Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

Sonoran Yellow Warbler (*Setophaga petechia sonorana*) (YWAR) Basic Conceptual Ecological Model for the Lower Colorado River

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July 2015

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Lower Colorado River Multi-Species Conservation Program

Sonoran Yellow Warbler (*Setophaga petechia sonorana*) (YWAR) Basic Conceptual Ecological Model for the Lower Colorado River

Prepared by:

Christopher J.W. McClure, Ph.D. and Robert Unnasch, Ph.D.

Sound Science, LLC

Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

July 2015

McClure, C.J.W. and R. Unnasch. 2015. Sonoran Yellow Warbler (*Setophaga petechia sonorana*) (YWAR) Basic Conceptual Ecological Model for the Lower Colorado River. Submitted to the Bureau of Reclamation, Boulder City, Nevada, by Sound Science, LLC, Boise, Idaho.

ACRONYMS AND ABBREVIATIONS

CEM	conceptual ecological model
CI	confidence interval
DBH	diameter at breast height
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LiDAR	light detection and ranging
Reclamation	Bureau of Reclamation
SE	standard error
U.S.	United States
USFWS	U.S. Fish and Wildlife Service
YWAR	Sonoran yellow warbler (*Setophaga petechia sonorana*)

Symbols

>	greater than
≥	greater than or equal to
<	less than
%	percent

Definitions

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

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

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

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

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

CONTENTS

Page

Foreword ... v

Executive Summary ... ES-1
Conceptual Ecological Models ... ES-1
Conceptual Ecological Model Structure ... ES-2
Results ... ES-4

Chapter 1 – Introduction ... 1
Sonoran Yellow Warbler Reproductive Ecology ... 1
Conceptual Ecological Model Purposes ... 2
Conceptual Ecological Model Structure for the YWAR ... 3

Chapter 2 – YWAR Life Stage Model ... 7
Introduction to the YWAR Life Cycle ... 7
YWAR Life Stage 1 – Nest ... 8
YWAR Life Stage 2 – Juvenile ... 8
YWAR Life Stage 3 – Breeding Adult ... 8
Life Stage Model Summary ... 9

Chapter 3 – Critical Biological Activities and Processes ... 11
Disease ... 12
Eating ... 12
Foraging ... 12
Molt ... 13
Nest Attendance ... 13
Nest Predation and Brood Parasitism ... 13
Nest Site Selection ... 14
Predation ... 15
Temperature Regulation ... 15

Chapter 4 – Habitat Elements ... 17
Anthropogenic Disturbance ... 19
Brood Size ... 19
Canopy Closure ... 19
Community Type ... 20
Food Availability ... 20
Genetic Diversity and Infectious Agents ... 21
Humidity ... 22
Intermediate Structure ... 22
Local Hydrology ... 23
Matrix Community ... 23
Nest Predator and Cowbird Density ... 24

Page

Parental Feeding Behavior 24
Parental Nest Attendance 24
Patch Size 25
Predator Density 25
Temperature 25
Tree Density 26

Chapter 5 – Controlling Factors 27
Fire Management 28
Grazing 28
Mechanical Thinning 28
Natural Thinning 29
Nuisance Species Introduction and Management 29
Pesticide/Herbicide Application 30
Planting Regime 30
Recreational Activities 30
Water Storage-Delivery System Design and Operation 31

Chapter 6 – Conceptual Ecological Model by Life Stage 33
YWAR Life Stage 1 – Nest 36
YWAR Life Stage 2 – Juvenile 43
YWAR Life Stage 3 – Breeding Adult 49

Chapter 7 – Causal Relationships Across All Life Stages 55
Anthropogenic Disturbance 56
Canopy Closure 56
Community Type 57
Food Availability 58
Intermediate Structure 58
Local Hydrology 59
Matrix Community 60
Nest Predator and Cowbird Density 60
Patch Size 61
Predator Density 61
Tree Density 62

Chapter 8 – Discussion and Conclusions 63
Most Influential Activities and Processes Across All Life Stages 63
Potentially Pivotal Alterations to Habitat Elements 64
Gaps in Understanding 65

Literature Cited 69

Acknowledgments 79

Tables

Table Page

ES-1 Outcomes of each of the three life stages of YWAR 3
1 YWAR life stages and outcomes in the LCR ecosystem 9
2 Distribution of YWAR critical biological activities and processes among life stages 11
3 Distribution of YWAR habitat elements and the critical biological activities and processes that they directly affect across all life stages 18
4 Habitat elements directly affected by controlling factors 27
5 Magnitude of influence of controlling factors on habitat elements 55

