenic disturbance, aquatic faunal composition, brood size, food availability, genetic diversity and infectious agents, local hydrology, matrix community, parental nest attendance, patch size; plant species composition, predator density, residual vegetation density, site topography, and vegetation density. The six controlling factors identified across all habitat elements are: fire management, habitat restoration, mechanical soil disturbance, nuisance species introduction and management, pesticide/herbicide application, and water storage-delivery system design and operation.

RESULTS

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

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

- Habitat restoration and water storage-delivery system design and operation can have a significant, lasting impacts on local hydrology, which may benefit CLRA survival and reproduction.

- While nuisance species introduction and management may have negative impacts on habitat values, some invasive species (e.g., crayfish such as *Procambarus clarkia* and *Orconectes* sp. [Reclamation 2008; Dudek and ICF 2012]) are actually critical to the recovery of CLRA and should be included in management planning.

- Fire management, mechanical soil disturbance, or some other strategy for managing vegetation in areas where scouring flows are not feasible is necessary to manage excess residual vegetation that is negatively impacting CLRA use of marsh habitat.

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

- The ecology of predation on CLRA and its significance on survival across all life stages, how this may vary among predator species and across different habitat settings, and whether it may be possible to manipulate these habitat conditions to improve CLRA survival even in the presence of predators.

- The presence of disease in the CLRA population and its significance in affecting survival across all life stages within the LCR.

- The impacts of chemical stressors such as selenium and pesticides/ herbicides within the LCR and their impact on the survival of CLRA across all life stages.

- CLRA movement patterns within the LCR, including any seasonal migratory movement.

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

Chapter 1 – Introduction

This document presents a conceptual ecological model (CEM) for the Yuma clapper rail (*Rallus longirostris yumanensis* Dickey) (CLRA). The purpose of this model is to help the Bureau of Reclamation (Reclamation), Lower Colorado River Multi-Species Conservation Program (LCR MSCP), identify areas of scientific uncertainty concerning CLRA ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure CLRA 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 CLRA population along the river and lakes of the lower Colorado River (LCR) and other protected areas. The model thus addresses the landscape as a whole rather than any single reach or managed area.

The most widely used sources of information for the CLRA conceptual ecological model are Eddleman (1989), U.S. Fish and Wildlife Service (USFWS) (2010), Nadeau et al. (2011), Dudek and ICF (2012), Reclamation (2008), and Rush et al. (2012). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The CEM also integrates numerous additional sources, particularly reports and articles completed since the aforementioned publications; information on current research projects; and the expert knowledge of LCR MSCP avian biologists. The purpose of the CEM is not to provide an updated literature review but to integrate the available information and knowledge into a CEM so it can be used for adaptive management.

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

YUMA CLAPPER RAIL REPRODUCTIVE ECOLOGY

CLRA usually begin breeding activities in March or early April, although males can begin calling as early as February (Rush et al. 2012). Nests are constructed on mud hummocks, in small shrubs, or in dense vegetation just above the water (Abbott 1940 *in* Reclamation 2008; Eddleman 1989). CLRA lay an average of six to eight eggs (Eddleman 1989), with incubation lasting 23–28 days. Both sexes participate in incubating and brood rearing; however, the females typically incubate during the day, whereas the males attend to the nest during the night (Eddleman 1989).

CLRA eggs hatch asynchronously, and the young are precocial, able to join their parents on foraging trips within 2 days of hatching (Hunter et al. 1991). Parents and young remain together as a family group for a month or so, with the parents still providing some care. The young fledge about 60 days after hatching (Arizona Game and Fish Department [AGFD] 2007) and do not associate with the family group thereafter (Rush et al. 2012).

Optimal CLRA habitat includes a mosaic of tall, emergent vegetation; shallow open water areas; and open dry ground (slightly higher than the water level) for foraging and movement and a band of riparian vegetation along the fringes of the marsh that provides cover and buffer areas that may be used seasonally (USFWS 2010). Primary food items taken by CLRA include crayfish (*Procambarus clarkii* and *Orconectes virilis*), fishes, larval amphibians, clams (Bivalvia), and other aquatic invertebrates (Reclamation 2008; Dudek and ICF 2012; USFWS 2010). The abundance and condition of the food supply affects adult health as well as the growth and development of the young during the nest and juvenile stages.

CONCEPTUAL ECOLOGICAL MODEL PURPOSES

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

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

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

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

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE FOR THE CLRA

The CEM methodology used here expands on that developed for the Sacramento-San Joaquin River Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al. 2012). The expansion incorporates recommendations of Wildhaber et al. (2007), Kondolf et al. (2008), Burke et al. (2009), and Wildhaber (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 (Wildhaber et al. 2007; Wildhaber 2011). That is, it distinguishes the major life stages or events through which the individuals of a species must pass to complete a full life cycle, including reproducing, and the biologically crucial outcomes of each life stage. These biologically crucial outcomes typically include the number of individuals recruited to the next life stage (e.g., fledgling to adult) or next age class within a single life stage (recruitment rate), or the number of viable offspring produced (fertility rate). It then identifies the factors that shape the rates of these outcomes in the study area and thereby shapes the abundance, distribution, and persistence of the species in that area.

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

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

- **Life-stage outcomes** – These consist of the biologically crucial outcomes of each life stage, including the number of individuals recruited to the next life stage (e.g., fledgling to adult), or the number of viable 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; the rate (intensity) of the activities and processes taken together determine the rate of recruitment of individuals to the next life stage.

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

- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the quality, abundance, and spatial and temporal distributions of important habitat elements. Controlling factors are also called "drivers." There may be a hierarchy of such factors affecting the system at different scales of time and space (Burke et al. 2009). For example, the availability of suitable nest sites for a riparian nesting bird may depend on factors such as canopy cover, community type, humidity, and intermediate structure, which in turn may depend on factors such as water storage-delivery system design and operation (dam design, reservoir morphology, and dam operations), which in turn is shaped by climate, land use, vegetation, water demand, and watershed geology.

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

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

Chapter 2 – CLRA Life Stage Model

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

INTRODUCTION TO THE CLRA LIFE CYCLE

The CLRA is one of four subspecies of the *obsoletus* group of clapper rails (Rush et al. 2012). Significant populations of CLRA are found within the LCR MSCP boundaries in Reaches 3 and 6 (Reclamation 2008). CLRA are secretive birds, but males can be heard calling at the beginning of the breeding season in February, with pair bonding following soon thereafter (Rush et al. 2012).

We have chosen to combine the egg and chick phases of development into a single life stage in our model even though they undergo different processes—e.g., eggs do not need to eat or molt. We have done this because both eggs and chicks occupy the same nest; therefore, management focused on the nest will cover eggs and chicks.

The potential migratory nature of the CLRA complicates its management. The LCR MSCP is mainly responsible for management on the breeding grounds, and we therefore focus on three life stages occurring within LCR MSCP lands—nest, juvenile, and breeding adult. The extent and importance of seasonal migration is not known, so the focus of this study is on management activities within the scope of Reclamation's responsibilities.

CLRA LIFE STAGE 1 – NEST

We consider the nest stage to be the first in the life cycle of the CLRA. It begins when the egg is laid and ends either when the young fledge or the nest fails. Nesting begins in March, and incubation lasts around 23–28 days, with males incubating at night and females during the day (Rush et al. 2012). Hatching success is high, but so is juvenile mortality (Eddleman 1989). Within 2 days of hatching, chicks accompany adults on foraging trips (Hunter et al. 1991). Family groups of rails remain together for up to 30 days after hatching, with chicks becoming independent of their parents at 35–42 days post-hatching (Rush et al. 2012). The life-stage outcome from the nest stage is the survival of eggs and associated chicks until they become independent. It is important to note that the outcome of the nest stage is inherently tied to the behavior and condition of the parents.

CLRA LIFE STAGE 2 – JUVENILE

This life stage begins when the chick has become independent from the parents and ends when the individual reaches sexual maturity. The precise timing of the end of this life stage for CLRA is unknown but is presumed to be around 1 year of age (Eddleman 1989). While there is a tremendous amount of overlap in the biological activities and processes, habitat elements, and controlling factors affecting both the juvenile and breeding adult life stages, we felt that differences in behavior and the way in which CLRA in these life stages interact with the environment were potentially significantly different enough to warrant the split.

CLRA LIFE STAGE 3 – BREEDING ADULT

This life stage begins when the rail reaches sexual maturity and ends when it stops reproducing. It is estimated that adult CLRA reach sexual maturity around 1 year of age. Breeding begins in March with the establishment of breeding territories (Eddleman 1989). Both males and females defend the territories. Nesting occurs from March through May but varies based on seasonal rainfall patterns (USFWS 2010). A single clutch of five to eight eggs is laid unless the clutch is lost, then the rails will re-nest up to five times in a season (AGFD 2007; Rush et al 2012).

The life-stage outcomes for breeding adults are survival and reproduction—here defined as the production of eggs. Most studies of bird demography define fecundity—or the reproductive rates of adults—as the number of offspring fledged (Etterson et al. 2011). We have separated the nest stage from adult fecundity to more clearly display the information regarding nest success so that it can be better assessed by management. Therefore, adult reproduction involves the acts of pairing, site selection, nest building, and the production of eggs.

LIFE STAGE MODEL SUMMARY

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

Table 1.—CLRA life stages and outcomes in the LCR ecosystem

Life stage	Life-stage outcome(s)
1. Nest	• Survival
2. Juvenile	• Survival
3. Breeding adult	• Survival • Reproduction

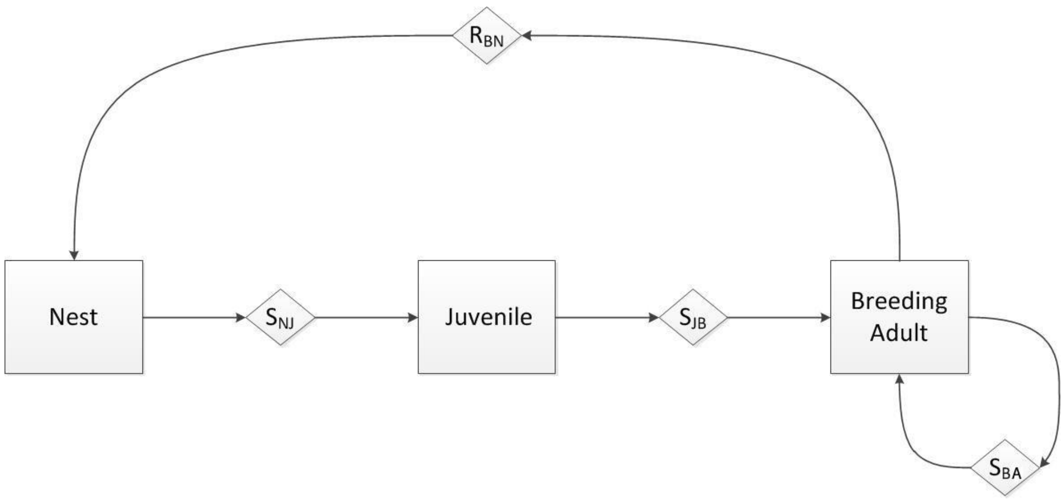

Figure 1.—Proposed CLRA life history model.
Squares indicate the life stages, and diamonds indicate the life-stage outcomes. S_{NJ} = survivorship rate, nest; S_{JB} = survivorship rate, juvenile; S_{BA} = survivorship rate, breeding adult; and R_{BN} = reproduction rate, breeding adult.

