Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Least Bittern (*Ixobrychus exilis*) (LEBI) Basic Conceptual Ecological Model for the Lower Colorado River

Photo courtesy of Dr. Courtney Conway, U.S. Geological Survey

U.S. Department of the Interior
Bureau of Reclamation

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Lower Colorado River Multi-Species Conservation Program

Least Bittern (*Ixobrychus exilis*) (LEBI) Basic Conceptual Ecological Model for the Lower Colorado River

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ACRONYMS AND ABBREVIATIONS

CEM	conceptual ecological model
ha	hectare(s)
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LEBI	least bittern (*Ixobrychus exilis*)
Reclamation	Bureau of Reclamation
WNV	West Nile Virus

Symbols

>	greater than
<	less than

Definitions

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

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

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

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

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

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Foreword

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

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

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

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

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

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

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

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

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

- A means of identifying appropriate monitoring indicators and metrics.

- A basis for implementing adaptive management strategies.

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

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

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

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

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

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

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

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

How to Use the Models

There are three important elements to each CEM:

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

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

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

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

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

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

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

Executive Summary

This document presents a conceptual ecological model (CEM) for the least bittern (*Ixobrychus exilis*) (LEBI). 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 LEBI ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure LEBI 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 LEBI 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 LEBI conceptual ecological model has five core components:

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

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

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

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

- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the abundance, spatial and temporal distributions, and other qualities of important 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 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 LEBI conceptual ecological model addresses the LEBI throughout its breeding range and also includes overwintering habitat in the lower Colorado River (LCR). Although many LEBI migrate farther south for the winter, LEBI also overwinter in the region. The model thus addresses the landscape as a whole rather than any single reach or managed area.

The most widely used sources of the information for the LEBI conceptual ecological model are BIO-WEST, Inc. (2005), Reclamation (2008), and Gibbs et al. (2009). 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 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 LEBI conceptual ecological model distinguishes and assesses four life stages and their associated outcomes as follows (table ES-1):

Table ES-1.—Outcomes of each of the four life stages of LEBI

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

The model distinguishes 8 critical biological activities and processes relevant to 1 or more of these life stages and their outcomes, 15 habitat elements relevant to 1 or more of these critical biological activities and processes for 1 or more life stages, and 8 controlling factors that affect 1 or more of these 15 habitat elements. Because the LCR is a highly regulated system, the controlling factors exclusively concern human activities.

The eight critical biological activities and processes identified across all life stages are: disease, eating, foraging, molt, nest attendance, nest site selection, predation and competition, and temperature regulation. The 15 habitat elements identified across all life stages are: anthropogenic disturbance, brood size, density of conspecifics, emergent vegetation assemblage, food availability, infectious agents, marsh size, parental feeding behavior, parental nest attendance, predator/competitor density, temperature, water depth, water quality, water turbidity, and woody vegetation assemblage. The eight controlling factors identified across all habitat elements are: fire management, fisheries management, marsh management and restoration, nuisance species introduction and management, off-marsh land use, recreational activities, wastewater and other contaminant inputs, and water storage-delivery system design and operation.

RESULTS

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

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

- Eating, foraging, and predation and competition are the most important critical biological activities and processes affecting survival of LEBI at all life stages. Although predation is ever-present, gaps in knowledge about predation rates and the importance of competition to LEBI remain. Other processes, such as disease, molt, and temperature regulation 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 LEBI at all life stages. For example, good nest sites may have more food, fewer predators, and fewer diseases present.

- The emergent vegetation assemblage and water depth are the most important habitat elements affecting LEBI use along the LCR.

- The link magnitude for infectious agents was strong, but this is a reflection of the tight connection between the presence of disease-causing organisms and disease. However, little is known about disease overall as a critical process along the LCR.

- Marsh management and restoration, along with nuisance species introduction and management, are the main controlling factors affecting the most habitat elements and critical biological activities and processes of LEBI either directly or indirectly. Linked closely to marsh management in particular is water storage-delivery system design and operation.

- Runoff from off-marsh land use and wastewater and other contaminant inputs can also affect the emergent vegetation assemblage via changes to water quality.

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 LEBI survivorship and recruitment along the LCR. Many of these gaps in understanding have been mentioned by others (Reclamation 2008), and most are a result of the difficulty in studying such secretive birds. Specifically, the findings suggest a need to improve the understanding of the following:

- Disease can affect most critical biological activities and processes, yet the effects of disease on LEBI along the LCR are unknown.

- Predation rates on adult and/or young LEBI along the LCR are unknown, as are the effects of other management activities on predator and/or competitor density.

- LEBI are highly secretive birds, and actual population estimates for this species are lacking for the LCR. Research into the detection probability for LEBI may aid in determining population estimates from existing data. New research to determine LEBI abundance in certain key habitats and LCR areas would improve our understanding of bittern use of the river and adjoining habitats.

- There are many management activities occurring along the LCR that could potentially affect LEBI habitat; in particular, the effects of fire management not only on the emergent vegetation assemblage but also on water quality and water turbidity. This is especially important given plans for prescribed fire management for Yuma clapper rails (*Rallus longirostris yumanensis*) using the same marsh systems.

- Fisheries management and monitoring activities should also be evaluated for impact during the LEBI breeding season.

- Nuisance species introduction and management also deserves a closer look to better understand the effects on LEBI and its habitat of both species introductions and control efforts to eradicate other pests. Of particular concern is the potential spread of golden algae (*Prymnesium parvum*) into LCR habitats.

- LEBI overwintering ecology remains unknown. What habitats are overwintering LEBI using along the LCR? Is there a critical marsh size for overwintering (versus larger marshes that are important for breeding)?

- What impact does recreation have on breeding and/or use of overwintering habitats along the LCR? How sensitive are LEBI at the LCR to anthropogenic disturbance?

- LEBI reports from elsewhere have noted offsite mortality due to collisions with cars or with barbed wire fencing, for example. Do these types of events occur with any regularity on lands adjacent to LCR wetlands?

- More research is needed to determine the effects of high selenium levels on LEBI productivity over the long term. Are there other toxins present in the system that could become problematic?

- How do changes in water quality affect LEBI prey species in LCR marshes? Although prey species diversity may change, is productivity sufficient to sustain populations?

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 LEBI. 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 least bittern (*Ixobrychus exilis*) (LEBI). 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 LEBI ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure LEBI 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 LEBI population in marshes and fringing wetlands 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 LEBI conceptual ecological model are BIO-WEST, Inc. (2005), Reclamation (2008), and Gibbs et al. (2009). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The CEM also integrates numerous additional sources, particularly reports and articles completed since the aforementioned publications; information on current research projects; and the expert knowledge of LCR MSCP biologists. The purpose of the 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 LEBI as presently understood, the purpose of the model, and introduces the underlying concepts and structure of the CEM. Succeeding chapters present and explain the model for LEBI along the LCR and evaluate the implications of this information for management, monitoring, and research needs.

Least Bittern Reproductive Ecology

LEBI typically return to the LCR to breed in April (BIO-WEST, Inc. 2005), although resident adults may begin breeding activity earlier in the season. An average of four to five eggs are laid, with both parents sharing incubation and tending to the hatched young (Bent 1926; Weller 1961). Nestlings leave the nest at 13–15 days yet do not fledge until 29 days, and both parents continue to feed them during this time (Palmer 1962). There is little information about juvenile movements post-fledging until they leave the breeding grounds in October. Most LEBI do migrate farther south for the winter, out of the LCR; however, some LEBI remain onsite. There is no information about what portion of the LEBI overwintering population on the LCR consists of juveniles, year-round residents, or overwintering adults from elsewhere. LEBI feed mainly on small fishes, amphibians, and aquatic invertebrates (Gibbs et al. 2009).

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 it 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 LEBI

The CEM methodology used here expands on that developed for the Sacramento-San Joaquin River Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al. 2012). The expansion incorporates recommendations of Wildhaber et al. (2007) Wildhaber (2011), Kondolf et al. (2008), and Burke et al. (2009) to provide greater detail on causal linkages and outcomes 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., juvenile to adult) or next age class within a single life stage (recruitment rate), or the number of viable offspring produced (fertility rate). It then identifies the factors that shape the rates of these outcomes in the study area and thereby shapes the abundance, distribution, and persistence of the species in that area.

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

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

- **Life-stage outcomes** – These consist of the biologically crucial outcomes of each life stage, including the number of individuals recruited to the next life stage (e.g., juvenile to adult), or the number of viable eggs 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 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 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 – LEBI 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 the LEBI along the LCR on which to build the CEM.

INTRODUCTION TO THE LEBI LIFE CYCLE

Because most LEBI do migrate, the LCR MSCP is mainly responsible for management on the breeding grounds. However, there is a sizeable overwintering population on the LCR that consists of young-of-the-year, year-round residential birds, and overwintering birds that come from elsewhere in the bittern's range. We therefore have included four life stages as occurring within LCR MSCP lands—nest, juvenile, overwintering individual, and breeding adult. Thus, the focus of this study is on management activities throughout the year as within the scope of Reclamation's responsibilities.

We also include both the egg and chick phases of development as a single life stage in the CEM 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. In addition, the juvenile stage consists of two phases, a non-flighted phase where the young have left the nest to forage but are unable to fly and remain dependent on parental care, and a post-fledging phase. Because there is insufficient information to further divide this overall timespan as it relates to survivorship, the phases have been combined for this model.

LEBI LIFE STAGE 1 – NEST

The nest stage includes both the egg and nestling phase. It begins when the first egg is laid and ends either when the young leave the nest, prior to fledging, or if the nest fails. On average, 4–5 eggs are laid over a 6-day period from mid-April to July. (Note: In southwest Arizona, where there are resident LEBI, nesting may begin earlier in the season, in March [Gibbs et al. 2009 and references therein].) Incubation, by both parents, begins after the first or second egg is laid and lasts around 20 days (Bent 1926; Weller 1961). Although the young do not fledge until 29 days after hatching, they may leave the nest in 13–15 days and begin to forage on their own. Both parents continue to feed them until they fledge (Palmer 1962). As bitterns are occasionally double-brooded, nestlings can be present at different times during the season. Overall nest success in a New York study in 1999–2000 was 44–52 percent (percent hatching combined with percent fledging) (Bogner and Baldassarre 2002). In South Carolina, 20–70 percent of the nests survived from laying to fledging depending on their location in the marsh (Post 1998). However, more research is needed to better understand survivorship along the LCR. The life-stage outcome from the nest stage is the survival of eggs and associated nestlings. It is important to note that the outcome of the nest stage is inherently tied to the behavior and condition of the parents.

LEBI LIFE STAGE 2 – JUVENILE

The juvenile stage has two components: (1) a non-flying phase when the young first leave the nest at about 13–15 days and begin to forage on their own nearby (while receiving supplemental feeding by their parents) (Palmer 1962) and (2) after fledging, which occurs at 29 days or so until they disperse (Bogner and Baldassarre 2002). Juveniles generally leave the breeding grounds in October, 1 or 2 weeks after the adults (BIO-WEST, Inc. 2005; Gibbs et al. 2009). (Some LEBI remain all year at LCR sites, and although there is no information about what portion of these overwintering individuals are young-of-the-year, it is possible that not all juvenile bitterns migrate out of the area.) There is insufficient information to further divide this overall timespan as it relates to survivorship. Pending improved information, the non-flying and flying juvenile phases have been combined. Additionally, there is no information about when LEBI reach sexual maturity. The life-stage outcome from the juvenile stage is the survival of the bird from leaving the nest and successfully fledging to become an overwintering individual along the LCR or offsite.

LEBI LIFE STAGE 3 – OVERWINTERING INDIVIDUAL

Although most LEBI migrate out of the LCR region, spending the winter farther south, some may be year-round residents in parts of the LCR (BIO-WEST, Inc. 2005). This life stage of the model addresses the portion of the LEBI population that either remains year round onsite (including young-of-the-year that remain after fledging during the winter months) or that migrates to the LCR to spend the winter months. Little information is available about habitat use on the wintering grounds (Gibbs et al. 2009). In San Diego County, California, wintering LEBI were found at the same sites that were used by bitterns during the breeding season (Unitt 2004), so LEBI likely use similar habitats throughout the year. Habitat use by LEBI during spring and fall migration in Missouri is also reported to be similar to breeding habitat (Reid 1989 *in* Gibbs et al. 2009). The life-stage outcome for an overwintering individual is survival to become a breeding adult.

LEBI LIFE STAGE 4 – BREEDING ADULT

The breeding adult stage begins when the bird returns to the breeding grounds (or begins to form pair bonds in the case of resident LEBI) and ends when birds depart the breeding grounds during fall migration. Generally, adults arrive on breeding grounds in April and remain until September (BIO-WEST, Inc. 2005), although resident adults may begin breeding activity earlier, in March (BIO-WEST, Inc. 2005).

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). Here 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 LEBI conceptual ecological model distinguishes four life stages as shown in table 1 and figure 1. The life stages are numbered sequentially beginning with the nest life stage.