Figures

Figure Page

1 Proposed YWAR life history model. 10
2 Diagram conventions for LCR MSCP conceptual ecological models. 35
3 YWAR life stage 1 – nest, basic CEM diagram. 39
4 YWAR life stage 1 – nest, high- and medium-magnitude relationships. 41
5 YWAR life stage 2 – juvenile, basic CEM diagram. 45
6 YWAR life stage 2 – juvenile, high- and medium-magnitude relationships. 47
7 YWAR life stage 3 – breeding adult, basic CEM diagram. 51
8 YWAR life stage 4 – breeding adult, high- and medium-magnitude relationships. 53
9 Most influential biological activities and processes affecting each life stage. Only elements with high- or medium-magnitude connections are presented. The legend is provided on figure 2. 64
10 Habitat elements that directly or indirectly affect the most influential biological activities and processes of YWAR. Note that eating and nest predation and brood parasitism only apply to the nest stage and are not shown, but they are affected by roughly the same processes as foraging and predation. The legend is provided on figure 2. 66

Attachments

Attachment

1	Species Conceptual Ecological Model Methodology for the Lower Colorado River Multi-Species Conservation Program
2	Sonoran Yellow Warbler Habitat Data

Foreword

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

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

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

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

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

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

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

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

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

- A means of identifying appropriate monitoring indicators and metrics.

- A basis for implementing adaptive management strategies.

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

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

It is important to note that CEMs are not meant to be used as prescriptive management tools but rather to give managers the information needed to help inform decisions. These models are conceptual and qualitative. They are not intended to provide precise, quantitative predictions. Rather, they allow us to virtually "tweak the system" free of the constraints of time and cost to develop a prediction of how a system might respond over time to a variety of management options; for a single species, 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 Sonoran yellow warbler (*Setophaga petechia sonorana*) (YWAR). 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 YWAR ecology, the effects of specific stressors, the effects of specific management actions aimed at species habitat restoration, and the methods used to measure YWAR habitat and population conditions. (Note: Attachment 1 provides an introduction to the CEM process. We recommend that those unfamiliar with this process read the attachment before continuing with this document.)

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

CONCEPTUAL ECOLOGICAL MODELS

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

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

- **Life stages** – These consist of the major growth stages and critical events through which an individual YWAR 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 fertilized eggs produced (fertility rate).
- **Critical biological activities and processes** – These consist of activities in which the species engages and biological processes that take place during each life stage that significantly beneficially or detrimentally shape the life-stage outcome rates for that life stage.
- **Habitat elements** – These consist of the specific habitat conditions, the abundance, spatial and temporal distributions, and other qualities that significantly beneficially or detrimentally affect the rates of the critical biological activities and processes for each life stage.
- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the abundance, spatial and temporal distributions, and other qualities of the habitat elements for each life stage. Controlling factors are also called "drivers."

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

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE

The YWAR conceptual ecological model addresses the YWAR throughout the Southwestern United States, paying particular attention to the lower Colorado River (LCR). The model thus addresses the landscape as a whole rather than any single reach or managed area. Although we focused on the Southwestern United States, we draw from studies conducted throughout the breeding range of the YWAR. Even though the YWAR is known to winter along the LCR at low densities (Rosenberg et al. 1991), the model does not address the biology of the YWAR during migration or in its winter range.

The basic sources of information for the YWAR CEM include (Rosenberg et al. (1991), Lowther et al. (1999), Wise-Gervais (2005), Floyd (2007), Heath (2008), and Reclamation (2008). These publications summarize and cite large bodies of earlier studies. 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 simply provide an updated literature review but to integrate the available information into a CEM so it can be used for adaptive management.

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

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

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

The YWAR conceptual ecological model distinguishes 9 critical biological activities or processes relevant to 1 or more of 3 life stages, 17 habitat elements relevant to 1 or more of these 9 critical biological activities or processes for 1 or more life stages, and 9 controlling factors that affect one or more of these 17 habitat elements. Because the LCR and its protected areas comprise a highly regulated system, the controlling factors mainly concern human activities, with the exception of natural thinning.

The nine critical biological activities and processes identified across all life stages are: disease, eating, foraging, molt, nest attendance, nest predation and brood parasitism, nest site selection, predation, and temperature regulation. The 17 habitat elements identified across all life stages are: anthropogenic disturbance, brood size, canopy closure, community type, food availability, genetic diversity and infectious agents, humidity, intermediate structure, local hydrology, matrix community, nest predator and cowbird density, parental feeding behavior, parental nest attendance, patch size, predator density, temperature, and tree density. The nine controlling factors identified across all habitat elements are: fire management, grazing, mechanical thinning, natural thinning, nuisance species introduction and management, pesticide/herbicide application, planting regime, recreational activities, 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 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:

- Predation and foraging/eating are likely the most important critical biological activities and processes affecting survival of YWAR at all life stages. Depredation of nests can be high (Theimer et al. 2011). The effects likely act at the landscape scale, and the effects of a change in the rates of predation probably last less than a decade. Other processes, such as disease, molt, and temperature regulation can be very important, but are less understood, especially within the LCR.