Chapter 3 – Critical Biological Activities and Processes

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

The CEM identifies eight critical biological activities and processes that affect one or more CLRA life stages. Table 2 lists the eight critical biological activities and processes and their distribution across life stages.

Table 2.—Critical biological activities and processes by life stage (Xs indicate that the critical biological activity or process is applicable to that life stage)

Life stage ➔ / **Critical biological activity or process ➔**	**Nest**	**Juvenile**	**Breeding adult**
Chemical stress	X	X	X
Disease	X	X	X
Eating	X		
Foraging		X	X
Molt	X	X	X
Nest attendance			X
Nest site selection			X
Predation	X	X	X

The most widely used sources of information used to identify the critical biological activities and processes are Eddleman (1989), AGFD (2007), USFWS (2010), Nadeau et al. (2011), Dudek and ICF (2012), Reclamation (2008), and Rush et al. (2012). The identification also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP biologists. The following paragraphs discuss the eight critical biological activities and processes in alphabetical order.

CHEMICAL STRESS

CLRA in every life stage are vulnerable to stress and mortality due to exposure to harmful chemicals, including selenium and pesticides/herbicides. Environmental contaminants are believed to have potential negative impacts on rail populations due to the bioaccumulation of these chemicals. Eddleman (1989) recognized selenium as a potential threat to rail survival finding high levels in adults, their eggs, and crayfish, the CLRA's primary food source. Pesticide/herbicide residue may also have negative impacts on CLRA survival (Dudek and ICF 2012).

DISEASE

This process refers to diseases caused either by lack of genetic diversity or by infectious agents. The prevalence of disease as a source of rail mortality is poorly known for most bird species and is difficult to separate from other causes of mortality. Eddleman (1989) recorded one case of hepatitis in CLRA. CLRA in all life stages are conceivably susceptible to disease.

EATING

This process only applies to the nest life stage because the chick must eat to stay alive and develop but do not actively forage within their environment in the same way as juveniles and adults. A nestling's ability to eat during the first weeks of life is determined by the foraging and provisioning rate of its parents. Some elements, such as siblings, number of chicks in the nest, and genetic diversity, are not traditionally considered aspects of habitat but are included in this section because of their effects on critical biological activities and processes.

FORAGING

CLRA forage in marsh habitat predominantly on crayfish but also small fishes, tadpoles, clams, and other aquatic invertebrates (Anderson and Ohmart 1985; Eddleman 1989; Rush et al. 2012). Foraging is done by chicks, juveniles, and adults, but it is important to note that foraging by the parents affects the provisioning rate to chicks and nest attendance by adults.

MOLT

CLRA chicks molt from natal down into juvenal plumage in about a month (USFWS 2010). A second body molt occurs after about 6 to 7 weeks when the juveniles obtain their adult ventral plumage (Eddleman 1989). After breeding, adults go through a pre-basic molt on their breeding grounds, lose their tail feathers, and are flightless for 3 to 4 weeks (Pyle 2008; Rush et al. 2012). Molting is an energetically costly process that may make nestlings more susceptible to death when resources are scarce.

NEST ATTENDANCE

Adequate nest attendance is important for successful reproduction. Both parents incubate the eggs in the nest and are responsible for feeding the young (Eddleman 1989). Breeding adults attend the nest, and this affects the survival of the nestlings.

NEST SITE SELECTION

Nest site selection is important for reproductive success. Nest success varies spatially as a result of food availability, hydrology, predator types and densities, vegetation characteristics, and other factors (USFWS 2010; Rush et al. 2012). The availability of high ground is also a factor in nest site selection of CLRA (Smith 1975; Bennett and Ohmart 1978; Eddleman 1989). Though adult rails can swim, chicks can drown when their downy plumage gets wet. Various aspects of local hydrology are critical for nest site selection of CLRA, including depth and fluctuation rates of water levels, timing and severity of seasonal flooding, and the amount of open water areas, to name a few (Nadeau et al. 2011; Dudek and ICF 2012).

PREDATION

Predation is a threat to CLRA in all life stages, and it obviously affects survival. CLRA are subject to predation by coyotes (*Canis latrans*); dogs (*Canis lupus*); cats (*Felis catus*); raccoons (*Procyon lotor*); ravens (*Corvus* sp.); great blue herons (*Ardea herodeas*); great horned owls (*Bubo virginianus*) and other owl species; northern harriers (*Circus cyanus*), and other hawk species (Eddleman 1989; Rush et al. 2012). Factors affecting adult mortality may include movement of predators into marsh habitat, increases in wintering raptors, and changes in CLRA habitat use due to changing water levels (Eddleman 1989). Marsh wrens (*Cistothorus palustris*), ravens, coyotes, raccoons and skunks (*Mephitis* sp.) are common predators of CLRA eggs and chicks (AGFD 2007).

Chapter 4 – Habitat Elements

Habitat elements consist of specific habitat conditions that ensure, allow, or interfere with critical biological activities and processes. These elements consist of anything in the environment from the perspective of the individual and thus should not be restricted to a traditional definition. For example, brood size is a habitat element that may affect an individual nestling.

This chapter identifies 14 habitat elements that affect 1 or more critical biological activities or processes across the 3 CLRA life stages. Some of these habitat elements differ in their details among life stages. Table 3 lists the 14 habitat elements and the 8 critical biological activities and processes that they *directly* affect across all CLRA life stages.

Table 3.—Habitat elements directly affecting critical activities and processes

Critical biological activity or process ➔ / **Habitat element ➔**	**Chemical stress**	**Disease**	**Eating**	**Foraging**	**Molt**	**Nest attendance**	**Nest site selection**	**Predation**
Anthropogenic disturbance				X		X	X	
Aquatic faunal composition				X				
Brood size				X		X		
Food availability				X		X	X	
Genetic diversity and infectious agents		X						
Local hydrology							X	
Matrix community	X			X			X	
Parental nest attendance			X					X
Patch size				X			X	X
Plant species composition				X			X	
Predator density				X			X	X
Residual vegetation density				X				
Site topography							X	
Vegetation density							X	

The diagrams and other references to habitat elements elsewhere in this document identify the habitat elements by a one-to-three-word short name. However, each short name in fact refers to a longer, complete name. For example, the habitat element "patch size" is the short name for "The size of the wetland habitat patches." The following paragraphs provide the full name for each habitat element and a detailed definition, addressing the elements in alphabetical order.

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

ANTHROPOGENIC DISTURBANCE

Full name: **Human activity within or surrounding a given habitat patch, including noise, pollution, and other disturbances associated with human activity**. This element refers to the existence and level of human disturbance within proximity of CLRA habitat. These human disturbances may be a cause for bird decline along the LCR in areas that are in proximity to development and/or areas that receive varying levels of human use. Human activities typically affect the behavior of individual birds, though chronic disturbance can impact habitat quality more significantly as well. Noise from human talking, radios, and vehicles may disturb rails, though it is unknown what level of noise is necessary to cause habitat abandonment. Artificial lights and other factors associated with human facilities development may impact behavior patterns, increase the risk of night predators, and affect nest site selection (USFWS 2010).

AQUATIC FAUNAL COMPOSITION

Full name: **The composition of aquatic fauna in the aquatic community**. The composition of the aquatic faunal community directly affects CLRA prey abundance and foraging activity. The diet of the CLRA is dominated by crayfish, with small fishes, tadpoles, clams, and other aquatic invertebrates also consumed (Bennett and Ohmart 1978; USFWS 2010). CLRA have been found to shift their habitat use depending on the seasonal availability of crayfish (Eddleman 1989). The composition of the aquatic faunal community (and thus CLRA prey abundance) is influenced by the structure and composition of vegetation. A primary prey source, crayfish, are found in dense cattail (*Typha* sp.) and bulrush (Cyperaceae) habitat (Bennett and Ohmart 1978).

Brood Size

Full name: **The number of young in the nest**. This element refers to the number of young that the parents must rear. Clutch size is related to the health of the parents, and the well-being of both parents depends in part on the availability of sufficient food resources in close proximity to the breeding territory as well as other factors such as predator density.

Food Availability

Full name: **The abundance of food available for adults and their young**. This element refers to the taxonomic and size composition of the invertebrates that an individual CLRA will encounter during the nest, juvenile, and adult stages as well as the density and spatial distribution of the food supply in proximity to the nest location. The abundance and condition of the food supply affects adult health as well as the growth and development of the young during the nest and juvenile stages. Chicks rely on their parents for nutrition for a very brief period before they begin to forage independently.

Genetic Diversity and Infectious Agents

Full name: **The genetic diversity of CLRA individuals and the types, abundance, and distribution of infectious agents and their vectors**. The genetic diversity component of this element refers to the genetic homogeneity versus heterogeneity of a population during each life stage. The greater the heterogeneity, the greater the possibility that individuals of a given life stage will have genetically encoded abilities to survive their encounters with the diverse stresses presented by their environment and/or take advantage of the opportunities presented. The infectious agent component of this element refers to the spectrum of viruses, bacteria, fungi, and parasites that individual CLRA are likely to encounter during each life stage.

Local Hydrology

Full name: **Aspects such as the depth and fluctuations of standing water or the presence of adjacent water bodies as well as the depth to the water table and soil moisture levels**. This element refers to anything that affects local water fluctuations such as the proximity of water to the nesting habitat, elevation, irrigation practices, and soil texture. The local hydrological conditions of a given patch might be the single most important determinant of CLRA habitat quality because they affect other aspects of habitat such as vegetation structure and abundance of prey. Various aspects of local hydrology are critical for nest site selection, including depth and fluctuation rates of water levels, timing and severity of seasonal flooding, and the amount of open water areas, to name a few (Nadeau et al. 2011; Dudek and ICF 2012).

MATRIX COMMUNITY

Full name: **The type of habitat surrounding the wetland habitat used by CLRA**. This element refers to the types of plant communities and land use activities surrounding the wetland habitat patches used by CLRA. For example, adjacent agricultural landscapes may have elevated pesticide/herbicide loads, which may affect foraging and survival of CLRA.

PARENTAL NEST ATTENDANCE

Full name: **The ability of parents to care for young during the nest stage**. This element refers to the capacity of parents to tend to the young. It is affected primarily by food availability and the presence of predators.

PATCH SIZE

Full name: **The size of wetland habitat patches**. This element refers to the areal extent of a given patch of wetland vegetation. Patch size may affect the number of breeding pairs that an area can support as well as the density of predators and competitors. Few studies are available that address the effect of patch size on CLRA foraging activity directly; however, home ranges of CLRA are smallest during the breeding season and largest in the post-breeding season (Conway et al. 1993). While CLRA can inhabit a range of patch sizes successfully, the mosaic of habitat features must be met within the area (USFWS 2010).