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

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

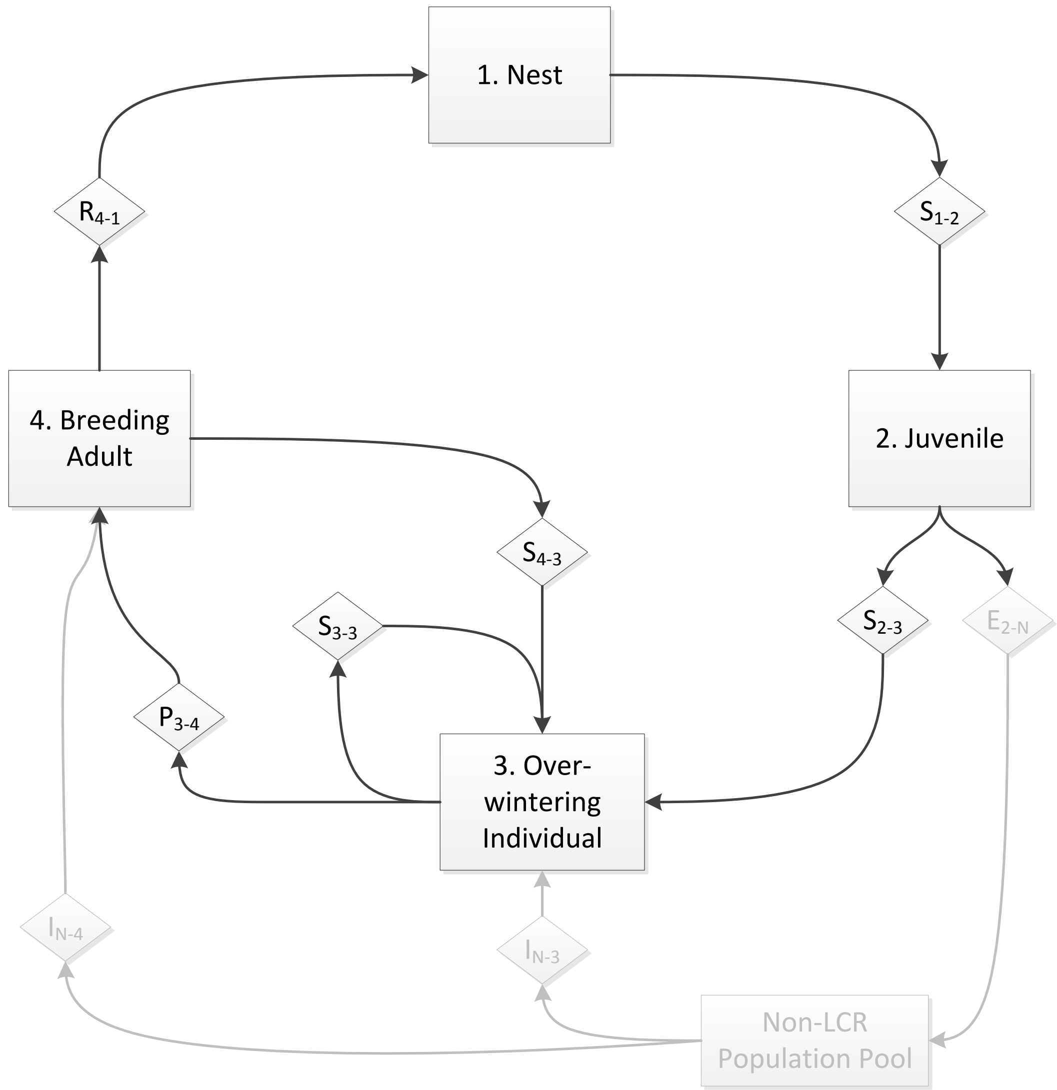

Figure 1.—Proposed LEBI life history model.
Squares indicate the life stage, and diamonds indicate the life-stage outcomes. S_{1-2} = survivorship rate from nest, S_{2-3} = survivorship rate of juveniles that stay along the LCR over winter, E_{2-N} = net emigration rate of juveniles that leave to join the non-LCR population pool (not assessed but part of life cycle), I_{N-3} = net immigration rate from the non-LCR population pool back into the LCR non-breeding adult population (not assessed but part of life cycle), I_{N-4} = net immigration rate from the non-LCR population pool directly into the LCR breeding adult population (not assessed but part of life cycle), S_{3-3} = annual survivorship rate of overwintering individuals that do not breed. P_{3-4} = annual rate of participation of adults in breeding, S_{4-3} = survivorship of breeding adults to return to the general population of adults, and R_{4-1} = reproductive output of breeding adults (rate of production of viable eggs).

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 LEBI life stages. Some of these activities or processes differ in their details among life stages. For example, LEBI of different life stages differ in their ability to forage for food. However, grouping activities or processes across all life stages into broad types makes it easier to compare the individual life stages to each other across the entire life cycle. Table 2 lists the eight critical biological activities and processes and their distribution across life stages.

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

Life stage ➔ **Critical biological activity or process ➔**	**Nest**	**Juvenile**	**Overwintering individual**	**Breeding adult**
Disease	X	X	X	X
Eating	X			
Foraging		X	X	X
Molt	X	X		X
Nest attendance				X
Nest site selection				X
Predation and competition	X	X	X	X
Temperature regulation	X	X	X	X

The most widely used sources of the information used to identify the critical biological activities and processes are BIO-WEST, Inc. (2005), Reclamation (2008), and Gibbs et al. (2009). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The identification also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP biologists. The following paragraphs discuss the eight critical biological activities and processes in alphabetical order.

DISEASE

This process refers to diseases caused either by lack of genetic diversity or by infectious agents. Although there is little information available about LEBI in relation to disease susceptibility (Gibbs et al. 2009), LEBI in all life stages are conceivably susceptible to disease. There is reference to susceptibility to a parasitic fish nematode (*Eustrongilides*) (see Gibbs et al. 2009 and references therein). Also, in a California study of West Nile Virus (WNV), LEBI were one of the nine most frequently infected bird species (Wheeler et al. 2009).

EATING

This process only applies to the nest life stage because nestlings 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. (Juveniles may still be fed by adults for some time after leaving the nest and possibly after fledging [see the habitat element of parental feeding behavior].)

FORAGING

LEBI are generalist feeders, preying mainly on small fishes, amphibians, and aquatic invertebrates (Gibbs et al. 2009). Foraging is done by juveniles and adults, but it is important to note that foraging by the parents affects the provisioning rate to nestlings (and somewhat to juveniles) and nest attendance by adults.

MOLT

LEBI are semialtricial and must molt from natal down into juvenal plumage. In addition, there is an annual post-nuptial molt in adults. This activity applies to both the nest and the juvenile stages as well as to the breeding adult stage. Molt is an energetically costly process (Gill 2007), especially at the nest and juvenile stages, and may make nestlings more susceptible to death when resources are scarce.

NEST ATTENDANCE

Nestlings rely on their parents to provide food, protection from predators, and thermoregulation. In the case of LEBI, both males and females incubate, brood, and feed young chicks (Palmer 1962; Gibbs et al. 2009). Nest attendance is performed by breeding adults (and is dependent in part on their survivorship) and affects the nest life stage (egg hatching and the provisioning rate to nestlings).

NEST SITE SELECTION

Breeding males typically select the nest site, with females providing additional nesting materials for construction (Terres 1980). Nest placement can affect vulnerability to predation, environmental conditions in the nest, susceptibility to flooding, and foraging rates.

PREDATION AND COMPETITION

Predation and competition are threats to LEBI at all life stages and obviously affect survival to varying degrees. Although the most common predators of LEBI are well known (see the habitat element “predator and competitor ensity”), the rates of predation and/or the intensity of competition (e.g., with introduced fish or crayfish [*Orconectus sp.*] or bullfrogs [*Lithobates catesbeianus*] over food resources) at any LEBI life stage are not known. For this reason, predation and competition have been addressed together in this model. However, should more information become available about competition’s effects on LEBI, predation and competition could be addressed separately in future CEM versions.

TEMPERATURE REGULATION

Temperature regulation is important for any organism inhabiting a region as hot as that of the LCR. Although overheating is possible during all life stages, most of the concern has been directed at eggs and nestlings (Rosenberg et al. 1991). However, adults can affect the temperature regulation of eggs and nestlings through their own behavior (incubation, brooding, or shading) and through nest placement and construction (e.g., LEBI will bend vegetation over the nest to form a protective canopy) (Gibbs et al. 2009).

Chapter 4 – Habitat Elements

Habitat elements consist of specific habitat conditions that ensure, allow, or interfere with critical biological activities and processes. Although brood size is not traditionally considered an aspect of habitat, it is included in this section because of its effects on critical biological activities and processes.

Briefly, typical LEBI breeding habitat consists of expansive marshes with dense emergent vegetation, occasionally with scattered shrubs, integrated with deeper areas of open water. Favored plant species include cattails (*Typha* sp.), sedges (*Carex* sp.), and rushes (*Scirpus* sp.).

This chapter identifies 15 habitat elements that affect 1 or more critical biological activities or processes across the 4 LEBI life stages. Some of these habitat elements differ in their details among life stages. For example, LEBI at different life stages experience different interactions with conspecifics or predation rates. However, using the same labels for the same *kinds* of habitat elements across all life stage makes comparison and integration of the CEMs for the individual life stages across the entire life cycle less difficult.

Table 3 lists the 15 habitat elements and the critical biological activities and processes that they *directly* affect across all LEBI life stages.

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

Critical biological activity or process ➔ **Habitat element ➔**	**Disease**	**Eating**	**Foraging**	**Molt**	**Nest attendance**	**Nest site selection**	**Predation and competition**	**Temperature regulation**
Anthropogenic disturbance			X		X			
Brood size		X	X		X			
Density of conspecifics						X		
Emergent vegetation assemblage			X			X	X	X
Food availability			X					
Infectious agents	X							
Marsh size						X		
Parental feeding behavior			X				X	
Parental nest attendance		X	X				X	
Predator/competitor density							X	
Temperature					X	X		X
Water depth			X			X	X	
Water quality								
Water turbidity			X					
Woody vegetation assemblage							X	

Note: Water quality does not affect any critical biological activity or process directly; rather, it affects foraging indirectly by its effects on the emergent vegetation assemblage and food availability. There is also no habitat element that directly affects molt.

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

The most widely used sources of the information used to identify the habitat elements are BIO-WEST, Inc. (2005), Reclamation (2008), and Gibbs et al. (2009). These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The identification also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP biologists.

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

ANTHROPOGENIC DISTURBANCE

Full name: **The presence of humans within or near wetlands used by bitterns and associated disturbance, including noise**. Whether due to recreational, land management, or scientific research activities, the presence of humans can disturb LEBI, causing changes in behavior that might ultimately affect survival. Most problematic would be disturbances during the nesting season that would discourage nesting or cause nest abandonment. Anthropogenic disturbance and its effect on birds has been reviewed by Barber et al. (2010) and Francis and Barber (2013). Anthropogenic disturbance is considered to be a habitat element, as it is an environmental characteristic with which a nesting, foraging, or overwintering bittern must contend. Although disturbances, particularly from recreational activities, have been reported to reduce nest success (Sandilands 2005) according to Gibbs et al. (2009), LEBI may be tolerant of some human presence if the habitat remains "undisturbed."

BROOD SIZE

Full name: **The number of young in the nest**. Clutch size is related to maternal health, and the well-being of both parents depends in part on the availability of sufficient food resources in close proximity to the breeding territory (during incubation, bitterns forage directly from the nest [Weller 1961]) in addition to other factors, including predator density. Brood size affects the likelihood that all siblings will survive the nest stage, as the youngest hatchling (LEBI have asynchronous hatching) may starve due to competition with their larger siblings for food (Ehrlich et al. 1988; Gibbs et al. 2009 and references therein).

DENSITY OF CONSPECIFICS

Full name: **The density of conspecifics, specifically of other LEBI in the same habitat**. LEBI are typically solitary nesters, with nest densities less than 1 per hectare (ha) (Rosenberg et al. 1991; Gibbs et al. 2009). However, LEBI will nest in higher densities (as close as 10 meters apart and up to 15 nests per ha) in marshes that are very productive in terms of food (Weller 1961; Kushlan 1973; Gibbs et al. 2009).

It is possible that the density of conspecifics affects foraging and other activities of juveniles and overwintering individuals. However, since little is known about LEBI behavior and habitat use along the LCR, other potential effects of LEBI density have not been incorporated into the CEM. As more information becomes available, the model can be broadened.

EMERGENT VEGETATION ASSEMBLAGE

Full name: **The species diversity, abundance/density, spatial and temporal distributions, and vertical structure of emergent vegetation**. LEBI usually nest over water and prefer nest sites with dense emergent vegetation (preferably of cattails, sedges, or rushes) interspersed with open water and occasional scattered woody shrubs. (Note: LEBI will occasionally nest or forage in other vegetation such as common reed (*Phragmites*) or tamarisk (*Tamarix* sp.) [Patten et al. 2003 *in* Sterling 2008; Gibbs et al. 2009]). Dense vegetation conceals nests and provides a microclimate needed for egg and nestling development. Tall emergent vegetation also provides essential materials for nest and forage platform construction as well as habitat structure for aquatic prey and for other species that may compete with or prey upon LEBI. Open water areas facilitate foraging, as bitterns forage from the edge of vegetation into open water. Therefore, although dense foliage is a classic characteristic of LEBI habitat. LEBI generally prefer marshes that contain a mix of both dense areas for nest placement and open water areas for foraging. In Iowa, a hemimarsh, with approximately equal extents of vegetated areas and open water areas that were well interspersed, was found to support the most bitterns (Weller and Spatcher 1965 *in* Gibbs et al. 2009). The distance to open water from nest sites is usually less than 10 meters (Gibbs et al. 2009).

FOOD AVAILABILITY

Full name: **The diversity, size, abundance, and spatial and temporal distributions of the species on which LEBI feed**. This element refers to the availability of food resources, whether fishes, amphibians, or invertebrates that individual LEBI will encounter during each life stage as well as the density and spatial and temporal distributions of the food supply in proximity to the nest. LEBI will nest in higher densities (as close as 10 meters apart/up to 15 nests per ha) in marshes that are more productive in relation to food (Weller 1961; Kushlan 1973; Gibbs et al. 2009); otherwise, they are solitary nesters with nest densities less than 1 per ha (Rosenberg et al. 1991; Gibbs et al. 2009).

INFECTIOUS AGENTS

Full name: **The types, abundance, and distribution of infectious agents**. Infectious agents refer to the spectrum of viruses, bacteria, fungi, and parasites capable of infecting LEBI that individual LEBI are likely to encounter during each life stage. The effects of disease and other infectious agents are poorly understood, although there is reference to susceptibility to a parasitic fish nematode (*Eustrongilides*) (see Gibbs et al. 2009 and references therein). Also, in a California study of WNV, LEBI were one of the nine most frequently infected bird species (Wheeler et al. 2009).