- Only two processes affect reproduction—nest attendance and nest site selection. These two critical biological activities and processes are especially important because they also affect the survival of the nestlings.

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 YWAR survivorship and recruitment along the LCR. Specifically, the findings suggest a need to assess the following:

- Nest site selection is by far affected by the most habitat variables and is likely one of the most well-studied processes. However, conflicting study results indicate that more research is needed, especially regarding intermediate structure.

- The effects of predation on juveniles and adults are poorly understood, whereas nest predation is better studied. In addition, the effects of different habitat characteristics on the rates of juvenile and adult depredation are also poorly understood. This likely reflects the relative ease of studying depredation of nests versus predation of free-flying birds. Studies of predation would likely be expensive and, therefore, would only be a priority if the persistence or population growth of YWAR populations along the LCR is considered sensitive to the survival of adults and juveniles.

- The effects of the matrix community on foraging and nest site selection are not well understood. The lack of understanding of the matrix community highlights the need to study the effects of certain habitat attributes at multiple spatial scales. The literature on specifically studying scales of site selection for yellow warblers is reviewed in chapter 3, "Nest Site Selection." The LCR MSCP might consider conducting studies similar to Saab's (1999) along the LCR.

- The results of quantitative and qualitative studies on the effects of food availability on foraging are conflicting. Therefore, there is uncertainty regarding the importance of food availability on the persistence and growth of YWAR subpopulations. In addition, although the effect of food availability on nest site selection is considered to be of low magnitude, there is major uncertainty. Therefore, studies of insect abundance at used versus non-used sites and of the effects of local hydrology and vegetation characteristics on insect abundance might be informative.

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 YWAR. 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 Sonoran yellow warbler (*Setophaga petechia sonorana*) (YWAR) in the Lower Colorado River Basin. 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 YWAR ecology, the effects of specific stressors, the effects of specific actions aimed at species habitat restoration, and the methods used to measure YWAR habitat and population conditions. The CEM methodology used here 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 YWAR population along the river and lakes of the lower Colorado River (LCR) and other protected areas within the basin. The model thus addresses the landscape in general rather than any single reach or managed area.

The most widely used sources of information for the YWAR conceptual ecological model are Rosenberg et al. (1991), Lowther et al. (1999), Wise-Gervais (2005), Floyd (2007), Heath (2008), and Reclamation (2008). These publications summarize and cite large bodies of earlier studies. 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 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 YWAR as currently understood, the purpose of the model, and introduces the underlying concepts and structure of the CEM. Succeeding chapters present and explain the model for YWAR along the LCR and evaluate the implications of this information for management, monitoring, and research needs.

SONORAN YELLOW WARBLER REPRODUCTIVE ECOLOGY

Yellow warblers are considered complete migrants, breeding in North America and wintering in Central America and northern South America. The breeding adult stage begins when the bird returns to the breeding grounds (initially after its first winter) and ends when it departs the breeding grounds during fall migration. YWAR begin arriving to their Southwestern U.S. breeding areas in mid-March (Wise-Gervais 2005) or April (Rosenberg et al. 1991; Small 1994; Reclamation 2008). In Arizona, breeding activity peaks in June, but occurs from late April to mid-July, and adults have been reported feeding fledglings as late as August 10 (Wise-Gervais 2005).

Males typically arrive on the breeding grounds before females (Lowther et al. 1999). Females build the nest and lay four or five eggs, which they alone incubate, although the males may feed the nesting female during this time (Lowther et al. 1999). The incubation period generally lasts 11–12 days, with young fledging 8–12 days after hatching (Lowther et al. 1999; Wise-Gervais 2005). While brooding is performed by the female alone, the male will help feed the nestlings (Lowther et al. 1999). After fledging, the young will remain with adults for an additional 17–21 days (Smith 1943).

YWAR typically nest in riparian cottonwood-willow (*Populus fremontii*, *Salix gooddingii*) forests along the LCR (Rosenberg et al. 1991; Reclamation 2008; Great Basin Bird Observatory [GBBO] 2011). They are generalist insectivores that take insect prey in proportion to availability (Lowther et al. 1999).