PLANT SPECIES COMPOSITION

Full name: **The composition of plant species in the plant community**. This element refers to the species composition of the plant community where CLRA are active. The plant species composition preferred by nesting CLRA has been considered in some studies as immaterial as long as the hydrologic characteristics were adequate. However, many studies have considered marsh species, including cattails and bulrush, as providing optimal habitat, while reed (*Phragmites* *australis*) is generally considered poor quality habitat (Eddleman 1989). Generally, low stem densities and residual vegetation coverage are considered suitable habitat for CLRA (Conway et al. 1993). In a study of CLRA habitat use of restored habitat in the Imperial National Wildlife Refuge, Nadeau et al. (2011) found that CLRA were more likely to be found in areas with lower densities of river bulrush (*Schoenoplectus robustus*) and moderate densities of *Phragmites* and southern cattail (*Typha domingensis*).

PREDATOR DENSITY

Full name: **The abundance and distribution of predators**. 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 CLRA during all life stages. The variables of this element include the species and size of the fauna that prey on CLRA during different life stages, the density and spatial distribution of these fauna in the habitat used by CLRA, and whether predator activity may vary in relation to other factors (e.g., time of day, patch size and width, matrix community type, etc.).

RESIDUAL VEGETATION DENSITY

Full name: **The density of senescent foliage surrounding the nest**. Some matting of previous years' vegetation is necessary for CLRA movement, especially across deep-water habitat (Eddleman 1989). However, CLRA use of habitat declines as levels of residual vegetation increase (Conway and Eddelman 2000).

SITE TOPOGRAPHY

Full name: **The topographic relief of the land surrounding the nest**. The availability of high ground is a factor in nest site selection of CLRA (Smith 1975; Bennett and Ohmart 1978). Though adult rails can swim, chicks can drown when their downy plumage gets wet. CLRA may select areas with higher ground for their nests, and these may include features such as jetties and levees (Anderson and Ohmart 1985; Eddleman 1989).

VEGETATION DENSITY

Full name: **The density of foliage surrounding the nest**. This element refers to the percent cover of vegetation in the vicinity of the CLRA nest site. The presence of CLRA has been correlated with higher levels of vegetation density, especially cattails and bulrush (Anderson and Ohmart 1985). Dense vegetation around the nest may provide camouflage from nest predators, although heterogeneity in vegetation cover within a given patch or landscape is also desirable. Optimum CLRA habitat includes a mosaic of tall, emergent vegetation; shallow (less than 30-centimeter-deep) open water areas; open dry ground (slightly higher than the water level) between water; vegetation; marsh edge for foraging and movement; and a band of riparian vegetation on the higher ground along the fringes of the marsh that provides cover and buffer areas that may be used seasonally (USFWS 2010). Nadeau et al. (2011) found the probability of CLRA occupancy in restored marsh habitat to be positively correlated with low densities of river bulrush and moderate densities of *Phragmites* and southern cattail.

Chapter 5 – Controlling Factors

Controlling factors consist of environmental conditions and dynamics, both natural and anthropogenic, which significantly affect the abundance, spatial and temporal distributions, and quality of critical habitat elements. They may also significantly directly affect some critical biological activities or processes. A hierarchy of such factors exists, with long-term dynamics of climate and geology at the top. However, this CEM focuses on six immediate controlling factors that are within the scope of potential human manipulation. The six 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. Table 4 lists the six controlling factors and the habitat elements they directly affect. Table 4 lists the seven controlling factors and the habitat elements they directly affect. Table 4 also lists the six habitat elements that are not directly affected by any controlling factor (anthropogenic disturbance, brood size, food availability, genetic diversity and infectious agents, parental nest attendance and predator density). These latter habitat elements are directly shaped by the condition of one or more other habitat elements rather than by any of the controlling factors.

Table 4.—Habitat elements directly affected by controlling factors

Controlling factor ➔ / **Habitat element ➔**	**Fire management**	**Habitat restoration**	**Mechanical soil disturbance**	**Nuisance species introduction and management**	**Pesticide/herbicide application**	**Water storage-delivery system design and operation**
Anthropogenic disturbance	N/A					
Aquatic faunal composition			X	X	X	
Brood size	N/A					
Food availability	N/A					
Genetic diversity and infectious agents	N/A					
Local hydrology		X				X
Matrix community		X				
Parental nest attendance	N/A					
Patch size	X	X				
Plant species composition	X	X	X	X		X
Predator density	N/A					
Residual vegetation density	X	X	X			
Site topography		X	X			X
Vegetation density	X	X	X			

Fire Management

This factor addresses any fire management (whether prescribed fire or fire suppression) along the LCR that could affect CLRA or their habitat. Effects may include creation of habitat that supports or excludes CLRA, a reduction in the food supply of invertebrates, or support of species that pose threats to CLRA such as predators, competitors, or carriers of infectious agents. Although typically not a major threat in most wetland habitats, fire has the potential to be a source of mortality during the breeding season (Reclamation 2008). Fire may have positive impacts on habitat for CLRA by removing decadent vegetation and encouraging growth of early successional emergent vegetation (Conway et al. 2010).

Climate change is also projected to affect fire frequency along the LCR (USFWS 2013).

Habitat Restoration

This factor addresses activities to restore the wetland and riparian habitat along the LCR, including manipulation of soils, vegetation, and water to restore structure and function to the community. The design and management of restored marsh habitat affects a number of critical factors related to habitat suitability for CLRA, including vegetation community characteristics and hydrology (Nadeau et al. 2011).

Mechanical Soil Disturbance

This factor covers the use of mechanical means to manipulate soil, such as disking and grading. Mechanical soil disturbance associated with river management activities may impact plant species establishment and marsh formation (Reclamation 2008). Mechanical soil disturbance such as disking may also discourage crayfish (Eddleman 1989).

Nuisance Species Introduction and Management

This factor addresses the intentional or unintentional introduction of nuisance species (animals and plants) and their control that affects CLRA survival and reproduction. The nuisance species may infect, prey on, compete with, or present alternative food resources for CLRA during one or more life stages; cause other alterations to the wetland food web that affect CLRA; or affect physical habitat features such as vegetation structure and cover.

PESTICIDE/HERBICIDE APPLICATION

This factor addresses pesticide/herbicide applications that may occur on or adjacent to CLRA habitat in the LCR region. The use of pesticides/herbicides was listed as a potential threat to CLRA by the USFWS (USFWS 2010). Effects may include pollution of runoff into wetland habitats that are toxic to prey of the CLRA and a reduced invertebrate food supply.

WATER STORAGE-DELIVERY SYSTEM DESIGN AND OPERATION

The LCR consists of a chain of reservoirs separated by flowing reaches. The water moving through this system is highly regulated for storage and delivery (diversion) to numerous international, Federal, State, Tribal, and municipal users and for hydropower generation.

The dynamic nature of a free-flowing river creates a mosaic of riparian and wetland habitats, and thus, a natural flow regime may be beneficial to CLRA. However, in some ways, current water management along the LCR has created more permanent marshes than would have existed historically. Large and small dams and diversions also create hydrologic conditions that help establish new marsh habitat (USFWS 2010). Unfortunately, a lack of scouring natural flows in the LCR leads to decadent vegetation that degrades habitat values for CLRA (Conway et al. 2010).

Chapter 6 – Conceptual Ecological Model by Life Stage

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

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

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

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

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

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

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

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

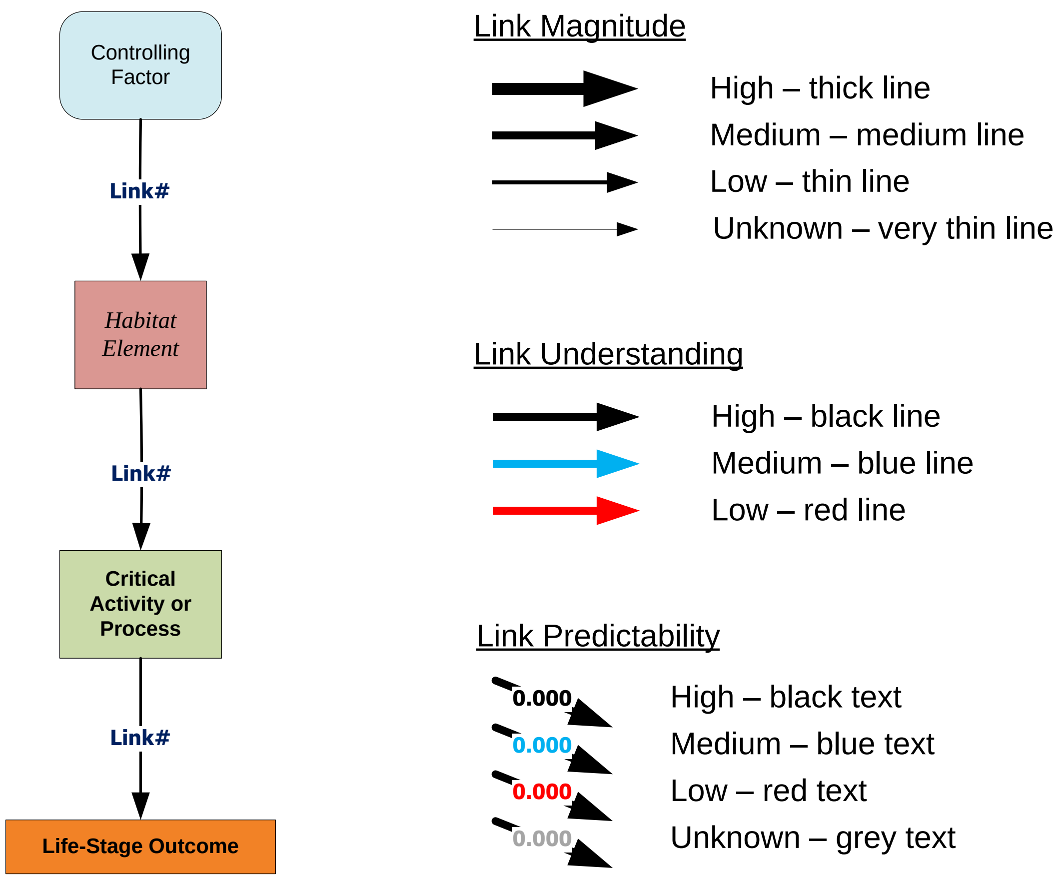

Figure 2.—Diagram conventions for LCR MSCP conceptual ecological models.

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

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

CLRA LIFE STAGE 1 – NEST

The nest stage is considered to be the first stage in the life cycle of the CLRA. It begins when the egg is hatched and ends when the chick has become independent from the mother. Success during this life stage – successful transition to the next stage – involves egg survival and chick survival and maturation.