MARSH SIZE

Full name: **The areal extent of marsh habitat**. Although an average marsh size may differ between riverine and reservoir systems, marsh size likely affects the number of breeding pairs that an area can support as well as the density of predators. Brown and Dinsmore (1986) found bitterns using marsh lands of more than 5 ha. Gibbs et al. 2009 recommend a marsh size of > 10 ha as optimal, although territorial individuals were found on a marsh only 0.4 ha in size (Gibbs and Melvin 1990 *in* Gibbs et al. 2009). According to the Ohio Breeding Bird Atlas, although LEBI can use a variety of marsh sizes, they rarely use small marshes or narrow strips of cattails along the water's edge (Peterjohn and Rice 1991); see Sterling (2008) for information about LEBI nesting in cattail patches in California.

PARENTAL FEEDING BEHAVIOR

Full name: **The ability and behavior of parents to feed and care for juveniles after they leave the nest**. This element refers to the capacity of both parents to provision food for LEBI young that have left the nest. The length of time that juveniles are fed once they leave the nest and then after fledging is unknown in this species. The feeding rate is dependent upon food availability and the number of young in the brood. This rate influences the amount of food and time spent foraging by the juvenile birds.

PARENTAL NEST ATTENDANCE

Full name: **The ability of both parents to care for young during the egg/incubation and nestling stages**. This element refers to the capacity of either or both parents to tend to the young. It is affected primarily by the presence of predators and food availability.

PREDATOR/COMPETITOR DENSITY

Full name: **The taxonomic and functional composition, abundance, and spatial and temporal distributions of species that may prey on or compete with LEBI during each life stage**. This element refers to a set of closely related variables that affect the likelihood that different kinds of predators or competitors will encounter and successfully prey on or compete with LEBI during any life stage. The variables of this element include the species and sizes of the fauna that prey on or compete with LEBI during different life stages and the density and spatial distribution of these fauna in the marsh habitat used by bitterns. Susceptibility to predation is related to emergent vegetation cover and nest location (e.g., depth of water at the nest or distance from land). The location of bittern nests in dense vegetation over water reduces the impact of most terrestrial predators, but all are vulnerable to raptors, snakes, turtles, and some mammals (e.g., raccoons [*Procyon lotor*]) (Gibbs et al. 2009). Little is known about depredation rates of juveniles or adults generally (Massachusetts Natural Heritage Endangered Species Program 2010). Other species, such as bass (*Micropterus* sp.) or carp (*Cyprinus*) (Weber and Brown 2009) may compete with LEBI for food resources.

TEMPERATURE

Full name: **The mean temperature in a habitat patch or nest site**. This element refers to the average temperature in the nesting habitat around the nest site (or during the nesting season). Avoiding thermal stress is important for any organism inhabiting a region as hot as that of the LCR. Although overheating is possible during all life stages, most of the concern has been directed at eggs and nestlings. (see the "Temperature Regulation" section in chapter 3 for more details.)

WATER DEPTH

Full name: **The average depth of water in marshes used by bitterns**. Bitterns typically build their nests over water that is between 25 and 60 centimeters deep (Gibbs et al. 2009 and references therein). Deep, open water areas are also important for foraging as long as there is adjacent vegetation from which they can forage. Additionally, LEBI are often associated with stable water regimes, especially at managed impoundments (Gibbs and Melvin 1990 *in* Gibbs et al. 2009; Jobin et al. 2009). High water levels may flood nests (McVaugh 1975 *in* Gibbs et al. 2009).

WATER QUALITY

Full name: **The condition of water in marsh habitat used for breeding or overwintering**. This element includes the presence of chemical pollutants, including pesticide residue. Pesticide runoff may harm prey populations and bioaccumulate, with repercussions for nesting success. Chemical runoff may alter plant species diversity and marsh vegetation structure and hence suitability for nesting bitterns. Although LEBI are reported to use brackish water habitats to some degree (Gibbs et al. 2009), high salinity concentrations due to the source of inflow and lack of circulation may become too high to support appropriate emergent vegetation such as cattails (Garnett 2012). In addition, runoff and resulting eutrophication coupled with higher salinity may lead to the development of algal blooms, in particular those of golden algae (*Prymnesium parvum*). Toxins produced by golden algae affect gill-breathing organisms such as fishes, bivalves, and crayfish and can lead to extensive fishkills under certain conditions (Sallenave 2010), reducing the food supply for LEBI.

WATER TURBIDITY

Full name: **The clarity of water in a marsh**. Bitterns are visual predators, stalking prey while perched among the reeds, and they need relatively clear water in order to locate their food (Gibbs et al. 2009). Water turbidity can have many causes (e.g., dredging and other construction or maintenance activities, recreation [motorboat disturbances of shallows – see Asplund 2000], substrate characteristics, dense algal blooms that block sunlight from penetrating the water column, and invasive carp that churn the benthic substrate [Lougheed et al. 1998]). Note that the density and arrangement of emergent marsh vegetation can also affect water turbidity caused by weather-related factors such as wind.

WOODY VEGETATION ASSEMBLAGE

Full name: **The stem density and spatial distribution of woody vegetation in a marsh**. LEBI predominantly use marsh habitat dominated by herbaceous emergent vegetation, selecting wetlands with only scattered shrubs or other woody vegetation (Gibbs et al. 2009). Extensive canopy cover of woody trees or shrubs precludes bittern use, although there is no data regarding percent cover of woody vegetation. Scattered trees or shrubs can provide perches for predators.

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. These may also significantly and 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 eight immediate controlling factors that are within the scope of potential human manipulation. The eight controlling factors identified in this CEM do not constitute individual variables; rather, each identifies a category of variables (including human activities) that share specific features, which makes it useful to treat them together. Table 4 lists the eight controlling factors and the habitat elements they *directly* affect. Table 4 shows five habitat elements that are not directly affected by any controlling factor (brood size, density of conspecifics, parental feeding behavior, parental nest attendance, and temperature). 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**	**Fisheries management**	**Marsh management and restoration**	**Nuisance species introduction and management**	**Off-marsh land use**	**Recreational activities**	**Wastewater and other contaminant inputs**	**Water storage-delivery system design and operation**
Anthropogenic disturbance		X				X		
Brood size	N/A*							
Density of conspecifics	N/A*							
Emergent vegetation assemblage	X		X	X				
Food availability		X		X				
Infectious agents				X				
Marsh size			X					
Parental feeding behavior	N/A*							
Parental nest attendance	N/A*							
Predator/competitor density		X		X		X		
Temperature	N/A*							
Water depth			X			X		X
Water quality	X		X	X	X	X	X	
Water turbidity	X		X	X	X	X		X
Woody vegetation assemblage	X		X	X				

* N/A values suggest that none of the identified controlling factors *directly* affect the habitat element. Controlling factors affect brood size, density of conspecifics, parental feeding behavior, and parental nest attendance indirectly. Temperature is determined by regional climate and local weather conditions as well as indirect effects of controlling factors.

Fire Management

This factor addresses any fire management (whether prescribed fire or fire suppression) along the LCR that could affect LEBI or their habitat. Effects may include the creation of habitat that supports or excludes LEBI (as proposed for Yuma clapper rails (*Rallus longirostris yumanensis*) [Reclamation 2008; Conway et al. 2010], reduction in the food supply, or support of species that pose threats to LEBI such as predators, competitors, or carriers of infectious agents. In addition, fire management may affect water quality and water turbidity through the release of soluble and insoluble materials into the water after a burn; however, the effect will vary depending on the severity and intensity of the fire (and whether wildfire or prescribed burn) and subsequent precipitation events that increase runoff from burned areas if offsite (Meixner and Wohlgemuth 2004; New Mexico Environment Department 2014).

Climate change is also projected to affect fire frequency along the LCR (U.S. Fish and Wildlife Service 2013).

Fisheries Management

This factor includes activities involved in managing habitat for rare native fishes that might affect habitat or prey of LEBI, either positively or negatively. Examples of such activities include fish monitoring, seining, electroshocking (may disturb nesting/feeding bitterns if present), or construction of riprap shoreline cover (depending on the location) (see LCR MSCP research and monitoring fisheries activities reports at http://www.lcrmscp.gov/fish/fish_res_mon.html). Fisheries management may alter the species composition of the aquatic community and introduce competitors into the system (e.g., stocked bonytail [*Gila elegans*] may compete with LEBI for the same prey). Improvement of backwater habitats and water quality for fish would benefit LEBI that also use these habitats. However, use of rotenone to remove non-native fish species would clearly be detrimental to the LEBI prey base. (See "Nuisance Species Introduction and Management," below.)

Marsh Management and Restoration

This factor addresses the active restoration program to restore marsh habitat within the LCR and includes not only mechanical or chemical clearing of existing vegetation but also the vegetation community planted and the pattern in which it is planted within restoration areas (e.g., density, interspersion with open water, etc.). The short, sparse vegetation required for the Yuma clapper rail, for example, differs from the tall, dense emergent vegetation selected by LEBI

(Reclamation 2008). This factor also includes other management activities, such as grading of the land surface, pond deepening, removal of decadent vegetation, etc., that may be part of any marsh management and restoration plan.

NUISANCE SPECIES INTRODUCTION AND MANAGEMENT

This factor addresses the intentional or unintentional introduction of nuisance species (animals and plants as well as microbes) and/or their control that affect LEBI survival and reproduction. The nuisance species may poison, infect, prey on, compete with, or present alternative food resources for LEBI during one or more life stages; cause other alterations to the riparian food web that affect LEBI; or affect physical habitat features such as vegetation cover. For example, bass, introduced by sport fishermen, may remove smaller fishes and aquatic insects that LEBI depend upon, as has been reported for the yellow bittern (*I. sinensis*) (Sawara 2013). Use of herbicides to control invasive plants, such as salt cedar (*Tamarisk* sp.) or common reed, may alter marsh vegetation structure. Clearing without replanting will make a marsh system unsuitable for longer time periods than if replanted with native emergents. Use of algicides to control golden algal blooms may affect other organisms in aquatic systems (Sallenave 2010). (Note: Under certain environmental conditions, blooms of golden alga may produce a toxin harmful to many gilled aquatic organisms [Sallenave 2010; Brooks et al. 2011; Roelke et al. 2011].)

OFF-MARSH LAND USE

This factor addresses activities occurring on lands adjacent to marshes that may affect nesting or residential LEBI. Agricultural and other land use activities on adjacent lands may result in erosion and sediment deposition into wetlands utilized by LEBI. Increased nutrient loads may lead to eutrophication, reducing water quality and increasing water turbidity. Construction of roads, power lines, and barbed wire fencing near marsh habitat may increase the frequency of LEBI collisions (Gibbs et al. 2009) during migration or movement to other marsh lands. However, since nothing is known about whether fatal encounters with hazardous features are a significant problem along the LCR, this aspect of off-marsh land use has not been included in the CEM.

RECREATIONAL ACTIVITIES

This factor addresses the disturbance to LEBI from recreational activity – in particular, the use of motor boats and jet skis that may swamp nests with their wake (BIO-WEST, Inc. 2005; Gibbs et al. 2009) or otherwise disturb nesting bitterns (Asplund 2000 and references therein). In addition, the use of motorized watercraft can affect water turbidity and water quality (Asplund 2000). Increased recreational use of an area may attract predators if resulting garbage is not managed properly.

WASTEWATER AND OTHER CONTAMINANT INPUTS

This factor includes contamination from main stem diversions that may include contaminants such as high concentrations of selenium. Bitterns collected from the Imperial National Wildlife Refuge had high selenium concentrations in their livers (higher than the toxic threshold) (Martinez 1994 *in* Reclamation 2008) that may have reproductive consequences. Selenium monitoring is a component of the current LCR marsh and backwater restoration program. The use of pesticides (e.g., dieldrin) was listed as a past threat to LEBI in Louisiana (see Causey and Graves 1969 in Gibbs et al. 2009). Drainage waters from agricultural lands that include pesticides may be toxic to prey of LEBI, reducing food availability. The effects may include sublethal poisoning of LEBI via ingestion of treated insects or fishes that bioaccumulate toxins.

WATER STORAGE-DELIVERY SYSTEM DESIGN AND OPERATION

Much of the habitat used by LEBI is along regulated waterways. The water moving through these systems is highly managed to allow for storage and delivery (diversion) to numerous international, Federal, State, Tribal, and municipal users and for hydropower generation. This factor includes river and off-channel water management, including pumping of groundwater and diversion of river water to manage water levels in refuge ponds as well as dewatering and flushing of marsh habitats. The amount of water, flooding frequency, water depth and stability, etc., all affect development and maintenance of backwater habitats and fringing marshes with sufficient water depth, water quality, vegetation density, and species composition for LEBI.

Chapter 6 – Conceptual Ecological Model by Life Stage

This chapter contains four sections, each presenting the CEM for a single LEBI 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 LEBI habitat and thus addresses 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.