CONCEPTUAL ECOLOGICAL MODEL PURPOSES

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

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

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

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

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE FOR THE YWAR

The CEM methodology used here expands on that developed for the Sacramento-San Joaquin River Delta Regional Ecosystem Restoration Implementation Plan (DiGennaro et al. 2012). The expansion incorporates recommendations of Wildhaber et al. (2007), Kondolf et al. (2008), Burke et al. (2009), and Wildhaber (2011) to provide greater detail on causal linkages and outcomes and explicit demographic notation in the characterization of life-stage outcomes (McDonald and Caswell 1993). Attachment 1 provides a detailed description of the methodology. The resulting model is a "life history" model, as is common for CEMs focused on individual species (Wildhaber et al. 2007; Wildhaber 2011). That is, it distinguishes the major life stages or events through which the individuals of a species must pass to complete a full life cycle, including reproducing, and the biologically crucial outcomes of each life stage. These biologically crucial outcomes typically include the number of individuals recruited to the next life stage (e.g., 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 YWAR 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 outcome 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 food availability, intermediate structure, and predator density, which in turn may depend on factors such as canopy closure, local hydrology, and patch size, which in turn are shaped by land use, vegetation management, and water demand.

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 – YWAR 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 YWAR along the LCR on which to build the CEM.

INTRODUCTION TO THE YWAR LIFE CYCLE

In the development of the CEM for YWAR, we could not find a complete demographic study of the species. We therefore chose to represent YWAR with a three-stage model, typical of migratory passerines, to be consistent with other species documented within the LCR MSCP and to be most useful to management.

Our model of the life cycle of a typical migratory bird distinguishes three life stages: nest, juvenile, and breeding adult. These life stages were included because they balance the need to understand the model in the context of past work and the need to present the ecological information necessary to effectively manage for the critical biological activities that drive the growth—or decline—of populations of migratory birds along the LCR.

In many studies of avian demography, nest survival is considered integral in the reproduction of adults because adults are heavily invested in the care of eggs and nestlings (Etterson et al. 2011). However, 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. In addition, we have chosen to combine the egg and nestling phases of development into a nest stage because both the eggs and nestlings occupy the same nest. Therefore, management focused on the nest will cover both eggs and nestlings.

The migratory nature of the YWAR complicates its management. The LCR MSCP is mainly responsible for management on the breeding grounds, and we therefore focus on three life stages occurring within LCR MSCP lands—nest, juvenile, and breeding adult. Although the yellow warbler has been reported to winter along the LCR at low densities (Rosenberg et al. 1991), the model does not address the biology of the YWAR during migration or in its winter range.

YWAR LIFE STAGE 1 – NEST

We consider the nest stage to be the first in the life cycle of YWAR. It begins when the egg is laid and ends either when the young fledge or the nest fails. YWAR generally lay eggs in Arizona, beginning in late April, with nests having young around mid-May (Reclamation 2008). Active YWAR nests have been recorded between April 28 and July 14 (Reclamation 2008). The nest life stage lasts about 25 days, starting with the first egg and ending when the last fledgling leaves the nest. In general, yellow warbler nestlings fledge 8 to 10 days post-hatching (Lowther et al. 1999).

The life-stage outcome from the nest stage is the survival of eggs and associated nestlings until fledging. It is important to note that the outcome of the nest stage is inherently tied to the behavior and condition of the parents.

YWAR LIFE STAGE 2 – JUVENILE

The juvenile stage begins at fledging and ends when the bird returns to the breeding grounds the next year. Fledglings will remain with adults 17–21 days post-fledging (Smith 1943). The life-stage outcome from the juvenile stage is the survival of the bird from fledging until its return to the breeding grounds the next calendar year. There are no studies available that analyze juvenile survival rates in this species.

YWAR LIFE STAGE 3 – BREEDING ADULT

The breeding adult stage begins when the bird returns to the breeding grounds after its first winter and ends when it departs the breeding grounds during fall migration. Yellow warblers begin arriving at Southwestern U.S. breeding areas in mid-March (Wise-Gervais 2005) or April (Rosenberg et al. 1991; Small 1994; Reclamation 2008). In Arizona, breeding activity peaks in June, but occurs from late April to mid-July, and adults have been reported feeding fledglings as late as August 10 (Wise-Gervais 2005).

Across the breeding range of yellow warblers, males tend to arrive on the breeding grounds before females (Lowther et al. 1999). The nest is built by the female who usually lays four or five eggs and conducts all of the incubation, during which she might be fed by the male (Lowther et al. 1999). The incubation period generally lasts 11–12 days, with young fledging 8–12 days after hatching (Lowther et al. 1999; Wise-Gervais 2005). While brooding is performed by the female alone, the male will help feed the nestlings (Lowther et al. 1999).

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 total 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.

It is important to note that the post-breeding period—after breeding but before migration—is a significant part of a bird's life cycle. During the post-breeding period, adults may prospect for potential future breeding areas or move into habitat types that differ from breeding areas and provide good conditions for migratory staging (Vega Rivera et al. 1998). Although males, females, and post-breeding individuals have different goals and responsibilities on the breeding grounds, they all have been included within the breeding adult life stage because we believe their habitat use is likely similar enough that management directed at breeding adults will likely benefit all demographics present on the breeding grounds.