The CEM (figure 3 and 4) recognizes six (of eight) critical biological activities and processes for this life stage, ordered as they appear on the following figures:

1. **Chemical Stress** – Chicks may suffer mortality by direct exposure to chemicals such as selenium and pesticides/herbicides if nests are located within an area of high concentrations of these chemicals, such as within an agricultural matrix (Rusk 1991). Eddleman (1989) recognized selenium as a potential threat to rail survival along the LCR, finding high levels in adults, their eggs, and crayfish, the CLRA's primary food source.

   The CEM identifies the matrix community surrounding a nest site as a secondary habitat element affecting chemical stress.

2. **Disease** – Although the literature does not emphasize disease as affecting population levels of CLRA, we believe disease bears mentioning. Disease affects clapper rails in the eastern United States to varying degrees, and one case of hepatitis has been documented in CLRA (Eddleman 1989; USFWS 2010; Rush et al. 2012).

   The CEM recognizes genetic diversity and infectious agents as a secondary habitat element affecting disease.

3. **Eating** – The chick must eat in order to maintain metabolic processes.

   The CEM recognizes brood size and parental nest attendance as secondary habitat elements affecting eating.

4. **Foraging** – The chick learns to forage very soon after hatching and must learn to effectively feed itself in order to maintain metabolic processes.

   The CEM recognizes anthropogenic disturbance, aquatic faunal composition, brood size, food availability, the matrix community, patch size, plant species composition, predator density, and residual vegetation density as secondary habitat elements affecting foraging.

5. **Predation** – Predation may affect the survival of eggs and chicks. There is no information on survival rates for chicks, which are subject to a variety of potential avian and mammalian predators (AGFD 2007; Rush et al. 2012).

   The CEM recognizes parental nest attendance, patch size, and predator density as secondary habitat elements affecting predation.

6. **Molt** – The chick must molt into juvenile plumage.

   The CEM does not recognize any habitat elements as directly affecting molt.

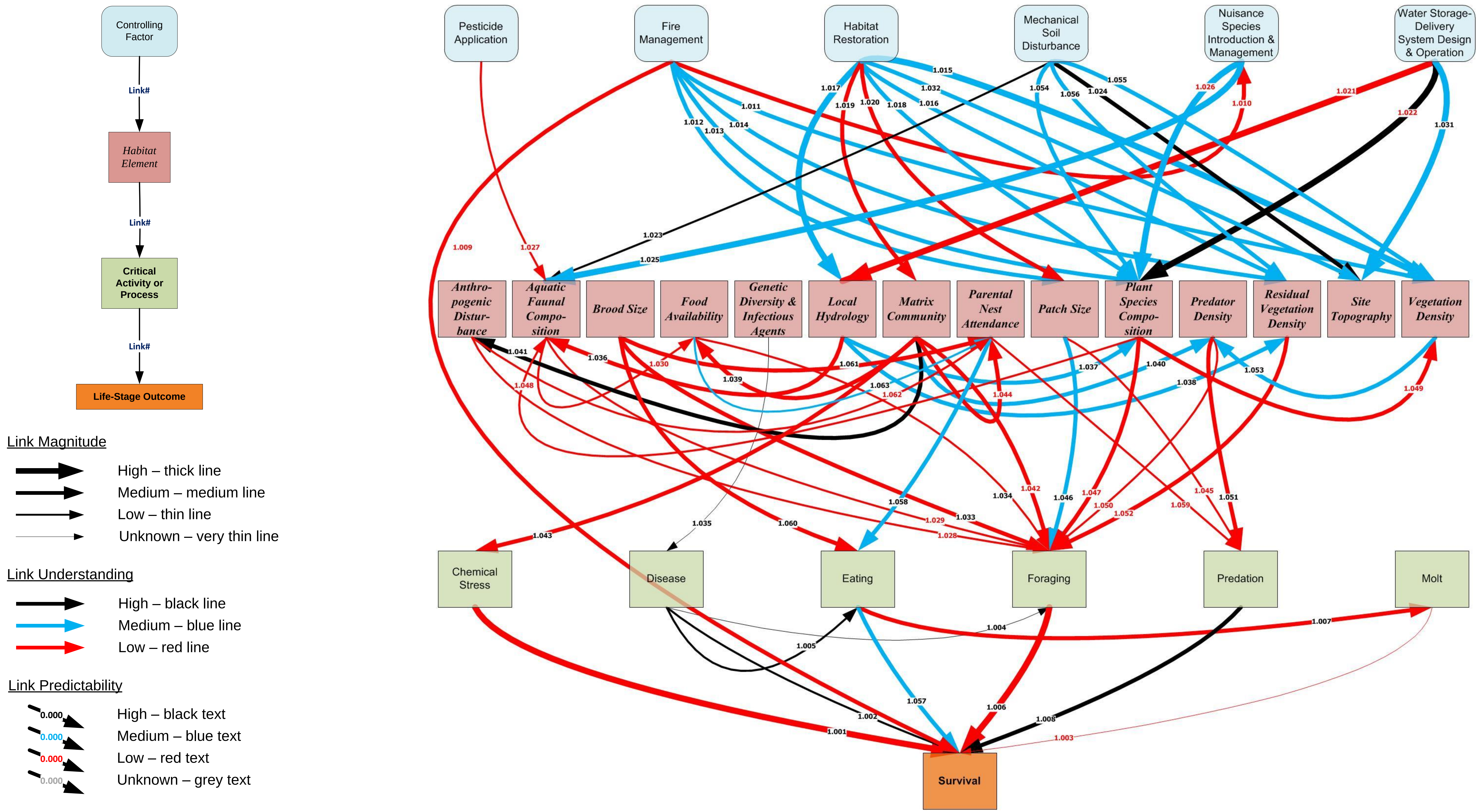

Figure 3.—CLRA life stage 1 – nest, basic CEM diagram.

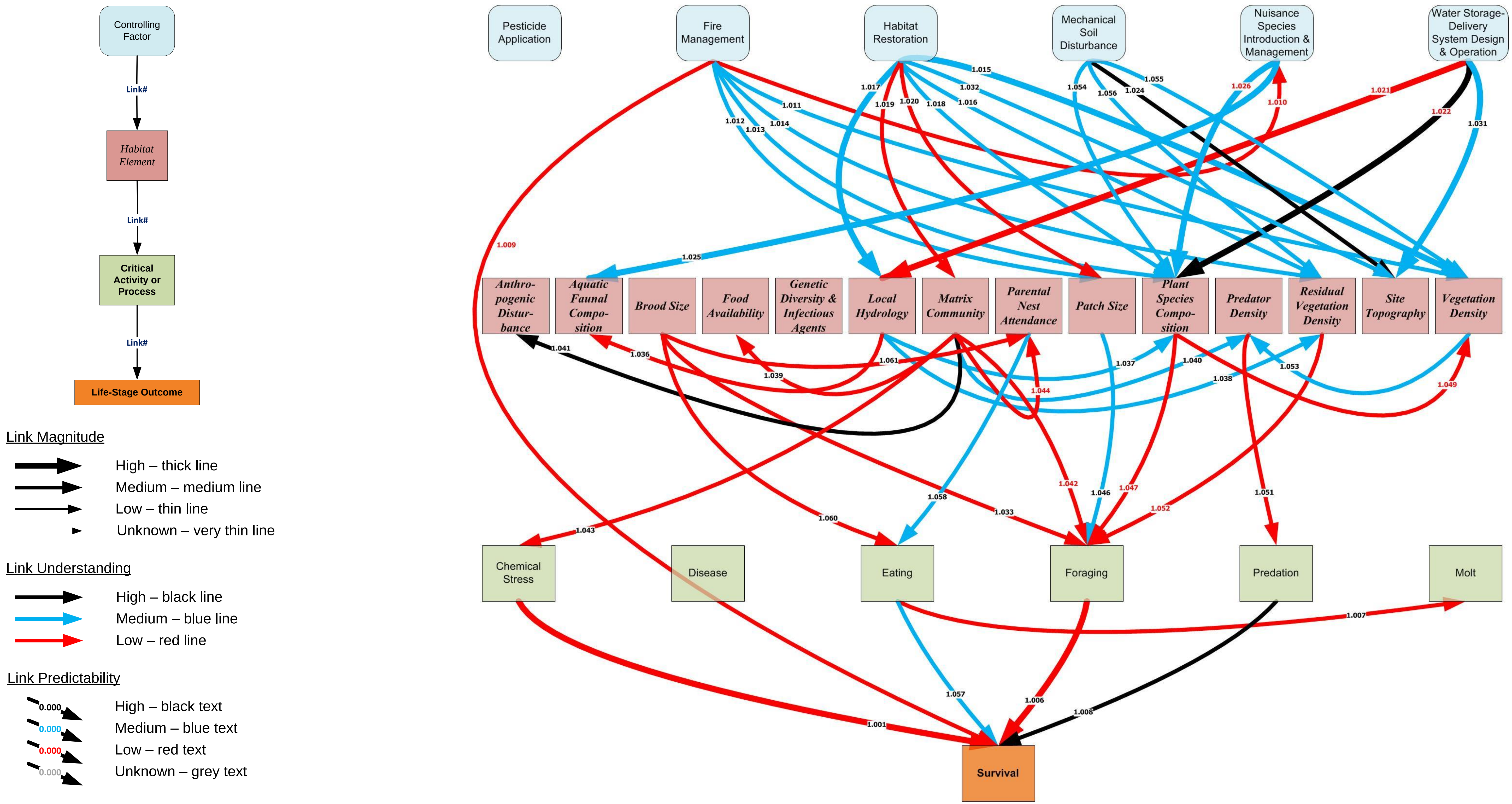

Figure 4.—CLRA life stage 1 – nest, high- and medium-magnitude relationships.

CLRA LIFE STAGE 2 – JUVENILE

The juvenile life stage begins when the chick has become independent from the parents and ends when the individual reaches sexual maturity. Success during this life stage – successful transition to the next stage – involves organism survival and maturation.

The CEM (figure 5 and 6) recognizes five (of eight) critical biological activities and processes for this life stage, ordered as they appear on the following figures.

1. **Chemical Stress** – Juvenile CLRA may suffer mortality by direct exposure to chemicals such as selenium and pesticides/herbicides if active within an area of high concentrations of these chemicals, such as within an agricultural matrix. Eddleman (1989) recognized selenium as a potential threat to rail survival along the LCR, finding high levels in adults, their eggs, and crayfish, the CLRA's primary food source. Rusk (1991) measured selenium concentrations in CLRA along the LCR and concluded that adults (and presumably juveniles) were at low risk for mortality but moderate to high risk of tetratogenicity.

   The CEM identifies the matrix community surrounding a nest site as a secondary habitat element affecting chemical stress.

2. **Disease** – Although the literature does not emphasize disease as affecting population levels of CLRA, we believe disease bears mentioning. Disease affects clapper rails in the eastern United States to varying degrees, and one case of hepatitis has been documented in CLRA (Eddleman 1989; USFWS 2010; Rush et al. 2012).

   The CEM recognizes genetic diversity and infectious agents as a secondary habitat element affecting disease.