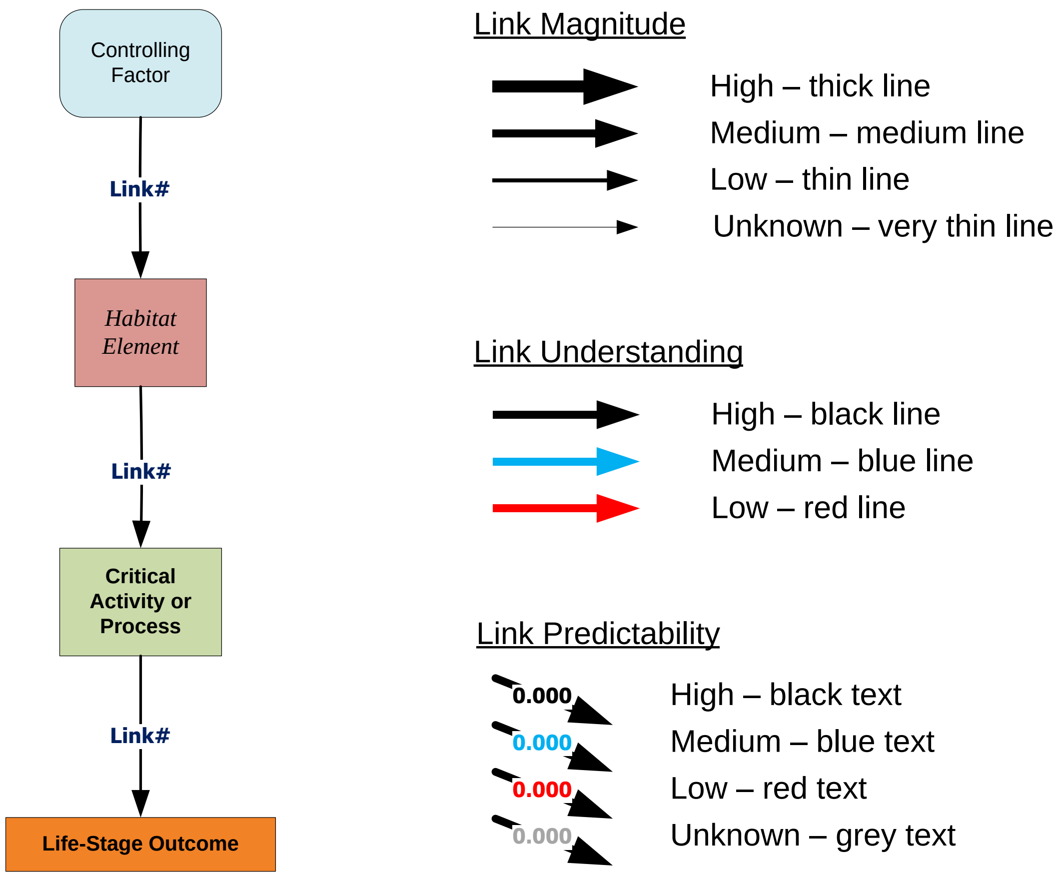

Figure 2.—Diagram conventions for LCR MSCP conceptual ecological models.

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 four life stages. For this reason, the discussion of controlling factor-habitat element linkages across all four life stages appears in a subsequent chapter.

LEBI LIFE STAGE 1 – NEST

The LEBI conceptual ecological model addresses the time spent in the nest as egg and nestling as the first life stage in the overall LEBI life cycle. It begins when the egg is laid and ends when the young leave the nest (but are still being fed by their parents). Success during this life stage – successful transition to the next stage – involves egg survival, maturation, and hatching followed by organism survival, maturation, and molt. The organisms actively interact with their environment. Critical biological activities and processes therefore consist of both activities and processes.

The CEM (figures 3 and 4) recognizes five (of eight) critical biological activities and processes for this life stage. Foraging, nest attendance, and nest site selection are not included, as they are part of other life stages. The critical biological processes and activities are presented here, ordered as they appear on the following figures:

1. **Disease** – Although the literature does not emphasize disease as affecting population levels of LEBI, we still feel that disease bears mentioning. In a California study of WNV, LEBI were one of the nine most frequently infected bird species (Wheeler et al. 2009). In addition to the possibility of direct mortality, infections may weaken birds, affecting their foraging ability and increasing vulnerability to other stressors.

   The CEM recognizes disease as potentially affecting eating, molt, survival, and temperature regulation. Because it has been studied so rarely along the LCR, there is no information on the magnitude of the effects.

   The CEM recognizes infectious agents as a habitat element directly affecting disease.

   The CEM recognizes water depth and water quality via infectious agents as habitat elements indirectly affect disease transmission.

2. **Eating** – The nestling is dependent on provisions by the parents. Eating is affected by disease and determines nestling survival and quality of molt.

   The CEM recognizes brood size and parental nest attendance as directly affecting eating.

3. **Molt** – The nestling must molt into juvenile plumage. This transition relies in part on successful foraging by the parent for energy-rich food.

   The CEM recognizes disease and eating as directly affecting molt. Molt directly affects survivorship.

4. **Predation and Competition –** Predation and competition directly affect survival of nestlings to successfully transition to the juvenile stage.

   The CEM recognizes the emergent vegetation assemblage that provides protective cover, parental nest attendance, predator/competitor density, and water depth (determines whether nest is reachable by terrestrial predators) as habitat elements directly affecting predation and competition.

   The CEM recognizes the emergent vegetation assemblage, marsh size, and the woody vegetation assemblage (which may provide perching sites for avian predators) as habitat elements indirectly affecting predation and competition via predator/competitor density.

5. **Temperature Regulation** – The nestling must maintain an optimum temperature to develop and survive.

   The CEM recognizes disease as the critical biological activity and process as directly affecting temperature regulation at the nest stage.

   The CEM recognizes the emergent vegetation assemblage, parental nest attendance, and temperature as habitat elements directly affecting temperature regulation. In turn, temperature regulation directly affects survival.

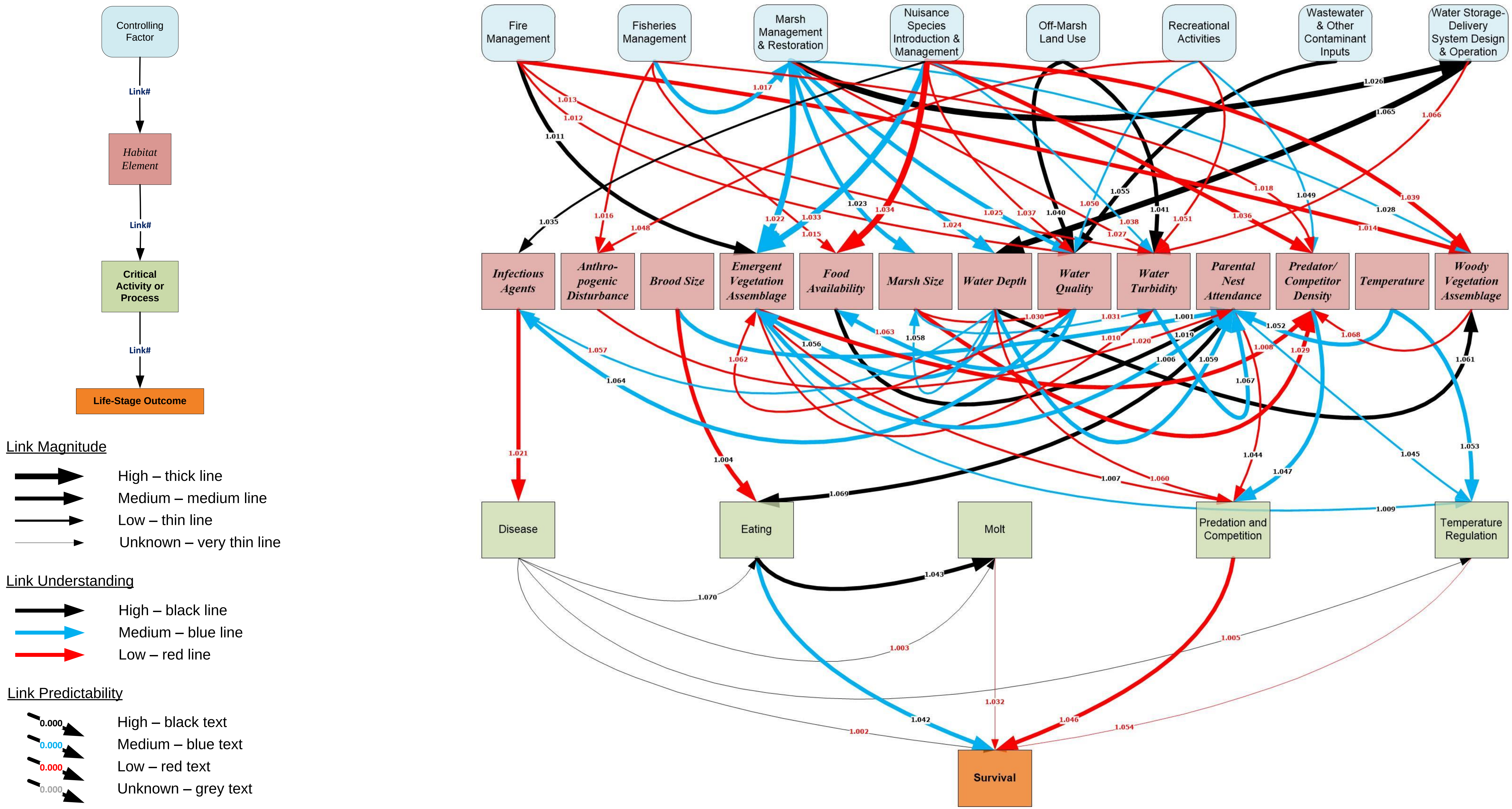

Figure 3.—LEBI life stage 1 – nest, basic CEM diagram.

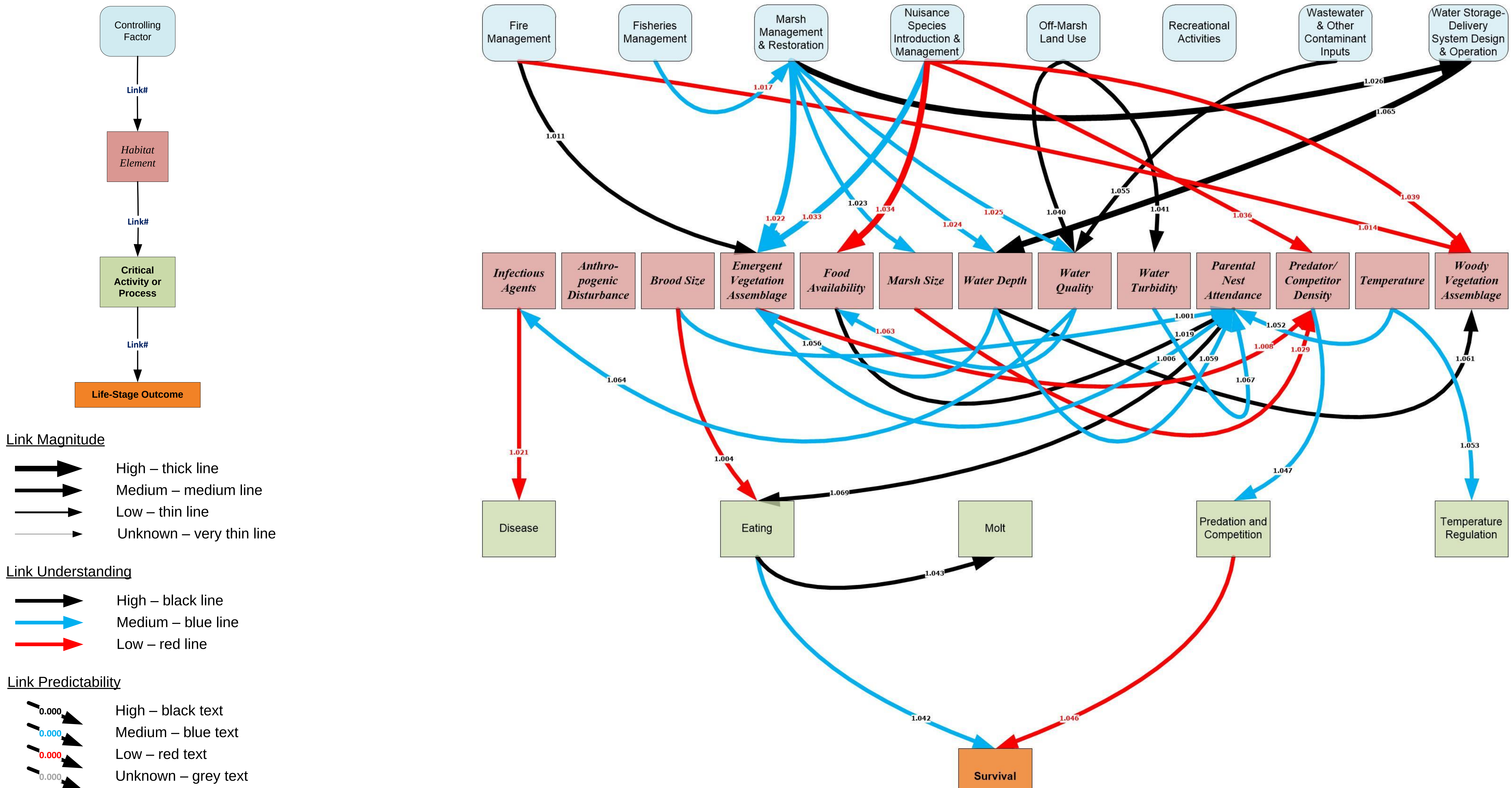

Figure 4.—LEBI life stage 1 – nest, high- and medium-magnitude relationships.

LEBI LIFE STAGE 2 – JUVENILE

As defined for this model, the juvenile stage begins when the young leave the nest (prior to fledging) and ends when the birds leave their natal marsh for overwintering habitat. Success during this life stage – successful transition to the next stage – involves completion of molt and fledging, organism survival, and maturation. The organisms actively interact with their environment. Critical biological activities and processes therefore again consist of both activities and processes.

The CEM (figures 5 and 6) recognizes five (of eight) critical biological activities and processes for this life stage. Eating, nest attendance, and nest site selection are not included, as they are part of other life stages. The critical biological processes and activities are presented here, ordered as they appear on the following figures:

1. **Disease** – Although the literature does not emphasize disease as affecting population levels of LEBI, we still feel that disease bears mentioning. Because it has been so rarely studied along the LCR, there is no information on the magnitude of the effect.

   The CEM recognizes infectious agents as a habitat element directly affecting disease transmission.

   The CEM recognizes water depth and water quality via infectious agents as habitat elements indirectly affecting disease transmission.

2. **Foraging** – Although still fed by its parents, the juvenile can now also forage for its own food in order to eat and maintain metabolic processes. Juvenile foraging activity is affected directly by disease.

   The CEM recognizes anthropogenic disturbance, the emergent vegetation assemblage, food availability, parental feeding behavior, water depth, and water turbidity as habitat elements directly affecting foraging.

   The CEM recognizes infectious agents (via disease) and water quality (via food availability) as habitat elements indirectly affecting foraging.

3. **Molt** – The juvenile must molt into juvenile plumage. This transition relies in part on successful foraging for energy-rich food. In addition to foraging, the CEM recognizes disease as the critical activity and biological process as directly affecting molt.