LIFE STAGE MODEL SUMMARY

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

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

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

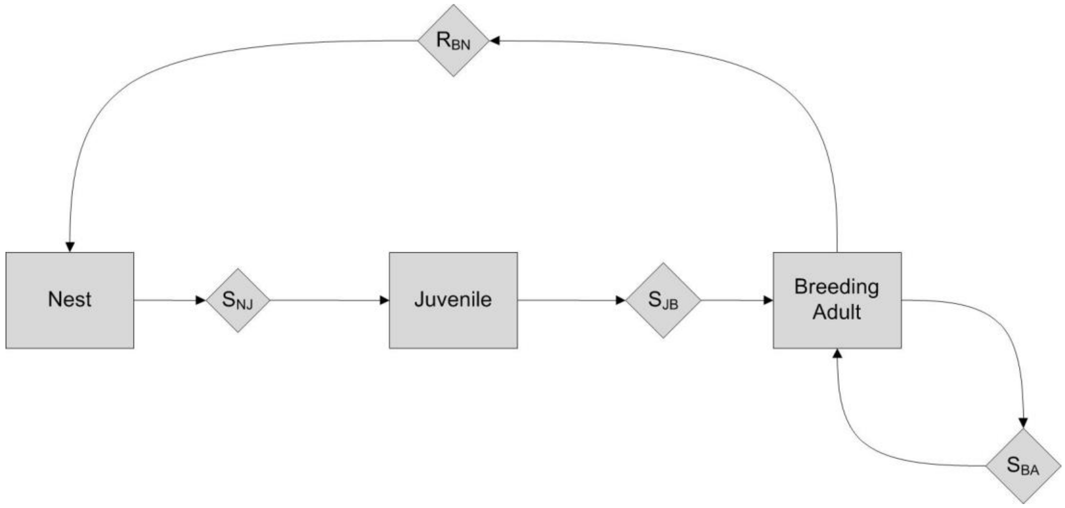

Figure 1.—Proposed YWAR life history model.
Squares indicate the life-stage, and diamonds indicate the life-stage outcomes. S_{NJ} = survivorship rate, nest; S_{JB} = survivorship rate, juveniles; S_{BA} = survivorship rate, breeding adults; and R_{BN} = reproduction rate, breeding adults.

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 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 nine critical biological activities and processes that affect one or more YWAR life stages. Some of these activities or processes differ in their details among life stages. However, using the same labels for the same *kinds* of activities or processes across all life stages makes comparison and integration of the CEMs for the individual life stages across the entire life cycle less difficult. Table 2 lists the nine critical activities and processes and their distribution across life stages.

Table 2.—Distribution of YWAR 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**	**Breeding adult**
Disease	X	X	X
Eating	X		
Foraging		X	X
Molt	X		
Nest attendance			X
Nest predation and brood parasitism	X		
Nest site selection			X
Predation		X	X
Temperature regulation	X	X	X

The basic sources of information used to identify the critical biological activities and processes are Rosenberg et al. (1991), Lowther et al. (1999), Wise-Gervais (2005), Floyd (2007), Heath (2008), and Reclamation (2008). The CEM also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP avian biologists. The following paragraphs discuss the nine critical biological activities and processes in alphabetical order.

DISEASE

This process refers to diseases caused by infectious agents, including the effects of ecto- and endo-parasites. Disease prevalence and intensity can be influenced by the lack of genetic diversity. Little is known about the effects of disease on the yellow warbler across its range (Lowther et al. 1999). However, there is a wealth of knowledge regarding avian diseases and parasites that affect passerine birds within North America, which indicates a large number of diseases (Morishita et al. 1999) that can be difficult to detect (Jarvi et al. 2002) and that have differing effects on different species (Merino et al. 2000; Palinauskas et al. 2008). YWAR in all life stages are conceivably susceptible to disease.

EATING

This process only applies to the nest 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 is determined by the provisioning rate of its parents. Note that although the parents will feed the juveniles (parental feeding behavior), this is assumed to affect foraging and, for simplicity, we do not include eating as a critical biological activity for juveniles; rather, food acquisition by juveniles and adults is classified as foraging.

FORAGING

Yellow warblers are generalist insectivores that forage by sallying, gleaning, and hovering (Frydendall 1967; Eckhardt 1979; Hutto 1981; Lowther et al. 1999; Yard et al. 2004). In Utah (Frydendall 1967) and Colorado (Eckhardt 1979), gleaning is by far the most often used strategy. Frydendall (1967) notes that individuals of the yellow warbler subspecies (*S. p. morcomi*) show no innate restriction to particular foraging heights and added that the height of their foraging is only limited by the height of the vegetation itself. Frydendall (1967) further classifies *S. p. morcomi* as a mid- to high-level forager. In Colorado, foraging was concentrated mostly in willows (Eckhardt 1979), whereas in Utah, foraging was mostly in box elder (*Acer negundo*), followed by willow (Frydendall

1967). Both juveniles and adults forage, but it is important to note that foraging by the parents affects the provisioning rate to nestlings and nest attendance by adults.