3. **Foraging** – The juvenile CLRA must forage effectively to feed itself and maintain metabolic processes.

   The CEM recognizes anthropogenic disturbance, aquatic faunal composition, food availability, the matrix community, patch size, plant species composition, predator density, and residual vegetation density as secondary habitat elements affecting foraging.

4. **Predation** – Predation may affect the survival of juvenile CLRA. There is no information on survival rates for juveniles, which are subject to a variety of potential avian and mammalian predators (AGFD 2007; Rush et al. 2012).

   The CEM recognizes patch size and predator density as secondary habitat elements affecting predation.

5. **Molt** – The juvenile must molt into adult plumage.

   The CEM does not recognize any habitat elements as directly affecting molt.

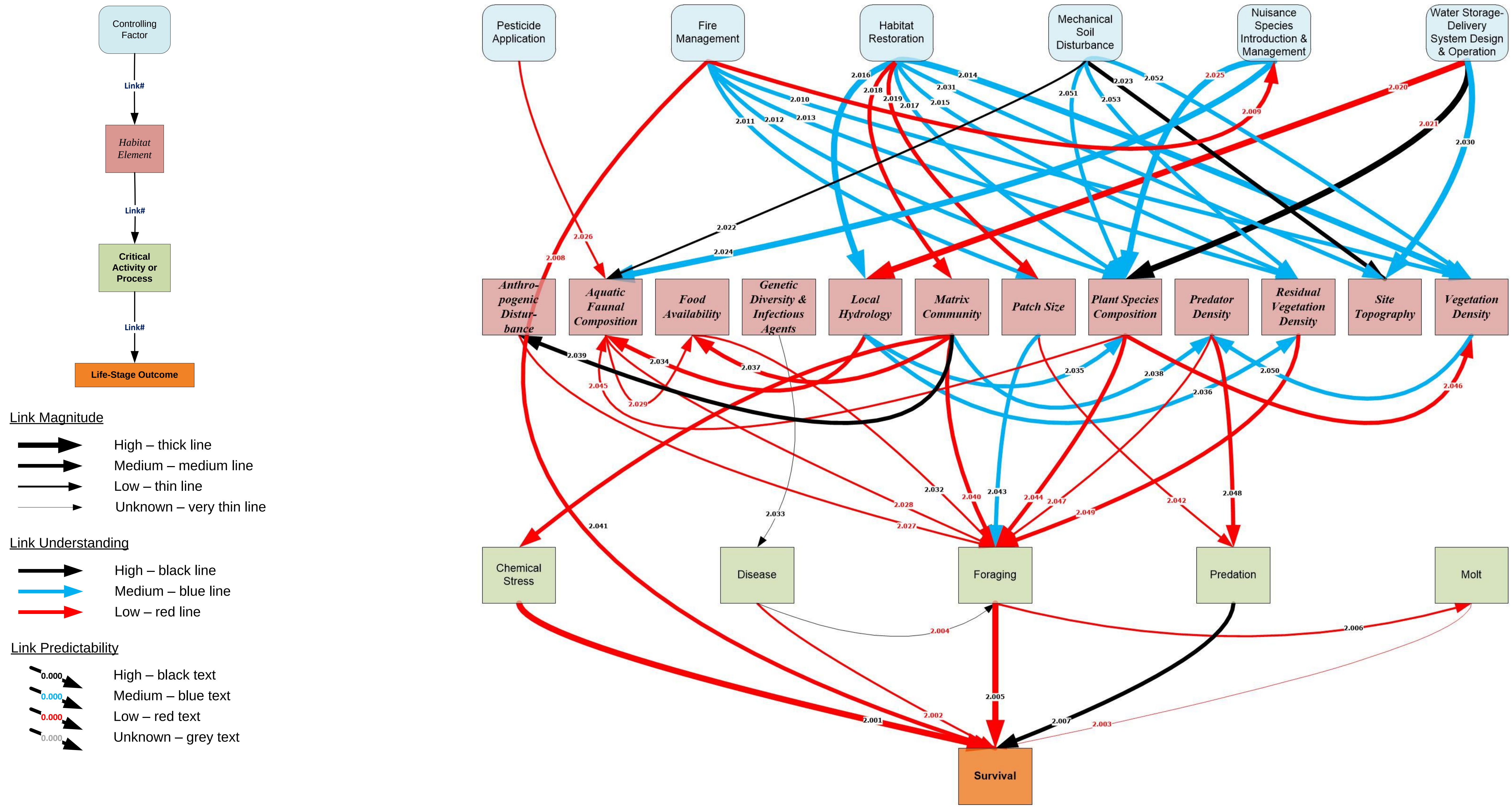

Figure 5.—CLRA life stage 2 – juvenile, basic CEM diagram.

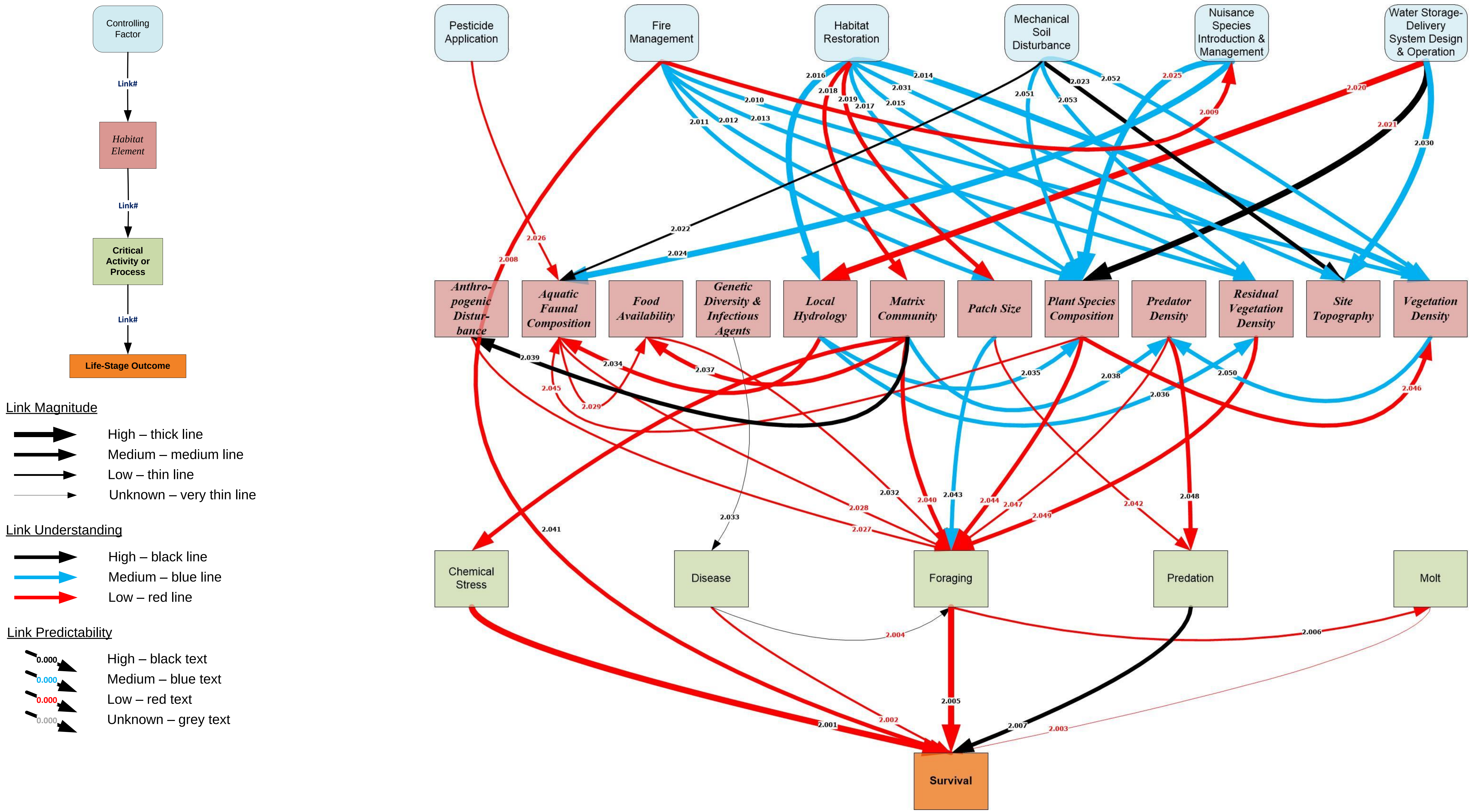

Figure 6.—CLRA life stage 2 – juvenile, high- and medium-magnitude relationships.

CLRA LIFE STAGE 3 – BREEDING ADULT

The breeding adult life stage begins when the rail reaches sexual maturity and ends when the rail stops reproducing. Success during this life stage involves organism survival and breeding.

The CEM (figures 7 and 8) recognizes six (of eight) critical biological activities and processes for this life stage, ordered as they appear on the following figures.

1. **Chemical Stress** – CLRA adults may suffer mortality by direct exposure to chemicals such as selenium and pesticides/herbicides if habitat is located within an area of high concentrations of these chemicals, such as within an agricultural matrix. Eddleman (1989) recognized selenium as a potential threat to rail survival along the LCR, finding high levels in adults, their eggs, and crayfish, the CLRA's primary food source.

   The CEM identifies the matrix community surrounding a nest site as a secondary habitat element affecting chemical stress.

2. **Disease** – Although the literature does not emphasize disease as affecting population levels of CLRA, we believe disease bears mentioning. Disease affects clapper rails in the eastern United States to varying degrees, and one case of hepatitis has been documented in CLRA (Eddleman 1989; USFWS 2010; Rush et al. 2012).

   The CEM recognizes genetic diversity and infectious agents as a secondary habitat element affecting disease.

3. **Foraging** – An adult CLRA must forage effectively to feed itself and its young.

   The CEM recognizes anthropogenic disturbance, aquatic faunal composition, brood size, food availability, the matrix community, patch size, plant species composition, predator density, and residual vegetation density as secondary habitat elements affecting foraging.

4. **Nest Attendance** – The breeding adult must attend to the nest to protect and feed the young.

   The CEM recognizes anthropogenic disturbance, brood size, and food availability as secondary habitat elements affecting nest attendance.

5. **Nest Site Selection** – This process involves nest site selection by breeding males and females and is important for reproductive success.

   The CEM recognizes anthropogenic disturbance, food availability, local hydrology, the matrix community, patch size, plant species composition, predator density, site topography, and vegetation density as secondary habitat elements affecting nest site selection.

6. **Predation** – Predation may affect the survival of adult CLRA.

   The CEM recognizes patch size and predator density as secondary habitat elements affecting predation.

7. **Molt** – The adult rail molts after breeding each season.

   The CEM does not recognize any habitat elements as directly affecting molt.