   The CEM recognizes anthropogenic disturbance, the emergent vegetation assemblage, food availability, water depth, and water turbidity, which all affect molt via foraging success, as habitat elements indirectly affecting molt. Molt, in turn, affects survival.

4. **Predation and Competition** – Avoiding predation and/or competition helps ensure that an individual will survive to the next life stage.

   The CEM recognizes the emergent vegetation assemblage that provides cover, parental feeding behavior, predator/competitor density, and water depth (which affects access to the nest) as habitat elements directly affecting predation and competition.

   The CEM recognizes marsh size and the woody vegetation assemblage (which provides perching sites for avian predators) as habitat elements indirectly affecting predation and competition.

5. **Temperature Regulation** – The juvenile must maintain an optimum temperature to develop and survive.

   The CEM recognizes disease as the critical biological activity and process as directly affecting temperature regulation.

   The CEM recognizes the emergent vegetation assemblage and temperature as habitat elements directly affecting temperature regulation. The first element guides site selection by LEBI and determines the amount of shade at the nest itself.

   The CEM recognizes infectious agents (via disease) and water depth, which affects the emergent vegetation assemblage (and humidity levels), as habitat elements indirectly affecting temperature regulation.

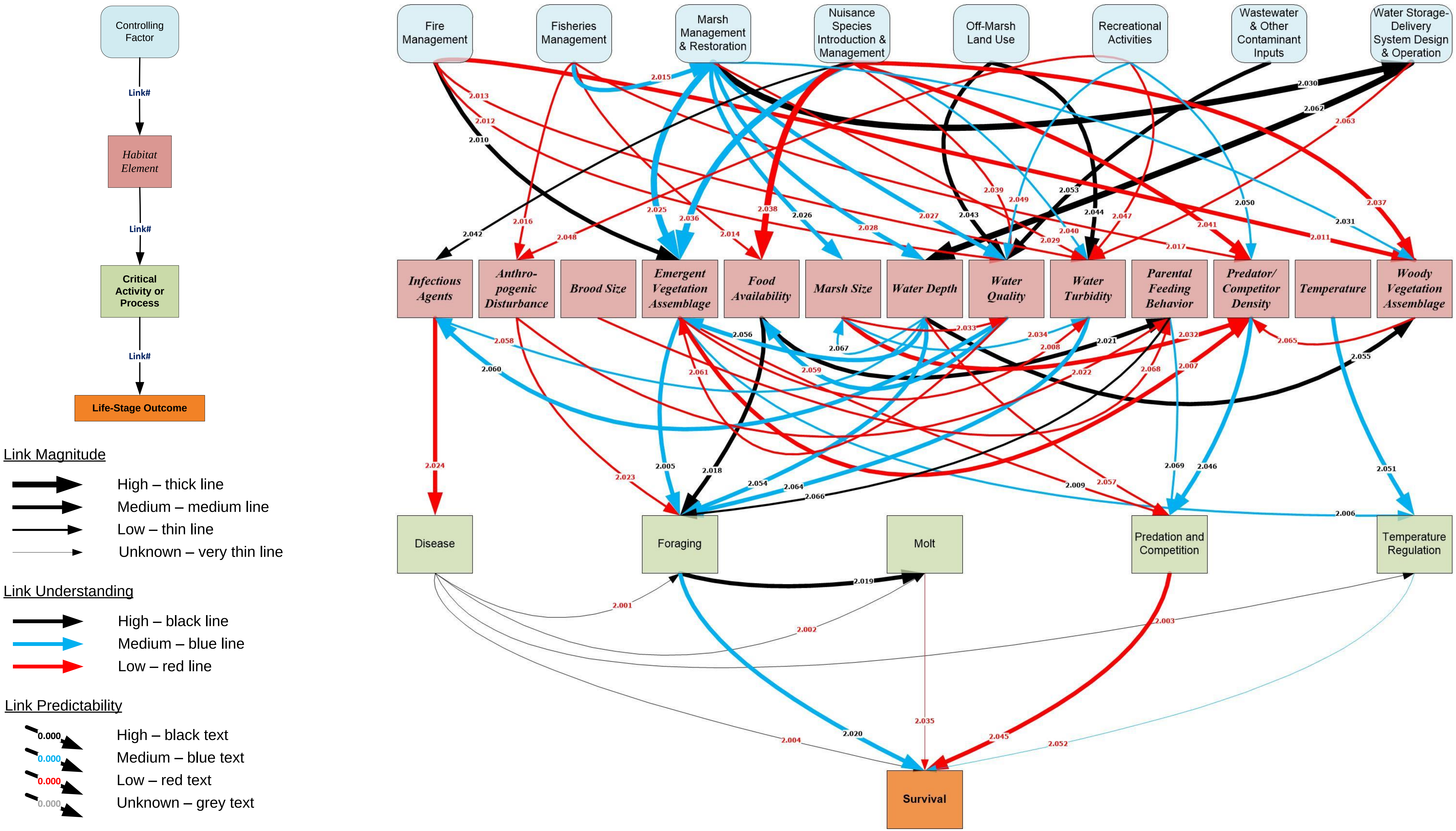

Figure 5.—LEBI life stage 2 – juvenile, basic CEM diagram.

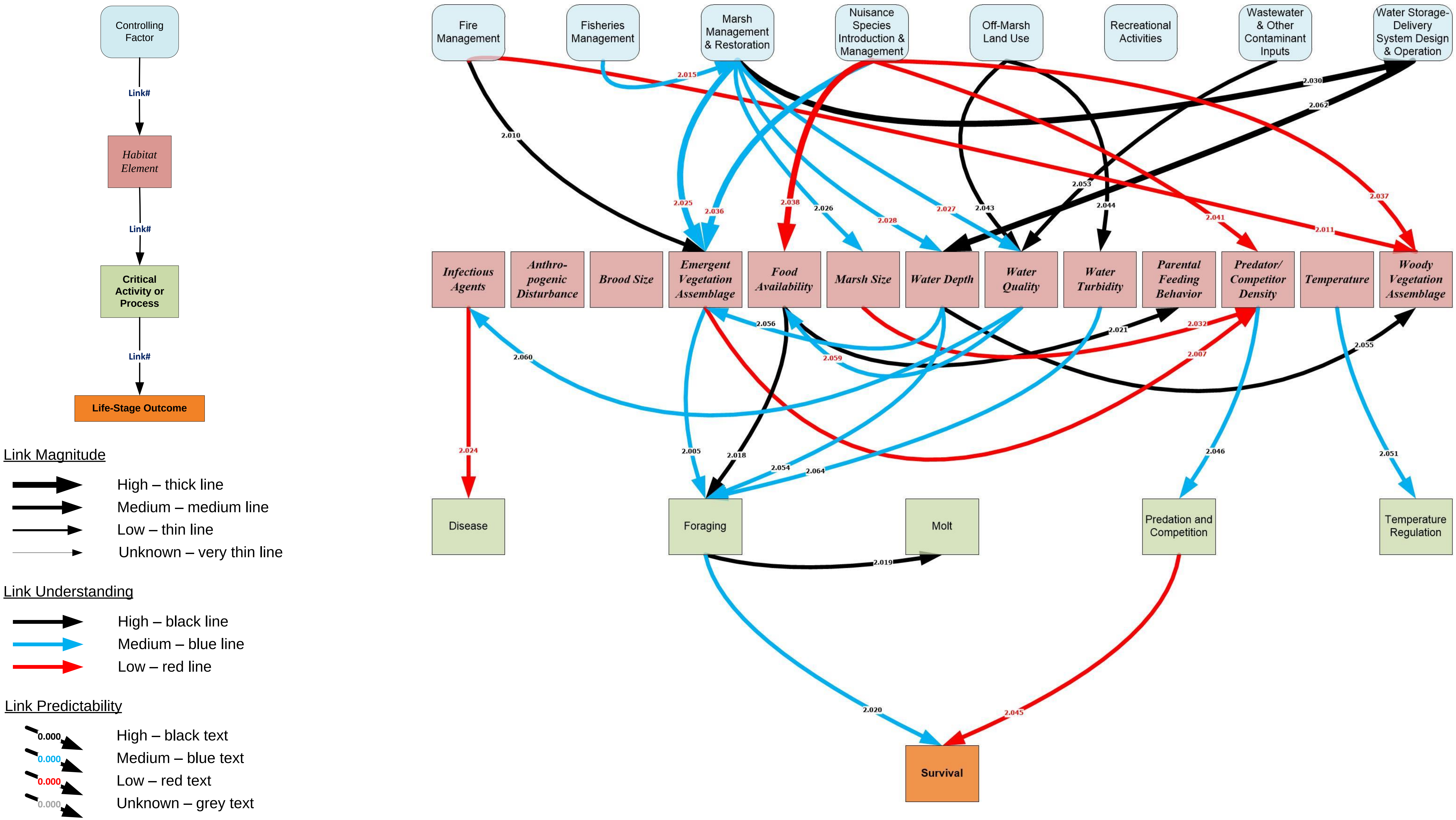

Figure 6.—LEBI life stage 2 – juvenile, high- and medium-magnitude relationships.

LEBI LIFE STAGE 3 – OVERWINTERING INDIVIDUAL

The overwintering individual stage refers to those birds that remain in LCR marsh habitats over the winter months. They may be juveniles that remain for the winter, year-round resident least bitterns, or overwintering LEBI that come from elsewhere. Success during this life (population) stage – successful transition to the next stage – involves organism survival. The organisms actively interact with their environment. Critical biological activities and processes therefore again consist of both activities and processes.

The CEM (figures 7 and 8) recognizes four (of eight) critical biological activities and processes for this life stage. Eating, molt, nest attendance, and nest site selection are not included, as they pertain to other life stages. The critical biological processes and activities are presented here, ordered as they appear on the following figures:

1. **Disease** – Although the literature does not emphasize disease as affecting population levels of LEBI, we still feel that disease bears mentioning. Because it has been so rarely studied at the LCR, there is no information on the magnitude of the effect.

   The CEM recognizes infectious agents as a habitat element directly affecting disease transmission.

   The CEM recognizes water depth and water quality via infectious agents as habitat elements indirectly affecting disease transmission.

2. **Foraging** – The overwintering individual must forage to feed itself.

   The CEM recognizes disease as the main critical biological activity and process as directly affecting foraging.

   The CEM recognizes anthropogenic disturbance, the emergent vegetation assemblage (LEBI use reeds for perching sites and foraging platforms; vegetation also provides camouflage), food availability, water depth, and water turbidity as habitat elements directly affecting foraging.

   The CEM recognizes water quality (via the food availability) as a habitat element indirectly affecting foraging.

3. **Predation and Competition** – Avoiding predation and/or intense competition helps ensure that an individual will survive to the next life stage.

   The CEM recognizes the emergent vegetation assemblage that provides protective cover, predator/competitor density, and water depth (which affects access to the nest) as habitat elements directly affecting predation and competition.

   The CEM recognizes marsh size and woody vegetation assemblage as habitat elements indirectly affecting predator/competitor density and, hence, predation and competition.

4. **Temperature Regulation** – The overwintering individual must avoid thermal stress and maintain an optimal temperature to survive.

   The CEM recognizes disease as the main critical biological activity and process as directly affecting temperature regulation.

   The CEM recognizes the emergent vegetation assemblage and temperature as habitat elements directly affecting temperature regulation.

   The CEM recognizes water depth and water quality via the emergent vegetation assemblage as habitat elements indirectly affecting temperature regulation.

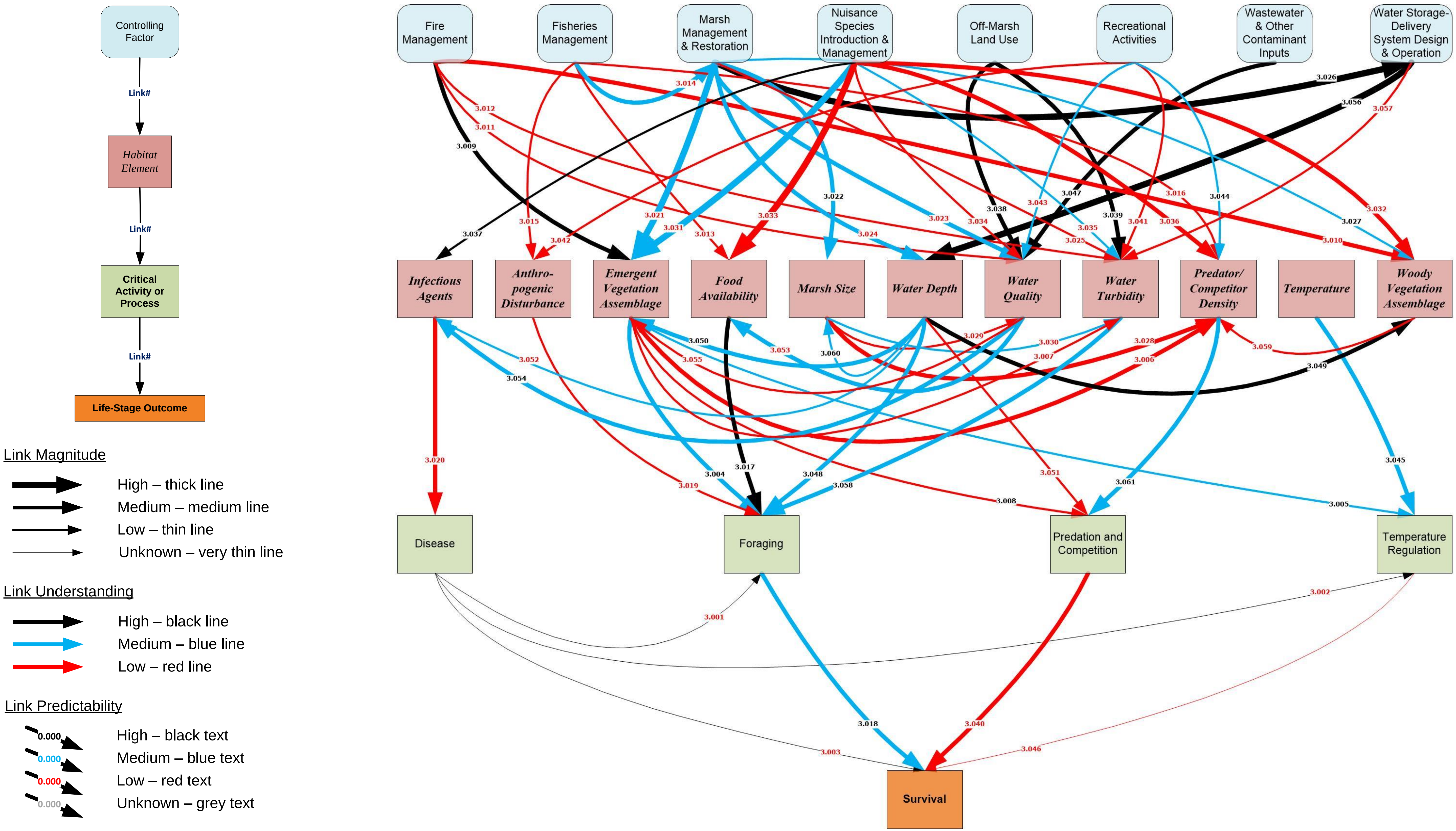

Figure 7.—LEBI life stage 3 – overwintering individual, basic CEM diagram.