MOLT

Nestling yellow warblers must molt from natal down into juvenal plumage while in the nest. The success of this molt is dependent upon the adult provisioning rate (Howell 2010). Molting is an energetically costly process that may make nestlings more susceptible to death when resources are scarce (Howell 2010). Feather quality may be negatively affected by poor diet, and the nestlings may compensate by shifting resources from other critical functions, such as the immune system, putting them at further risk (Birkhead et al. 1999).

YWAR in all life stages must molt on the breeding grounds, and nestlings sometimes begin their first pre-basic molt before fledging (Lowther et al. 1999). Pre-basic molt is during May – September for hatch year birds and June – September for after hatch year birds (Pyle et al. 1997). Therefore, both juvenile and breeding adults likely undergo at least some molt on the breeding grounds. Adult birds molt on the breeding grounds after the breeding season, and before autumn migration, and face the same challenges as nestlings (Howell 2010; Rimmer 1988).

NEST ATTENDANCE

The female does all of the incubating and brooding, but the male helps with feeding the young (Lowther et al. 1999). Along the LCR, female YWAR will incubate, or shade their eggs, depending on the temperature (Theimer et al. 2010). Although little information on responses to predators is available, yellow warblers will mob potential predators, and females will give distraction displays when confronted by potential nest predators (Lowther et al. 1999). Tewksbury et al. (2002) document a complicated interplay between the need for parents to guard against egg removal by cowbirds (*Molothrus ater*) while also foraging and avoiding nest predation. Nest attendance by breeding adults therefore affects the survival of nestlings (Tewksbury et al. 2002).

NEST PREDATION AND BROOD PARASITISM

Yellow warblers are frequent victims of brood parasitism (Lowther et al. 1999; Hansen and Rotella 2002; Wise-Gervais 2005; Morgan et al. 2006; Heath 2008), which certainly affects the number of yellow warbler offspring fledged from parasitized nests (Lowther et al. 1999; Ortega and Ortega 2000; Tewksbury et al. 2002; Timmer et al. 2011; Rock et al. 2013). However, the yellow warbler has evolved anti-parasitism strategies that include nest abandonment and/or the construction of new nests on top of parasitized clutches (Lowther et al. 1999), which allows them to fledge young from parasitized nests (Lowther et al. 1999; Tewksbury et al. 2002; Heath et al. 2010).

Although the rates and effects of brood parasitism for YWAR are poorly understood (Heath 2008; Reclamation 2008), Reclamation (2008) states that cowbird parasitism poses a "limited to moderate threat" to YWAR along the LCR, and Rosenberg et al. (1991) express doubt that brood parasitism is the principal cause of decline of YWAR. The latter note that the subspecies was abundant during the early 20^{th} century despite high rates of parasitism.

There is also heterogeneity in parasitism rates across regions (Lowther et al. 1999). Perhaps the only study of brood parasitism of YWAR is by Theimer et al. (2011), which reports 1 of 7 (14%) monitored nests parasitized at the Pahranagat National Wildlife Refuge and 6 of 22 (27%) nests parasitized at Mesquite, Nevada.

Nest predation is likely the most common cause of nest failure for yellow warblers, in general (Rogers 1994; Cain et al. 2003; Heath et al. 2010; Quinlan and Green 2012), and specifically for YWAR (Heath 2008), although studies on the effects of nest predation on YWAR productivity are lacking (Reclamation 2008). Theimer et al. (2011) reports that none of the 7 nests at the Pahranagat National Wildlife Refuge were depredated, whereas 13 of 22 (59%) nests at Mesquite, Nevada, were depredated.

Nest predation and brood parasitism have been combined for the nestling and egg stages because (1) cowbirds are both nest predators and brood parasites (Tewksbury et al. 2002; Latif et al. 2011; Theimer et al. 2011) and (2) habitat characteristics (vegetation density, patch size, etc.) likely affect both processes similarly. Further, Tewksbury et al. (2002) demonstrate that, in Montana, females in parasitized nests increased their nest attendance, thus increasing the need for the males to feed the females and increasing the activity at a nest. The increase in activity at nests increased the likelihood of nest predation—providing a link whereby brood parasitism leads to an increase in predation (Tewksbury et al. 2002).