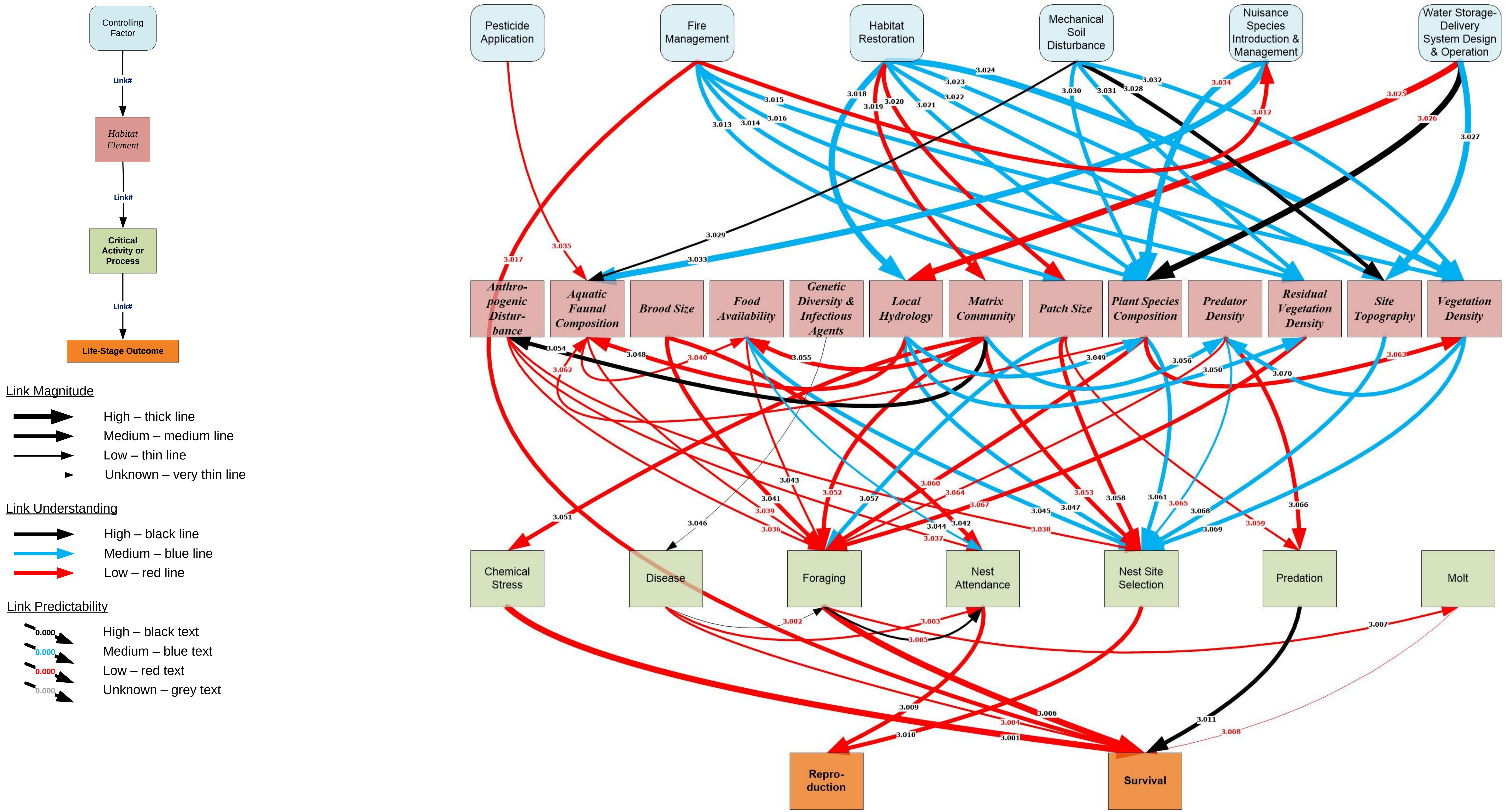

Figure 7.—CLRA life stage 3– breeding adult, basic CEM diagram.

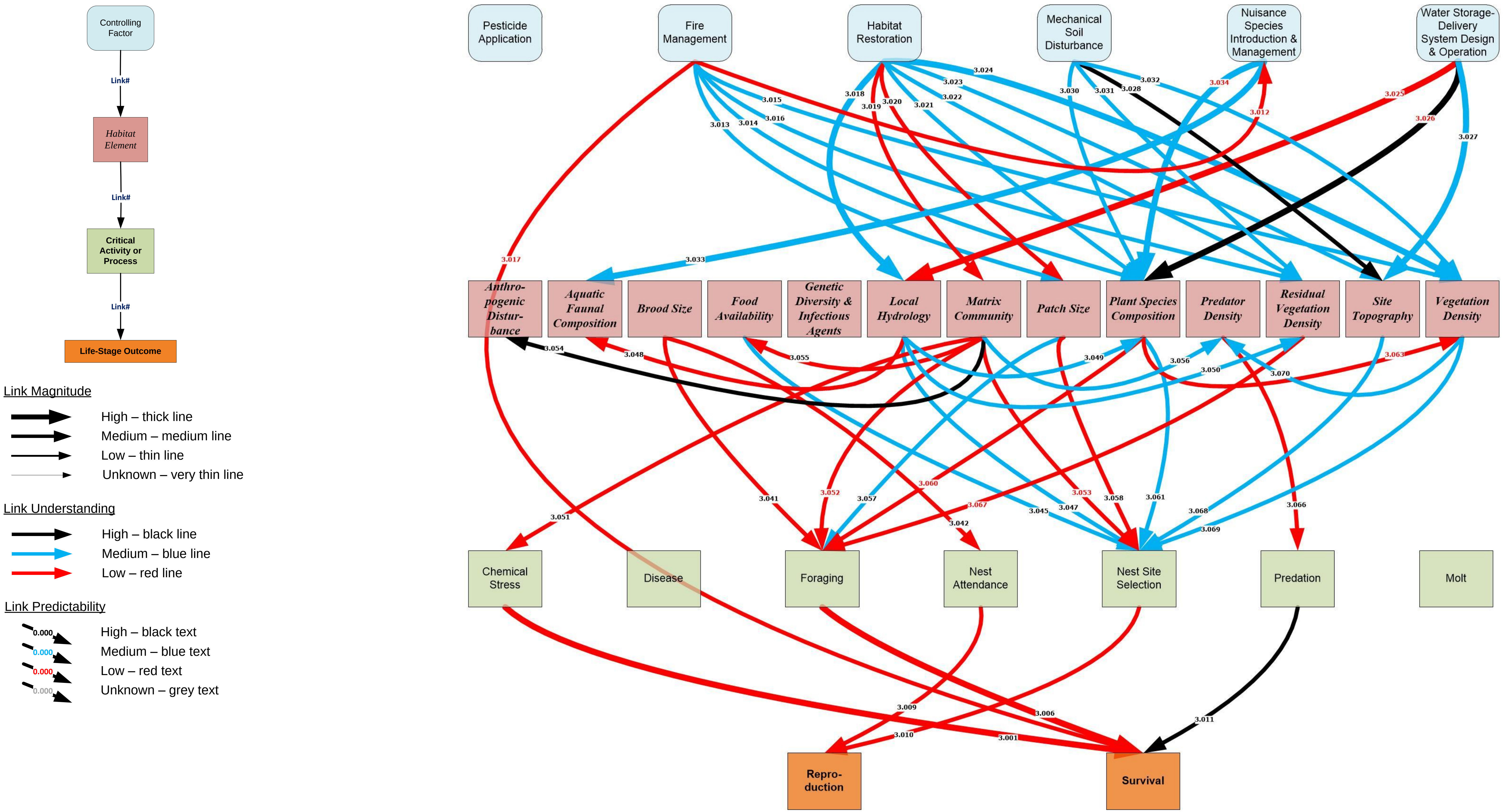

Figure 8.—CLRA life stage 3 – breeding adult, high- and medium-magnitude relationships.

Chapter 7 – Causal Relationships Across All Life Stages

The six controlling factors discussed in chapter 5 have the same influence on the same habitat elements for all life stages for which those habitat elements matter. Table 5 shows the magnitudes of *direct* influence of the 6 controlling factors on 8 of the 14 habitat elements. The structure of table 5 is the same as for table 4, but table 5 shows the magnitudes of the relationships instead of just their presence/absence. The paragraphs following the table discuss the relative effects of the different controlling factors on each habitat element.

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

Controlling factor ➔ / **Habitat element ➔**	**Fire management**	**Habitat restoration**	**Mechanical soil disturbance**	**Nuisance species introduction and management**	**Pesticide/herbicide application**	**Water storage-delivery system design and operation**
Anthropogenic disturbance	N/A*					
Aquatic faunal composition			**Low**	**High**	**Low**	
Brood size	N/A*					
Food availability	N/A*					
Genetic diversity and infectious agents	N/A*					
Local hydrology		**High**				**High**
Matrix community		**Med**				
Parental nest attendance	N/A*					
Patch size	**Med**	**Med**				
Plant species composition	**Med**	**Med**	**Med**	**High**		**High**
Predator density	N/A*					
Residual vegetation density	**Med**	**Med**	**Med**			
Site topography		**Med**	**Med**			**High**
Vegetation density	**Med**	**High**	**Med**			

* N/A values suggest that none of the identified controlling factors *directly* affect the habitat element.

AQUATIC FAUNAL COMPOSITION

The controlling factors that affect the composition of the aquatic faunal community include mechanical soil disturbance, nuisance species introduction and management, and pesticide/herbicide application. Since crayfish and other aquatic invertebrate species are the main prey items for CLRA in all life stages, management that impacts this habitat element is critical.

Eddleman (1989) advised that mechanical soil disturbance such as disking may discourage crayfish from CLRA foraging habitat and should be avoided in areas of importance to CLRA.

Nuisance species can change the structure of entire communities in ways that negatively impact listed species (Lodge et al. 2006). Aquatic invasive species such as quagga mussels (*Dreissena bugensis*) and invasive plant species such as tamarisk (*Tamarix* sp.) may affect CLRA habitat (USFWS 2010). However, non-native crayfish species are the principal prey of CLRA, and their continued success in marsh habitat within the LCR is therefore very important for the recovery of CLRA (Inman et al. 1998).

Pesticide/herbicide application and the runoff from areas where they are applied may impact the composition of aquatic invertebrates and vertebrates in the foraging areas of CLRA.

LOCAL HYDROLOGY

The primary controlling factors affecting local hydrology are habitat restoration and water storage-delivery system design and operation.

Habitat restoration for the CLRA is driven primarily by alterations to the hydrology of marsh habitat to improve conditions for the species. Optimum habitat for CLRA is complex and includes maintaining appropriate water levels and timing of seasonal flooding (Dudek and ICF 2012). Nadeau et al. (2011) suggest that restored habitat utilize automated irrigation procedures to stabilize water depths and reduce the time and money needed to maintain water delivery.