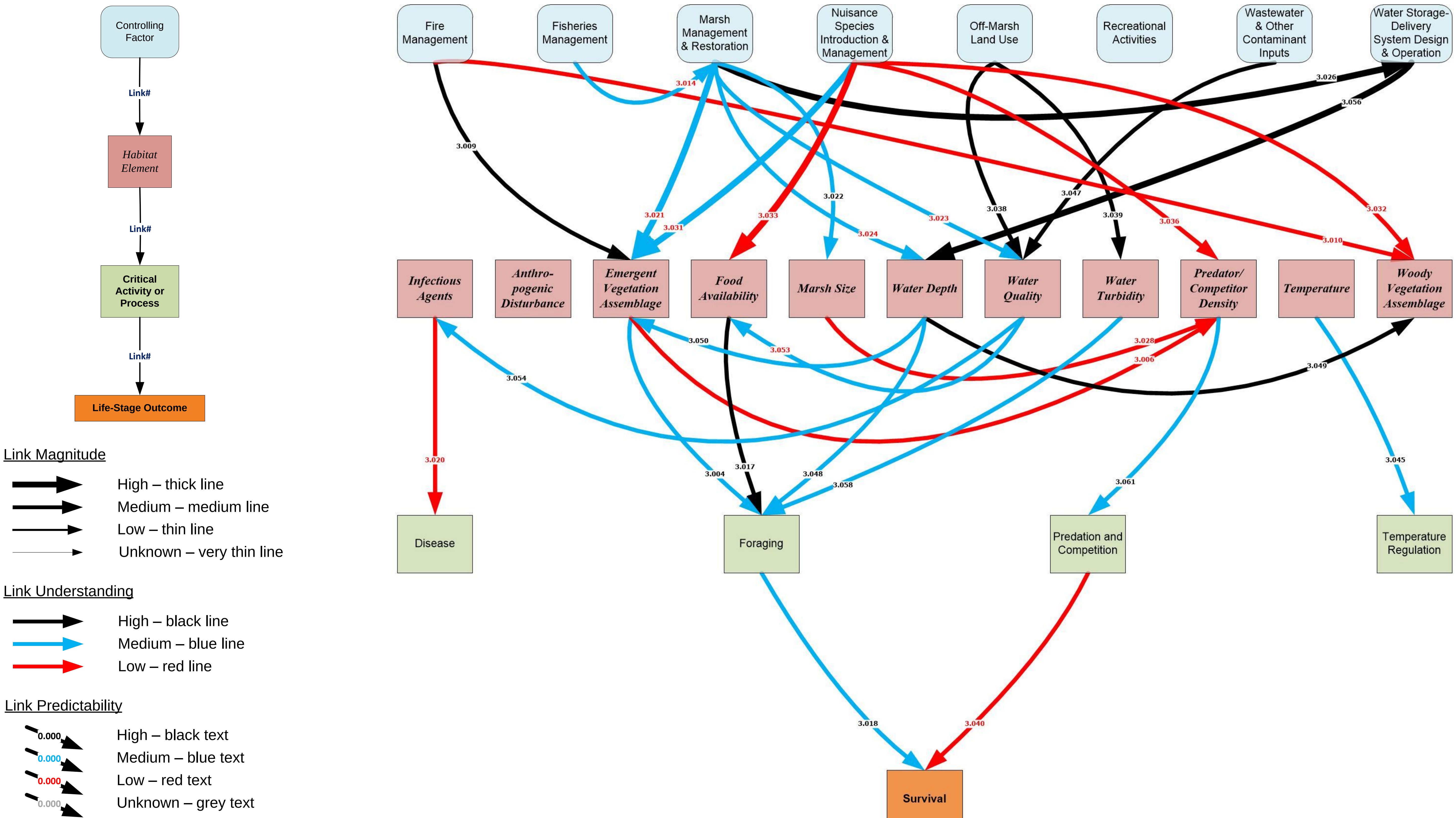

Figure 8.—LEBI life stage 3 – overwintering individual, high- and medium-magnitude relationships.

LEBI LIFE STAGE 4 – BREEDING ADULT

The breeding adult stage begins when the bird returns to its breeding grounds after its first winter or begins pair bonding and territory establishment in the case of residential birds. Success during this life stage – successful transition to the next stage – involves organism survival and breeding. The organisms actively interact with their environment. Critical biological activities and processes therefore again consist of both activities and processes.

The CEM (figures 9 and 10) recognizes seven (of eight) critical biological activities and processes for this life stage. Eating is not included, as it is part of the nest life stage. The critical biological activities and processes are presented here, ordered as they appear on the following figures:

1. **Disease** – Although the literature does not emphasize disease as affecting population levels of LEBI, we still feel that disease bears mentioning. Because it has been so rarely studied along the LCR, there is no information on the magnitude of the effect.

   The CEM recognizes infectious agents as a habitat element directly affecting disease. Because LEBI typically nest in relatively low densities, density of conspecifics has not been included as a habitat element link to disease in the model.

   The CEM recognizes water depth and water quality via infectious agents as habitat elements indirectly affecting disease transmission.

2. **Foraging** – The breeding adult must forage to feed itself and its young.

   The CEM recognizes disease as the main critical biological activity and process as directly affecting foraging.

   The CEM recognizes anthropogenic disturbance, the emergent vegetation assemblage (LEBI use reeds for perching sites and foraging platforms; vegetation also provides camouflage), food availability, water depth, and water turbidity as habitat elements directly affecting foraging.

   The CEM recognizes water quality (via the food availability) as a habitat element indirectly affecting foraging.

3. **Molt** – Breeding adults must complete an annual post-nuptial molt. This transition relies in part on successful foraging for energy-rich food.

   The CEM recognizes disease as the critical biological activity and process as directly affecting molt.

   The CEM recognizes anthropogenic disturbance, the emergent vegetation assemblage, food availability, water depth, and water turbidity, which all affect molt via foraging success, as habitat elements indirectly affecting molt. Molt, in turn, affects survival.

4. **Nest Attendance** – The breeding adult must build and attend to the nest to incubate eggs and to brood and feed young.

   The CEM recognizes disease and foraging as the critical biological processes and activities that directly affect parental care. Nest attendance, in turn, affects reproductive output.

   The CEM recognizes brood size (number of young in the nest that the parent must rear), anthropogenic disturbance, the predator/competitor density, and temperature as the habitat elements that directly affect nest attendance.

   The CEM recognizes anthropogenic disturbance, the emergent vegetation assemblage, food availability, water depth, and water turbidity via effects on foraging as the habitat elements that indirectly affect nest attendance.

5. **Nest Site Selection** – The breeding adult must choose where to place the nest, thereby affecting breeding success.

   The CEM recognizes the density of conspecifics (presence of other bitterns in the marsh), the emergent vegetation assemblage, food availability, predator/competitor density, temperature, water depth, and the woody species assemblage as habitat elements directly affecting nest site selection.

   The CEM recognizes anthropogenic disturbance via the density of conspecifics and marsh size, via the density of conspecifics and water quality's effects on food availability, as habitat elements indirectly affecting nest site selection.

6. **Predation and Competition** – Avoiding predation and/or competition helps ensure that an individual will survive to the next life stage.

   The CEM recognizes the emergent vegetation assemblage that provides cover, predator/competitor density, and water depth (which affects nest access to terrestrial predators) as habitat elements directly affecting predation and competition.

   The CEM recognizes marsh size and the woody species assemblage via predator/competitor density as habitat elements indirectly affecting predation and competition.

7. **Temperature Regulation –** The breeding adult must avoid thermal stress and maintain an optimum temperature to survive.

   The CEM recognizes disease and nest site selection as critical biological processes and activities directly affecting temperature regulation.

   The CEM recognizes the emergent vegetation assemblage and temperature as habitat elements directly affecting temperature regulation.

   The CEM recognizes infectious agents via disease and water depth and water quality via the emergent vegetation assemblage as habitat elements indirectly affecting temperature regulation.

The habitat elements that most strongly affect all life-stage outcomes through their cumulative effects across all critical biological activities and processes include the optimal combination of the emergent vegetation assemblage, food availability, and water depth.

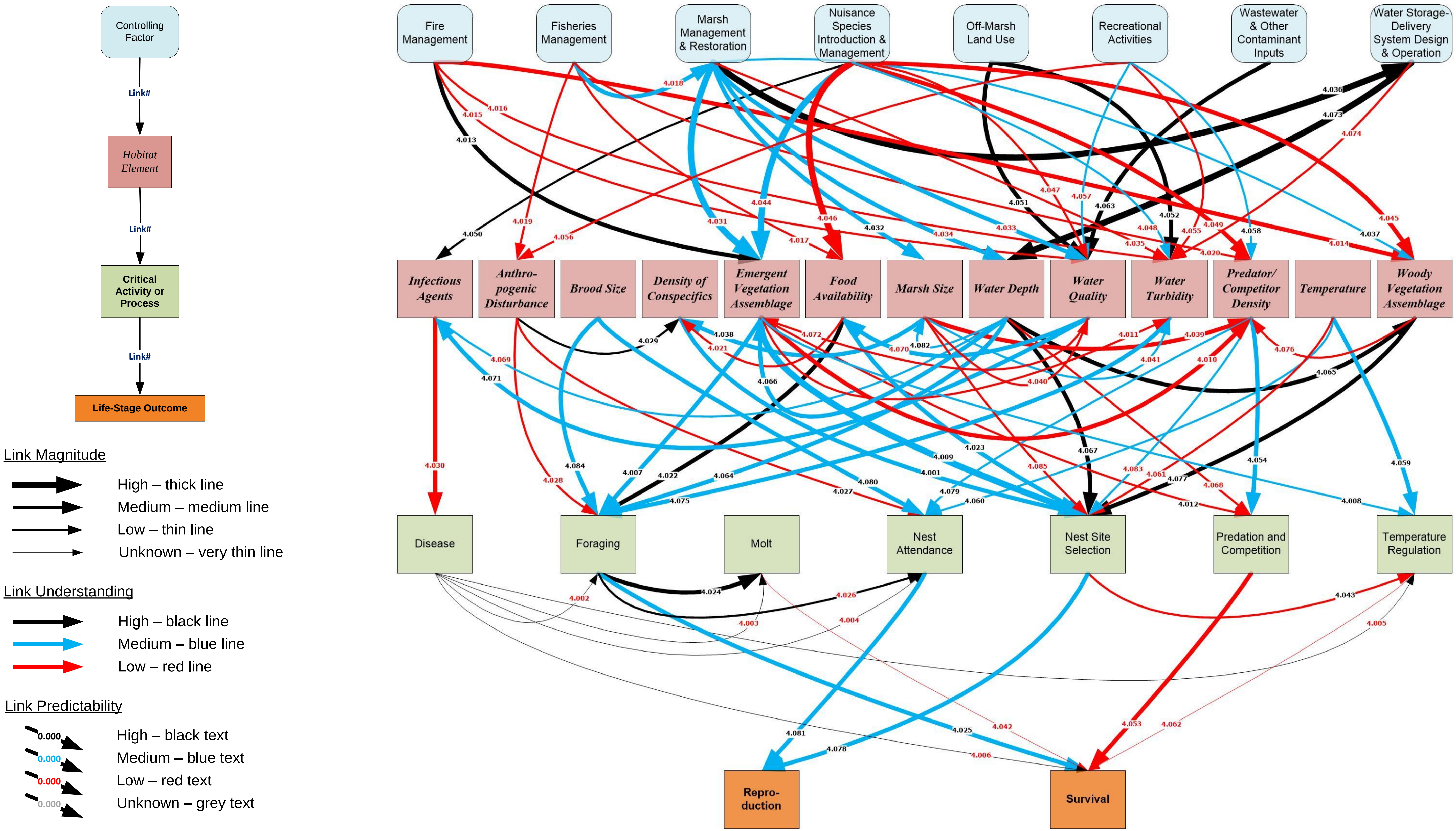

Figure 9.—LEBI life stage 4 – breeding adult, basic CEM diagram.