NEST SITE SELECTION

The process of habitat selection for birds is hierarchical, with birds selecting sites using information at progressively smaller scales (Hutto 1985; Block and Brennan 1993), and the yellow warbler is no exception (Knopf and Sedgwick 1992;

Quinlan and Green 2012). The GBBO (2011) found that YWAR nest sites along the LCR were associated with habitat variables ranging in scales from 1 kilometer away from a territory to within a territory. Allen et al. (2005) state that yellow warblers along the Santa Ana River were associated with similar habitat variables across regional, watershed, and river scales.

Saab (1999) reports that yellow warblers in Idaho were associated with habitat attributes across several scales of selection. She suggests that birds within her study site were mostly influenced by landscape attributes and that the matrix community should be the primary consideration in selecting riparian reserves. Quinlan and Green (2012) and Knopf and Sedgwick (1992) both suggest that yellow warblers select nest sites based more on characteristics of a given patch of riparian habitat or territory than on the nest substrate itself. Therefore, although the scales of selection used by YWAR are poorly understood, it might be the case that larger scales of selection are generally more important for predicting YWAR habitat use.

PREDATION

Predation is a threat to YWAR in all life stages, and it obviously affects survival. The predators of and rates of depredation upon eggs and nestlings are much better understood than the depredation of adults. Predators of adults are likely to be similar to those of other birds sharing habitat with yellow warblers (Lowther et al. 1999).

TEMPERATURE REGULATION

Temperature regulation is important for any organism inhabiting a region with temperatures as high as that of the LCR. Adults can affect the temperature of eggs and nestlings through their incubation, brooding, and shading behaviors (Theimer et al. 2011) as well as through nest placement. At the northern edge of the yellow warbler's range, nests are better insulated and larger than elsewhere, presumably as an adaptation to colder temperatures (Briskie 1995; Rohwer and Law 2010). Similar modifications in nest construction may also occur in warmer regions in response to the need to regulate egg and nestling temperatures.

Chapter 4 – Habitat Elements

As noted earlier, habitat elements consist of specific, pivotal habitat conditions that ensure, allow, or interfere with critical biological activities and processes. Some elements, such as brood size, are not traditionally considered aspects of habitat but are included in this section because of their effects on critical biological activities and processes.

The typical breeding habitat for YWAR is cottonwood-willow riparian forests (Reclamation 2008). In fact, Rosenberg et al. (1991) suggest that the decline of YWAR populations along the LCR is mostly due to loss of suitable cottonwood-willow riparian forests.

This section identifies 17 habitat elements that affect 1 or more critical biological activities or processes across the 3 YWAR life stages. Some of these habitat elements apply to multiple spatial scales. For example, canopy closure could act at the patch and microhabitat scales, with YWAR choosing patches with the preferred amount of open areas for foraging and nest sites within those patches with sufficient canopy closure to regulate nest temperature. However, using the same labels for the same *kinds* of habitat elements across all life stages makes comparison and integration of the CEMs for the individual life stages across the entire life cycle less difficult. Table 3 lists the 17 habitat elements and the critical biological activities and processes that they *directly* affect across all YWAR life stages.

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 label predator density is the short name for "The abundance and distribution of predators that affect YWAR during the post-fledging and adult stages." The following paragraphs below provide the full name for each habitat element and provide a detailed definition, addressing the elements in alphabetical order.

The basic sources of information used to identify the habitat elements are Rosenberg et al. (1991); Lowther et al. (1999); Wise-Gervais (2005); Floyd (2007); Heath (2008); and Reclamation (2008). The identification also integrates information from both older and more recent works as well as the expert knowledge of LCR MSCP avian biologists.

Lowther et al. (1999) is the Birds of North America Online account for the yellow warbler range-wide. The account by Lowther et al. provides a wealth of information, although it is a range-wide account and only sparingly discusses YWAR specifically. Reclamation (2008) provides the species account for the YWAR. GBBO (2011) is a report of the results of a study of YWAR (and other species) nesting habitat along the LCR 2008–10. Wise-Gervais (2005), Floyd

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

Critical biological activity or process ➔ / **Habitat element 🡇**	**Disease**	**Eating**	**Foraging**	**Molt**	**Nest attendance**	**Nest predation and brood parasitism**	**Nest site selection**	**Predation**	**Temperature regulation**
Anthropogenic disturbance			X		X		X	X	
Brood size		X	X		X				
Canopy closure			X			X	X	X	X
Community type			X			X	X	X	
Food availability			X		X		X		
Genetic diversity and infectious agents	X								
Humidity					X				X
Intermediate structure			X			X	X	X	X
Local hydrology	N/A*								
Matrix community			X				X		
Nest predator and cowbird density						X			
Parental nest attendance		X				X			X
Parental feeding behavior			X					X	
Patch size						X		X	
Predator density					X		X	X	
Temperature					X				X
Tree density						X	X	X	

Note: Local hydrology does not affect any critical biological activity or process *directly*; it acts through humidity. No habitat element *directly* affects molt; rather, the effects are *indirect* from infectious agents via disease and food availability via foraging.