The complexity of water management opportunities and constraints involved with alterations to main stem water storage and delivery are great. While the ideal of a free-flowing river creating a mosaic of riparian and wetland habitats and, thus, a natural flow regime to benefit the CLRA appears optimal on the surface, in some ways, current water management along the LCR has created more suitable CLRA habitat than would have existed historically. Large and small dams and diversions also create hydrologic conditions that help establish new marsh habitat

(USFWS 2010). Unfortunately, a lack of scouring natural flows in the LCR leads to decadent vegetation that degrades habitat values for CLRA (Conway et al. 2010). Alternate management prescriptions, such as fire management or mechanical soil disturbance, are needed to reduce the decadent vegetative residue present in many of the marsh sites inhabited by CLRA.

MATRIX COMMUNITY

The controlling factor that directly affects the matrix community includes habitat restoration, which may change the matrix community if type conversion occurs (e.g., from farmed fields to riparian forest or marsh habitat).

PATCH SIZE

The controlling factors that directly affect patch size include fire management and habitat restoration.

Fire affects many aspects of vegetation structure and composition, and severe fire may reduce overall patch size (Busch 1995).

Habitat restoration would increase overall patch size.

PLANT SPECIES COMPOSITION

The controlling factors that directly affect plant species composition include fire management, habitat restoration, mechanical soil disturbance, nuisance species introduction and management, and water storage-delivery system design and operation.

Fire affects many aspects of vegetation structure and composition. Little evidence exists that burning was extensive in marsh environments historically in the Southwest. Native wetland vegetation is not well adapted to fire, so lightning and human-induced fires can severely alter riparian species composition and, thus, CLRA habitat (Busch 1995). Some evidence exists that fire in riparian habitats can increase the cover of some nuisance species like tamarisk (Di Tomaso 1998). Fire is an effective means of removing residual vegetative growth from marsh habitat, thus improving foraging habitat for CLRA (Conway et al. 2010).

Habitat restoration must take into consideration both plant species composition as well as density to provide suitable habitat for CLRA. Nadeau et al. (2011) found that CLRA were more likely to be found in areas with lower densities of river bulrush and moderate densities of *Phragmites* and southern cattail.

Mechanical soil disturbance, such as disking or grading, is another way to remove decadent vegetation in marsh habitat; however, it may have negative side effects, including the reduction of crayfish abundance in the marsh (Eddleman 1989) and is only an option when water can be drained from the marsh to initiate the activity.

Nuisance species such as feral pigs (*Sus scrofa*) occur within the LCR MSCP area and may negatively impact plant community composition in marsh habitat where they forage and wallow (J. Kahl 2015, personal communication).

Water movement in the LCR is highly regulated, and this has disrupted the natural flows that shape riparian habitat in the system. Water storage-delivery system design and operation impacts water availability in marsh and riparian habitat and determines where various tree species can grow.

RESIDUAL VEGETATION DENSITY

The controlling factors that impact the amount of residual vegetation in a marsh site include fire management, habitat restoration, and mechanical soil disturbance.

Fire affects many aspects of vegetation structure and composition. Little evidence exists that burning was extensive in marsh environments historically in the Southwest. Native wetland vegetation is not well adapted to fire, so lightning and human-induced fires can severely alter riparian species composition and, thus, BLRA habitat (Busch 1995). Some evidence exists that fire in riparian habitats can increase the cover of some nuisance species like tamarisk (Di Tomaso 1998). Fire is an effective means of removing residual vegetative growth from marsh habitat, thus improving foraging habitat for some marsh birds, but a study looking at the effects of prescribed fire on rails along the LCR did not detect an effect on BLRA (Conway et al. 2010).

Habitat restoration must take into consideration both plant species composition as well as density to provide suitable habitat for CLRA. While some matting of vegetation is necessary for CLRA movement, especially across deep-water habitat (Conway et al. 2003), CLRA use of habitat declines as levels of residual vegetation increase (Conway et al. 2006). Since hydrologic processes no longer operate to remove this vegetation with scouring flows, active management is necessary to decrease the amount of thatch accumulating in marsh habitats favored by CLRA.

Mechanical soil disturbance, such as disking or grading, is another way to remove decadent vegetation in marsh habitat; however, it may have negative side effects, including the reduction of crayfish abundance in the marsh (Eddleman 1989), and it is only an option when water can be drained from the marsh to initiate the activity.

SITE TOPOGRAPHY

The controlling factors that affect site topography include habitat restoration, mechanical soil disturbance, and water storage-delivery system design and operation.

Habitat restoration efforts aiming to improve hydrologic conditions that favor CLRA may require the addition or removal of dams and diversion possibly in conjunction with alterations in water movement within the main stem. Careful consideration needs to be given to the design of restored habitat to ensure the water depths are appropriate for CLRA (Nadeau et al. 2011).

Mechanical soil disturbance, such as disking or grading, is another way to remove decadent vegetation in marsh habitat; however, it may have negative side effects, including the reduction of crayfish abundance in the marsh (Eddleman 1989), and it is only an option when water can be drained from the marsh to initiate the activity.

Water movement in the LCR is highly regulated, and this has disrupted the natural flows that shape riparian habitat in the system. Water storage-delivery system design and operation impacts water availability in marsh and riparian habitat and determines where various tree species can grow.

VEGETATION DENSITY

The controlling factors that impact the density of vegetation in a marsh site include fire management, habitat restoration, and mechanical soil disturbance.

Fire affects many aspects of vegetation structure and composition. Little evidence exists that burning was extensive in marsh environments historically in the Southwest. Native wetland vegetation is not well adapted to fire, so lightning and human-induced fires can severely alter riparian species composition and, thus, CLRA habitat (Busch 1995). Some evidence exists that fire in riparian habitats can increase the cover of some nuisance species like tamarisk (Di Tomaso 1998). Fire is an effective means of removing residual vegetative growth from marsh habitat, thus improving foraging habitat for CLRA (Conway et al. 2010).

Habitat restoration that balances a mosaic of senescent and actively growing vegetative cover in marsh habitat will likely improve conditions for CLRA (Conway et al. 2006). Special consideration should be given to species selection in restoration efforts to maximize favorable habitat for CLRA (Nadeau et al. 2011).

Mechanical soil disturbance, such as disking or grading, is another way to remove decadent vegetation in marsh habitat; however, it may have negative side effects, including the reduction of crayfish abundance in the marsh (Eddleman 1989), and it is only an option when water can be drained from the marsh to initiate the activity.

Chapter 8 – Discussion and Conclusions

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

MOST INFLUENTIAL ACTIVITIES AND PROCESSES ACROSS ALL LIFE STAGE

Figure 9 identifies the critical biological activities and processes that the assessment found most strongly directly affect the success of CLRA in each life stage (high or medium magnitude). The findings presented in this diagram may be summarized as follows:

- Chemical stress, foraging, and predation are the most important critical biological activities and processes affecting survival of CLRA in all life stages. Other processes, such as disease and molt, can be very important, but are less understood, especially within the LCR.

- Only two processes directly affect reproduction – nest attendance and nest site selection. Nest site selection is especially important, as it can indirectly influence survival of CLRA at all life stages. For example, good nest sites may be in close proximity to more food, have fewer predators, and may have fewer diseases present.

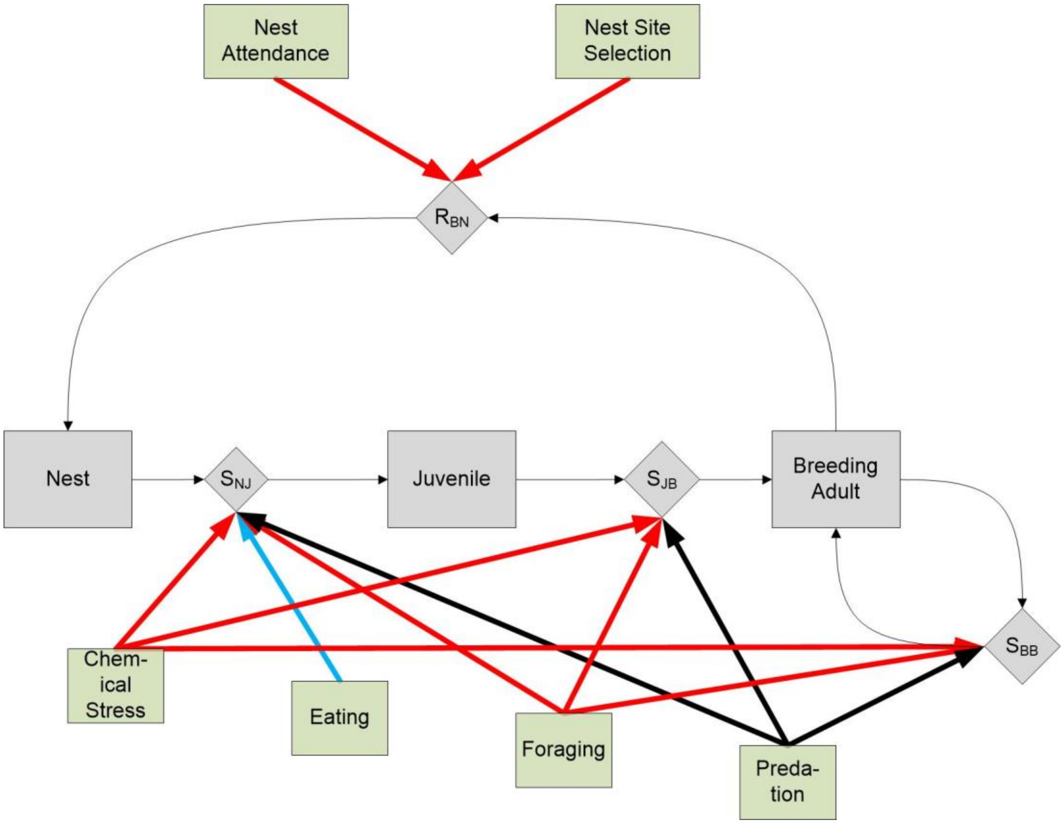

Figure 9.—Most influential biological activities and processes affecting each life stage of CLRA. Only elements with high- or medium-magnitude connections are presented. The legend is provided on figure 2.

POTENTIALLY PIVOTAL ALTERATIONS TO HABITAT ELEMENTS

Figure 10 identifies the habitat elements that the assessment indicates most strongly affect the critical biological activities and processes identified on figure 9 across all life stages (high- or medium-magnitude). The findings presented in this diagram may be summarized as follows:

- Nest site selection is by far affected by the most habitat variables likely because this critical biological activity and process is the most researched among those in figure 10 and also because, during the breeding season, this factor determines if the birds are present or not.

- Habitat restoration and water storage-delivery system design and operation can have a significant, lasting impacts on local hydrology, which may benefit CLRA survival and fecundity.

- While nuisance species introduction and management may have negative impacts on habitat values, some invasive species (e.g., crayfish such as *Procambarus clarkia* and *Orconectes* sp. [Reclamation 2008; Dudek and ICF 2012]) are actually critical to the recovery of CLRA and should be included in management planning.

- Fire management, mechanical soil disturbance, or some other strategy for managing vegetation in areas where scouring flows are not feasible is necessary to manage excess residual vegetation that is negatively impacting CLRA use of marsh habitat.