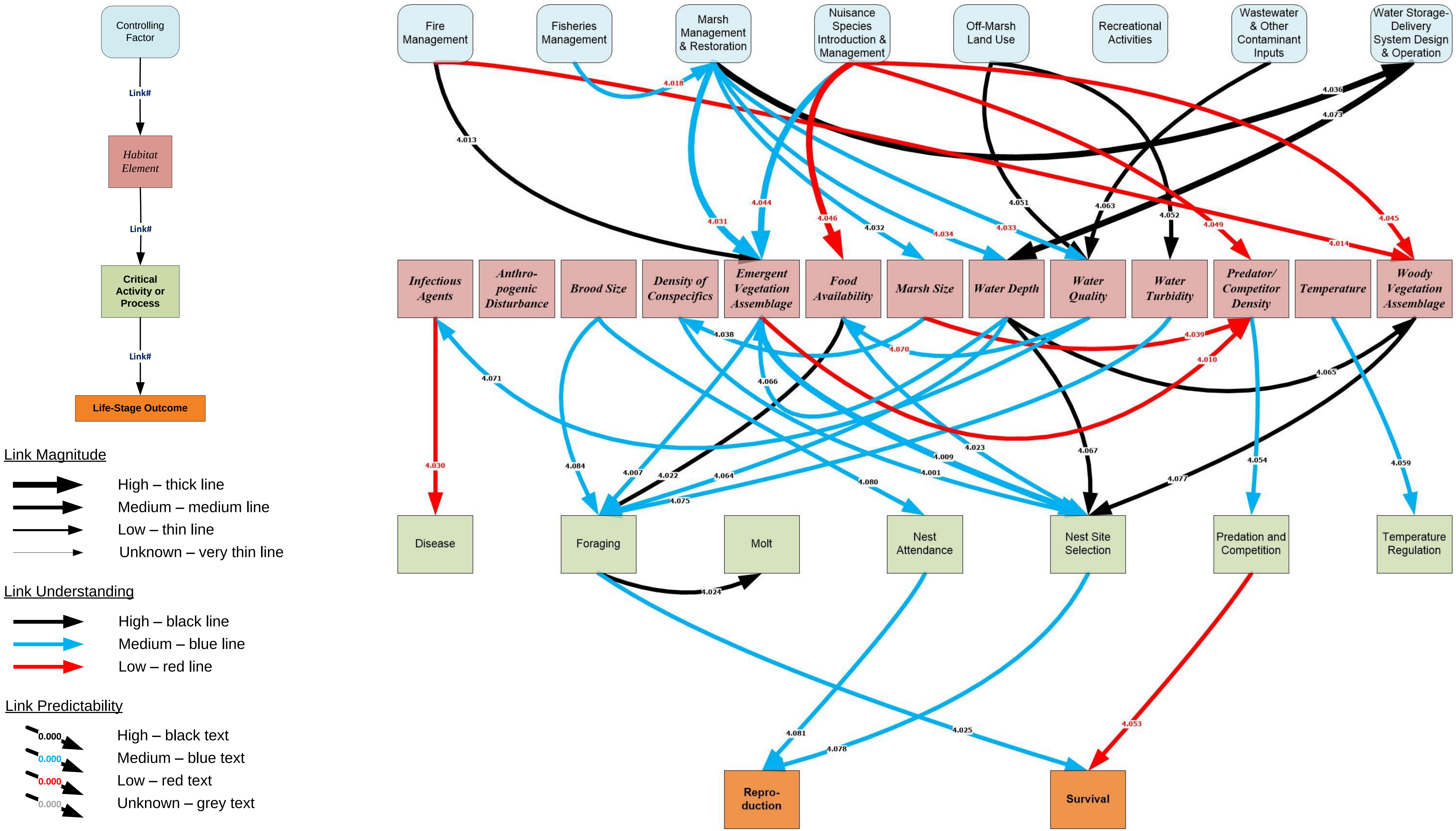

Figure 10.—LEBI life stage 4 – breeding adult, high- and medium magnitude relationships.

Chapter 7 –Causal Relationships Across All Life Stages

The eight 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 8 controlling factors on the 15 habitat elements. The structure of table 5 is the same as for table 4, but table 5 shows the magnitudes of the relationships instead of just their presence/absence. The paragraphs following the table discuss the relative effects of the different controlling factors on each habitat element. The magnitudes of direct influences of controlling factors on habitat elements is color coded in the table as follows:

High = H, Medium = M, Low = L

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

Controlling factor ➔ / **Habitat element affected ➔**	**Fire management**	**Fisheries management**	**Marsh management and restoration**	**Nuisance species introduction and management**	**Off-marsh land use**	**Recreational activities**	**Wastewater and other contaminant inputs**	**Water storage-delivery system design and operation**
Anthropogenic disturbance		L				L		
Brood size	N/A*							
Density of conspecifics	N/A*							
Emergent vegetation assemblage	M		H	H				
Food availability		L		H				
Infectious agents				L				
Marsh size			M					
Parental feeding behavior	N/A*							
Parental nest attendance	N/A*							
Predator/competitor density		L		M		L		
Temperature	N/A*							
Water depth			M					H
Water quality	L		M	L	M	L	M	
Water turbidity	L		L	L	M	L		L
Woody vegetation assemblage	M		L	M				

* N/A values suggest that none of the identified controlling factors *directly* affect the habitat element. Controlling factors affect brood size, density of conspecifics, parental feeding behavior, and parental nest attendance *indirectly*. Temperature is determined by regional climate and weather conditions at a site.

ANTHROPOGENIC DISTURBANCE

This habitat element is directly affected by the controlling factors of fisheries management and recreational activities. The effects of each depend on the management or monitoring activity and its timing and duration. For the purposes of this model, effects are considered to be short term and of relatively low impact.

DENSITY OF CONSPECIFICS

There are no controlling factors that affect the density of conspecifics directly. The density of LEBI in a marsh is related to the quality of the habitat. Some controlling factors, such as fisheries management, marsh management and restoration, and nuisance species introduction and management, will work indirectly by affecting the food availability and marsh size, in turn determining the density of LEBI and brood size. Certain recreational activities, if any, could increase anthropogenic disturbance, affecting LEBI use of a marsh (hence, density). The effect is during the nesting season at the marsh scale.

EMERGENT VEGETATION ASSEMBLAGE

The controlling factors that directly affect the emergent vegetation assemblage include fire management, marsh management and restoration, and nuisance species introduction and management.

Fire management, where decadent vegetation is burned off, will affect the vegetation structure directly and could significantly affect habitat use by LEBI. Least bitterns often use old nests and dead vegetation to construct their nests each year.

Marsh management and restoration (a direct effect) and water storage-delivery system design and operation (an indirect effect via water depth) can have large, long-term effects on the emergent vegetation assemblage, as these activities can drastically alter water levels and the configuration of the habitat for the long term. Too much water over a long time period will flood emergent vegetation and kill plants. Conversely, if a marsh is drained and the soil dries out, vegetation will not survive.

Nuisance species introduction and management also will have an effect on vegetation. In most cases, removal of non-native invasive species will enhance the quality of the emergent vegetation assemblage, although there may be a lag time depending on what management techniques are applied (vegetation removal alone or paired with native vegetation planting). (Note: LEBI have used common reed for nesting where native vegetation is not available [Sterling 2008].)

Indirectly, fisheries management, off-marsh land use, and wastewater and other contaminant input, can have modest effects through nutrient or pollutant inputs that alter water quality and affect plant growth.

FOOD AVAILABILITY

This habitat element is directly affected by fisheries management and nuisance species introduction and management and indirectly by fire management (via water quality and/or water turbidity), off-marsh land use, wastewater and other contaminant inputs, and water storage-delivery system design and operation (via water depth). Effects on food availability are usually relatively short-lived, affecting productivity during the nesting or overwintering season and at the marsh level.

INFECTIOUS AGENTS

Nuisance species introduction and management has a direct effect on infectious agents in a marsh system; however, the effects depend on the pathogen and scale of introduction. Otherwise, other controlling factors may affect infectious agents indirectly via their impacts on water depth or water quality. Water depth is a critical factor in the production of mosquitoes and may contribute to the transmission of infectious agents such as WNV.

MARSH SIZE

Marsh size is directly affected by marsh management and restoration activities that alter the shape and/or contour of the wetland. These effects will be constrained somewhat by the underlying hydrology and geology, but effects can be long lasting. Additionally, water storage-delivery system design and operations that either flood or drain water away from the wetland will also strongly affect the size of a marsh system via changes in water depth. Fringing marshes in impoundments will be more closely linked to such water delivery operations.

PREDATOR/COMPETITOR DENSITY

Predator/competitor density is directly affected by fisheries management activities, nuisance species introduction and management, and recreational activities.

Although effects are at the site level, fisheries management and nuisance species introduction and management can result in long-term changes, as introduced species can persist in the landscape.

Certain recreational uses may attract predators/competitors via garbage or feeding of animals such as nest predators (e.g., raccoons), but these effects will be short term.

Predator/competitor density is indirectly affected by water storage-delivery system design and operation that alters the amount of water present in a marsh. Lower water levels may make nests more accessible to terrestrial mammalian predators. Woody vegetation that serves as potential avian predator perches is also affected by water levels in that higher water levels or long-term flooding would remove woody vegetation.

WATER DEPTH

Water depth is directly and largely controlled by marsh management and restoration activities, which change the contour of a wetland by deepening pools or otherwise altering wetland size and shape, and water storage-delivery system design and operation.

Marsh management occurs at the site level, whereas water storage-delivery system design and operation can affect large areas, but for either, effects can be long term.

The effects of other controlling factors on water depth (fire management, fisheries management, nuisance species introduction and management, off-marsh land use, and recreational activities) are unknown.

WATER QUALITY

Water quality is affected directly by a number of controlling factors, including fire management, marsh management and restoration, off-marsh land use, nuisance species introduction and management, recreational activities, and wastewater and other contaminant inputs

Fire management may affect water quality by release of soluble and insoluble materials into water after a burn, although the effect is usually short lived.

Marsh management and restoration may have short-term effects via sedimentation or long-term effects if stored toxins are released.

Runoff from off-marsh land use and wastewater and other contaminant inputs greatly affect water quality. The effects will be at the site level but can last for years.

Nuisance species introduction and management may also affect water quality, for example, if golden algae become established in the system.

Recreational activities, such as extensive motor boat use, could also adversely impact water quality; however, the effects at the marsh level may not last.

WATER TURBIDITY

Water turbidity is affected directly by fire management, marsh management and restoration, nuisance species introduction and management, off-marsh land use, recreational activities, and water storage-delivery system design and operation.

Fire management may affect water turbidity by the release of soluble and insoluble material into water after a burn, and the impact of increased sedimentation from runoff and eutrophication and excessive algal growth will reduce visibility in a wetland. These effects occur at the site level and are usually short term.

Marsh management and restoration could also increase water turbidity if extensive pond excavation were undertaken, but the effects would be short term.

Nuisance and invasive species such as zebra or quagga mussels may reduce water turbidity by their filtering activity, as would water storage-delivery design and operation diversions downstream from dams that retain sediment, and these effects could be long term.

Off-marsh management resulting in erosion and runoff into a marsh can increase water turbitity, but the effects would likely be short term.

Recreational boating activity in a wetland or the presence of non-native species such as carp can stir up sediments, increasing turbidity, but the effects are short term.

WOODY VEGETATION ASSEMBLAGE

The woody vegetation assemblage is affected directly by the controlling factors of fire management, marsh management and restoration, and nuisance species introduction and management.

The woody vegetation assemblage can be directly affected by fire management activities that are hot enough to remove shrubs and trees in addition to decadent marsh vegetation.

Marsh management and restoration and nuisance species introduction and management that incorporate woody vegetation removal or planting would also directly affect the woody vegetation assemblage depending on the activity. The effects could be long term if management is ongoing.

Chapter 8 – Discussion and Conclusions

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

MOST INFLUENTIAL ACTIVITIES AND PROCESSES ACROSS ALL LIFE STAGES

Figure 11 identifies the critical biological activities and processes that this assessment found most strongly directly or indirectly affect the success of each life stage (high or medium magnitude). The findings presented in this diagram may be summarized as follows:

- Eating, foraging, and predation and competition are the most important critical biological activities and processes affecting survival of LEBI at all life stages. Although predation is ever-present, gaps in knowledge about predation rates and the importance of competition to LEBI remain. Other processes, such as disease, molt, and temperature regulation 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 at all life stages. For example, good nest sites may have more food, few predators, and few diseases present.

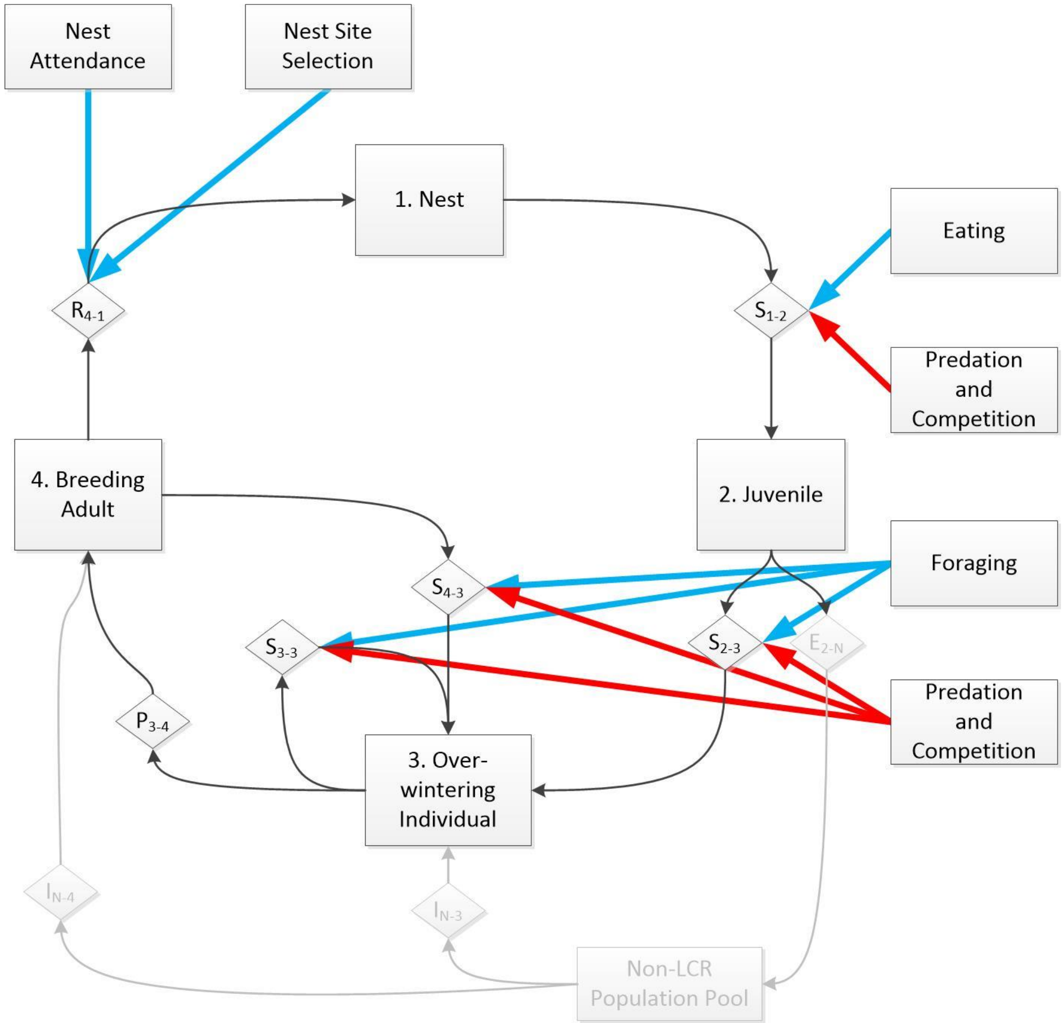

Figure 11.—Most influential biological activities and processes affecting each life stage of LEBI. Only elements with high- or medium-magnitude connections are presented. The legend is provided on figure 2.

POTENTIALLY PIVOTAL ALTERATIONS TO HABITAT ELEMENTS

Figure 12 identifies the habitat elements that this assessment indicates most strongly directly or indirectly affect the critical biological activities and processes identified on figure 11 across all life stages (high or medium magnitude). The findings presented in this diagram may be summarized as follows:

- The habitat elements that most influenced biological activities and processes and LEBI breeding success were the emergent vegetation assemblage and water depth.

- The link magnitude for infectious agents was strong, but this is a reflection of the direct connection between the presence of disease-causing organisms and disease. However, little is known about disease overall as a critical process at the LCR system.

- Other habitat elements were also important, but the species composition and arrangement of vegetation with open water on a marsh is critical. Creating these conditions in marsh restoration and construction activities is the best way to provide for LEBI along the LCR.

- Marsh management and restoration, along with nuisance species introduction and management, are the controlling factors affecting the most habitat elements and critical biological activities and processes of LEBI, whether directly or indirectly. Linked closely to marsh management in particular is water storage-delivery system design and operation.

- Runoff from off-marsh land use and wastewater and other contaminant inputs also strongly affect the emergent vegetation assemblage and food availability via changes to water quality.

- Although fire management did not rank quite as high, it is also an important activity, especially given the interest in modifying and creating marsh habitat for the Yuma clapper rail, a bird with habitat preferences diametrically opposed to LEBI.

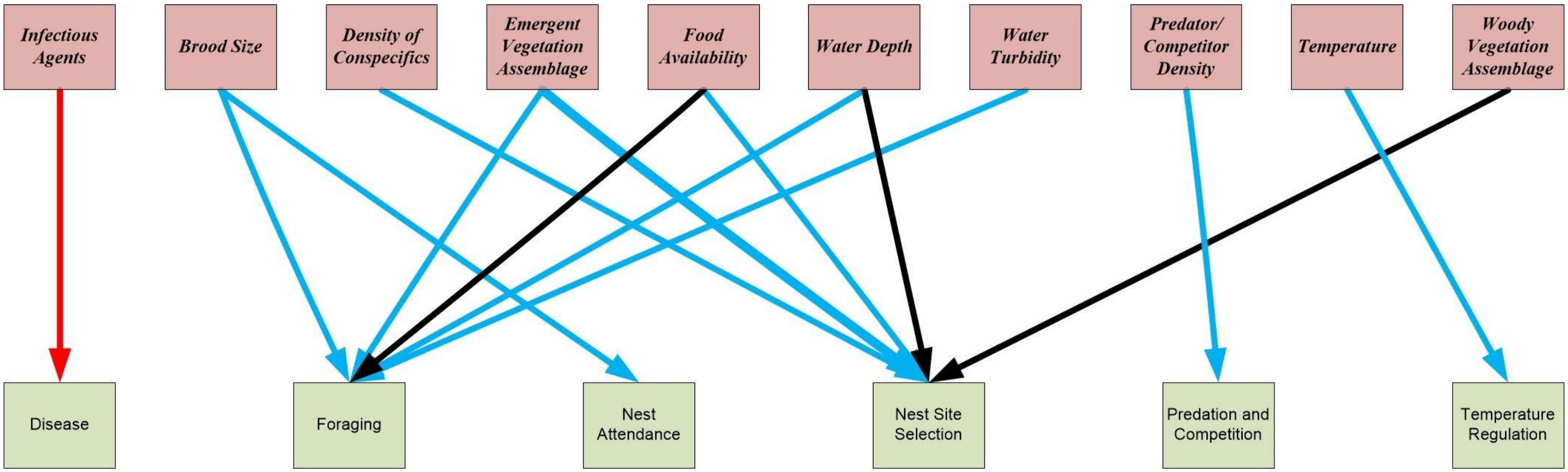

Figure 12.—Habitat elements that directly or indirectly affect the most influential biological activities and processes across all life stages of LEBI. The legend is provided on figure 2.

GAPS IN UNDERSTANDING

Figures 11 and 12 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. In gathering information for this CEM, it became apparent that there are many knowledge gaps when it comes to LEBI. The two figures show large numbers of blue and red arrows, indicating relationships that the assessment identifies as having a low or medium level of scientific understanding. Each of these arrows identifies a causal relationship that may warrant further field, laboratory, or literature investigation.

Many of these gaps in understanding have been mentioned by others (Reclamation 2008). Some of these are related to basic biology and life history; others are specific to life along the LCR. For example:

- Disease can affect most critical biological activities and processes, yet the effects of disease on LEBI along the LCR are unknown, as are the infectious agents that may be present.

- Predation rates on LEBI along the LCR are unknown, as are the effects of other management activities on predator/competitor density.

- There are many management activities occurring along the LCR that could potentially affect LEBI habit; in particular, fire management's effects not only on the emergent vegetation assemblage but also on water quality and water turbidity. This is especially important given plans for prescribed fire management for Yuma clapper rail using the same marsh systems.

- Fisheries management and monitoring activities should also be evaluated for impacts during the LEBI breeding season.

- Nuisance species introduction and management also deserve a closer look to better understand the effects of either species introductions and/or control efforts to eradicate other pests of LEBI and its habitat.

- Overwintering ecology remains unknown. What habitats are overwintering LEBI using along the LCR? Is there a critical marsh size for overwintering (versus larger marshes that are important for breeding)?

- Additional research is needed to determine the effects of high selenium levels on LEBI productivity over the long term. Are there other toxins present in the system that could become problematic?

- How do changes in water quality affect LEBI prey species in LCR marshes? Although prey species diversity may change, is productivity sufficient to sustain populations?

- What impact does recreation have on breeding and/or use of overwintering habitats at the LCR? How sensitive are bitterns along the LCR to anthropogenic disturbance?

- LEBI reports from elsewhere have noted offsite mortality due to collisions with cars or with barbed wire fencing, for example. Do these types of events occur with any regularity on lands adjacent to LCR wetlands?

- LEBI are highly secretive birds, and actual population estimates for this species are lacking along the LCR. Research into detection probabilities for LEBI may aid in determining population estimates from existing data. New research to determine LEBI abundance in certain key habitats and LCR areas would improve our understanding of bittern use of the river and adjoining habitats.

This list of uncertainties is not meant to be exhaustive but only to highlight topics the literature identifies as potentially pivotal to LEBI recruitment along the LCR and to identify important 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), Wildhaber (2011), Kondolf et al. (2008), and Burke et al. (2009) for a more hierarchical approach and adds explicit demographic notation for the characterization of life-stage outcomes (McDonald and Caswell 1993). This expanded approach provides greater detail on causal linkages and outcomes. The expansion specifically calls for identifying **four** types of model components for each life stage, and the causal linkages among them, as follows:

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

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

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

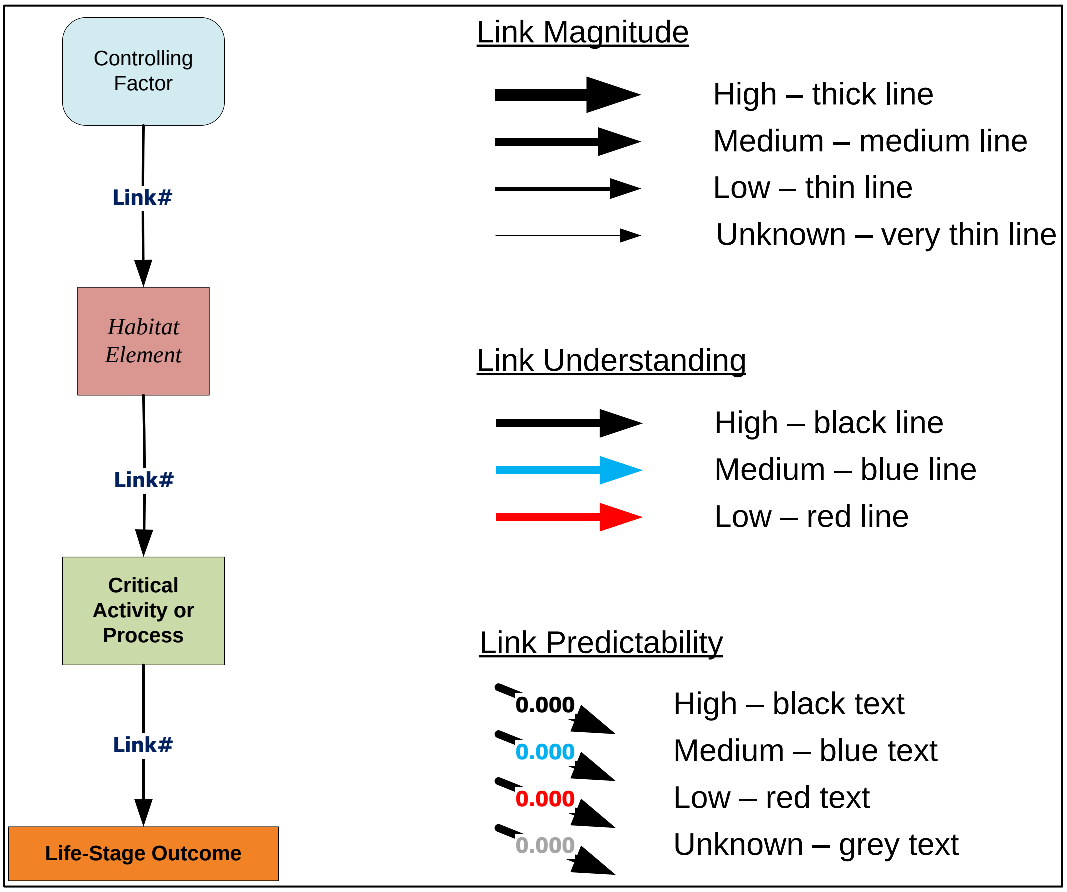

Figure 1-1.—Conventions for displaying cause and effect nodes, linkages, link magnitude, link understanding, and link predictability.

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ATTACHMENT 2

Least Bittern Habitat Data

Table 2-1.—Least bittern habitat data

Habitat element	Value or range	Location	Reference
Anthropogenic disturbance	No quantifiable values found in literature.		
Density of conspecifics	Least bittern solitary nesters, with nest density < 1 per hectare (ha).	Lower Colorado River; rangewide	Rosenberg et al. 1991; Gibbs et al. 2009
	If large marsh with good food resources, then nests can be 10 meters apart (15 nests per ha) or less.	Iowa, Florida	Weller 1961; Kushlan 1973; Gibbs et al. 2009
Emergent vegetation assemblage	*Typha* spp., *Scirpus* spp., and *Carex* spp. dominant vegetation, also *Sagittaria* spp. or *Myriscus* spp.; nests in clumps of vegetation at least 2 meters high.	Rangewide	Palmer 1962; Gibbs et al. 2009
	Nest sites predominantly cattail (*Typha* spp.)or bulrush (Cyperaceae).	Lower Colorado River	Rosenberg et al. 1991; BIO-WEST, Inc. 2005; Corman 2005.
	Marsh structural type 1, 2, 3, and 5.	Lower Colorado River	Anderson and Ohmart 1976 *in* BIO-WEST, Inc. 2005
	Hemimarsh configuration – half open water, half dense vegetation.	Iowa	Weller and Spatcher 1965 *in* Gibbs et al. 2009
	Distance between nest and open water < 10 meters.		Gibbs et al. 2009
	Distance between nest and open water 6 inches – 20 feet with average 8 feet (approximately 2.4 meters).	Iowa	Weller 1961
	No values provided on vegetation height or density.		
Food availability	Species lists available.	Rangewide	Gibbs et al. 2009
Infectious agents	No quantifiable values found in literature.		
Marsh size	> 5 acres.	Iowa	Brown and Dinsmore 1986
	> 10 ha optimal.	Rangewide	Gibbs et al. 2009
	0.4 ha.	Maine	Gibbs and Melvin 1990 *in* Gibbs et al. 2009
	Rarely use small marshes or narrow strips of cattails at water's edge.	Ohio	Peterjohn and Rice 1991
	Nested in patches of *Typha* sp. 37 x 4 meters wide; 76 x 15 meters wide.	California	Sterling 2008

Table 2-1.—Least bittern habitat data

Habitat element	Value or range	Location	Reference
Predator/competitor density	Species list available.	Rangewide	
Temperature	No quantifiable values in the literature.		
Water depth at nest	25–60 centimeters deep.	Rangewide	Gibbs et al. 2009 and references therein
	8–96 centimeters deep.	Iowa	Weller 1961
Water quality	High salinity levels may affect vegetation composition (e.g., cattail cannot survive > 30 parts per thousand).	Lower Colorado River	Garnett 2012
Water turbidity	No quantifiable values found in literature.		
Woody vegetation assemblage	Only scattered shrubs or woody vegetation in marshes used for breeding; no values for shrub density found in literature.	Rangewide	Gibbs et al. 2009

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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