GAPS IN UNDERSTANDING

Figures 9 and 10 use the conventional color coding of individual causal relationships to identify relationships that the CEM identifies as having high, intermediate, or low levels of scientific confirmation. As noted in attachment 1, "Low" scientific understanding of a relationship means that it is "… subject to wide disagreement or uncertainty in peer-reviewed studies from within the ecosystem of concern and in scientific reasoning among experts familiar with the ecosystem." In many cases, the scientific principles are well understood, but the factual details are insufficiently understood within the LCR. The figures highlight that the level of understanding of how the various controlling factors impact the habitat elements is fairly well understood. However, the large numbers of red arrows for relationships between habitat elements and biological activities and processes indicate that these relationships have a low level of scientific understanding. Each of these red arrows identifies a causal relationship that may warrant further field, laboratory, or literature investigation. The following paragraphs highlight some potentially important areas of low understanding; however, these are not meant to represent a list of required or even feasible areas for research. Decisions about which research issues to pursue will be determined by LCR MSCP staff based on a variety of factors.

Specifically, the findings suggest a need to improve the understanding of:

- The ecology of predation on CLRA and its significance on survival across all life stages, how this may vary among predator species and across different habitat settings, and whether it may be possible to manipulate these habitat conditions to improve CLRA survival even in the presence of predators.

Yuma Clapper Rail (*Rallus longirostris yumanensis*) (CLRA)
Basic Conceptual Ecological Model for the Lower Colorado River

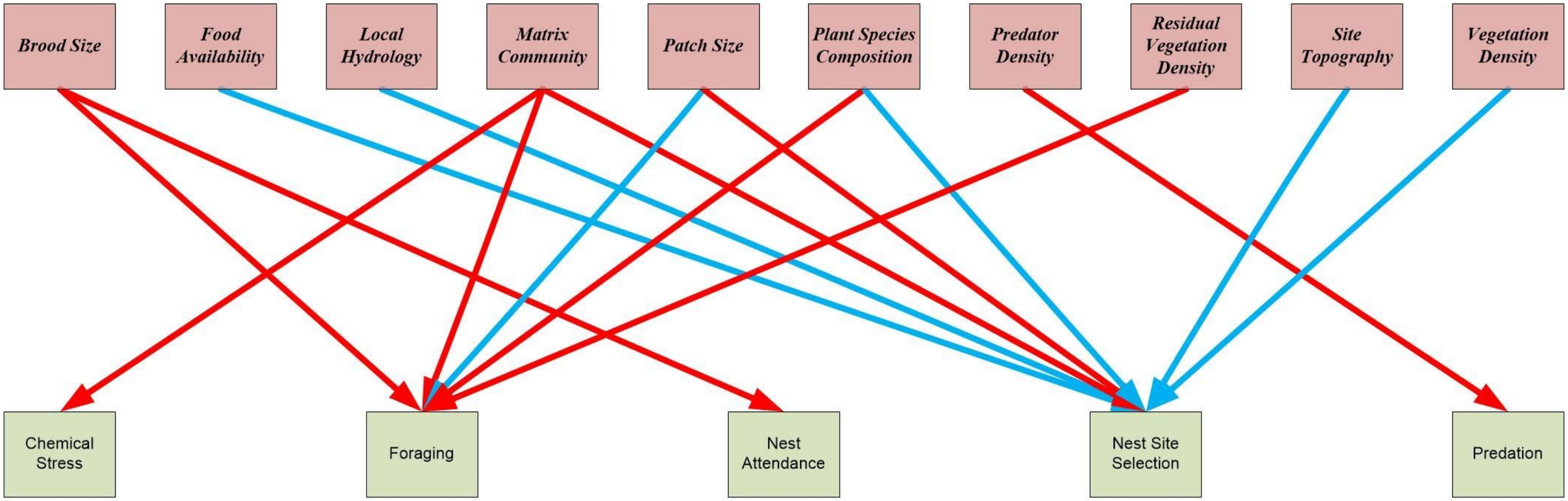

Figure 10.—Habitat elements that directly affect the most influential biological activities and processes across all life stages of CLRA. Only elements with high- or medium-magnitude connections within this life stage are presented. The legend is provided on figure 2.

- The presence of disease in the CLRA population and its significance in affecting survival across all life stages within the LCR.

- The impacts of chemical stressors such as selenium and pesticides/ herbicides within the LCR and its impact on survival of CLRA across all life stages.

- CLRA movement patterns within the LCR, including any seasonal migratory movement.

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

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ATTACHMENT 1

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

Overview of Methodology

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

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

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

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

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

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

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

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

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

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

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

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

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

(1) The effect of one controlling factor on another

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

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

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

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

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

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

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

Conceptual Ecological Models as Hypotheses

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

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

Characterizing Causal Relationships

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

(1) The character and direction of the effect

(2) The magnitude of the effect

(3) The predictability (consistency) of the effect

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

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

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

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

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

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

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

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

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

Conceptual Ecological Model Documentation

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

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

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

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

Link Attribute Ratings, Spreadsheet Fields, and Diagram Conventions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

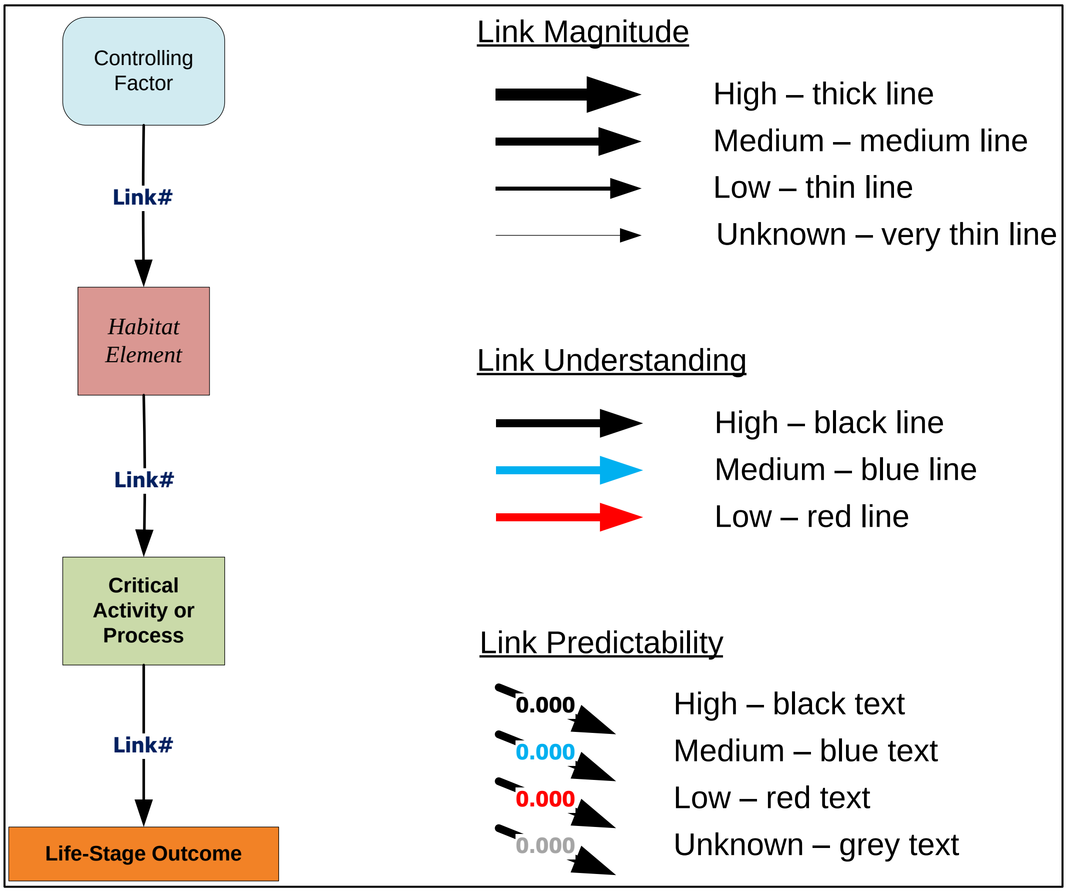

Figure 1-1.—Conventions for displaying cause and effect nodes, linkages, link magnitude, link understanding, and link predictability.

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ATTACHMENT 2

Yuma Clapper Rail Habitat Data

Table 2-1.—Yuma clapper rail (CLRA) habitat data

Habitat element	Value or range	Location	Reference
Aquatic faunal composition	CLRA diet dominated by crayfish	California	Anderson and Ohmart 1985; Eddleman 1989; Conway et al. 1993
	Crayfish abundance highest in moderately dense cattails (*Typha* sp.) or very dense cattails	Lower Colorado River; Salton Sea	Smith 1975; Bennett and Ohmart 1978
	Crayfish abundance highest in late April to mid-May and lowest in winter	Salton Sea	Bennett and Ohmart 1978
Local hydrology	Some water < 30 centimeters deep around margins of marsh during nesting season	Lower Colorado River	Conway et al. 1993; Rush et al. 2012
	Stable water levels	California; Lower Colorado River	Gould 1975; Anderson and Ohmart 1985
	Deeper water necessary in winter	Lower Colorado River	Conway et al. 1993
	0–65 millimeters of water	Lower Colorado River	Nadeau et al. 2011
Patch size	Breeding season = 7–8 hectares (ha); post-breeding season = 15 ha; late winter = 24 ha	Lower Colorado River	Conway et al. 1993
	Large-scale management units = 150 ha	Lower Colorado River	Eddleman 1989
	Minimum patch size = 8 ha	Salton Sea	Bailey et al. 1983
	CLRA density = 1 pair/13.5 ha	Topock Marsh; Lower Colorado River	Smith 1975
	Year-round home range average = 7.5 ha	Lower Colorado River	Rosenberg et al. 1991

Table 2-1.—Yuma clapper rail (CLRA) habitat data

Habitat element	Value or range	Location	Reference
Plant species composition	Moderately dense cover of cattail and bulrush (Cyperaceae)	Lower Colorado River	Gould 1975; Anderson and Ohmart 1985; Eddleman 1989
	Vegetation height > 2 meters	Lower Colorado River	Anderson and Ohmart 1985; Eddleman 1989
	Tolerant of some tamarisk and tree cover	Lower Colorado River	Eddleman 1989; U.S. Fish and Wildlife Service 2010
	Low densities of river bulrush (*Schoenoplectus robustus*) and moderate densities of *Phragmites* and southern cattail (*Typha domingensis*)	Lower Colorado River	Nadeau et al. 2011
Residual vegetation density	CLRA avoid areas with heavy accumulation of dead emergent vegetation	Lower Colorado River	Conway et al. 1993; Conway et al. 2010
Vegetation density	Low to moderate stem densities < 80 stems/square meter coupled with shallower water in nesting season	Lower Colorado River	Conway et al. 1993
	Lower basal cover coupled with deeper water in winter	Lower Colorado River	Conway et al. 1993
	Low densities of river bulrush and moderate densities of *Phragmites*, and southern cattail	Lower Colorado River	Nadeau et al. 2011

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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