(2007), Heath (2008), and Rosenberg et al. (1991) are accounts cited in the Arizona and Nevada Breeding Bird Atlases, California Birds of Special Concern, and Birds of the Lower Colorado River Valley, respectively. 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 habitats used by YWAR and associated disturbance, including noise**. Whether due to recreational, land management, or scientific research activities, anthropogenic disturbance can affect both breeding success and survival of birds (Barber et al. 2010; Francis and Barber 2013). Noise might mask conspecific cues such as songs or calls, making it more difficult for YWAR to attract or find mates or defend territories. McClure et al. (2013) found that road noise severely affects yellow warbler site use during migration (attachment 2), although the effect during the breeding season is unstudied. Anthropogenic disturbance is considered to be a habitat element, as it is an environmental characteristic with which a nesting, foraging, or overwintering warbler must contend.

BROOD SIZE

Full name: **The number of young in the nest**. This element refers to the number of young that the parents must rear. Yellow warblers usually lay four to five eggs, and clutch size is related to maternal health. YWAR rarely attempt a second brood in a season after successfully fledging young. The well-being of both parents depends in part on the availability of sufficient food resources in close proximity to the breeding territory as well as other factors such as predator density (see the habitat element of predator and cowbird density).

CANOPY CLOSURE

Full name: **The density of foliage in the overstory**. This element refers to the density of canopy vegetation in the vicinity of the YWAR nest site as it might be measured using light detection and ranging (LiDAR). Of course, measures of canopy foliage such as canopy closure, cover, leaf area index, and density are interrelated and all assess some aspect of the density of foliage in the overstory (Jennings et al. 1999; Korhonen et al. 2006; Smith et al. 2009). Ohmart (1994) considers the overstory to be the most important layer of vegetation for desert riparian habitats because of its ameliorating effects on temperature.

Various measures of canopy closure have been examined regarding yellow warblers. Whitmore (1975, 1977) reports that the yellow warbler was positively associated with canopy cover—the percent of the forest floor covered by the vertical projection of tree crowns (Jennings et al. 1999)—along the Virgin River in Utah. The GBBO (2011) measured canopy closure—the proportion of sky hemisphere obscured by vegetation (Jennings et al. 1999)—and found that sites used by YWAR had a higher average canopy closure than non-used sites along the LCR (attachment 2). Conversely, Quinlan and Green (2012) reports that British Columbia yellow warbler territories had lower canopy closure (*sensu* Jennings et al. 1999) than did random sites (attachment 2). Canopy cover is often related to tree stem density (James 1971; Rudnicki et al. 2004).

COMMUNITY TYPE

Full name: **The species composition of the riparian forest patch**. This element refers to the species composition of riparian habitat used for breeding by YWAR. In general, yellow warblers are associated with deciduous trees and riparian forests (Lowther et al. 1999). Along the LCR, YWAR nest in cottonwood-willow forests (Rosenberg et al. 1991; Reclamation 2008; GBBO 2011). Although quantitative information on the percentages of cottonwoods and willows preferred by YWAR is scant, the GBBO (2011) found that YWAR are positively associated with the presence of cottonwoods and willows and negatively associated with mesquite (*Prosopis* sp.) (attachment 2). Allen et al. (2005) found that the presence of yellow warbler was negatively associated with the *Baccharis* species. YWAR will also use communities that include invasive species such as tamarisk (*Tamarix* spp.) (Rosenberg et al. 1991; Wise-Gervais 2005; Heath 2008; Reclamation 2008). The relationship between YWAR and invasive community types is further discussed in under the controlling factor of nuisance species introduction and management.

FOOD AVAILABILITY

Full name: **The abundance of food available for adults and their young**. This element refers to the taxonomic and size composition of the invertebrates that an individual YWAR will encounter during each life stage as well as the density and spatial distribution of the food supply in proximity to the nest. Yellow warblers are generalist insectivores that take insect prey in proportion to availability (Lowther et al. 1999) (see “Foraging” in chapter 3 for more information on foraging strategies). The abundance and condition of the food supply affects adult health as well as the growth and development of the young during the nest and juvenile stages. It is interesting to note that although Allen et al. (2005) found that yellow warblers are associated with increasing amounts of native arthropods in Riverside County, California, the GBBO (2011) did not find an association with YWAR nest sites and two indicators of food abundance—ant hills and mistletoe (Santalales).

There do not appear to be any studies conducted that looked specifically at the diet of YWAR (Heath 2008; Reclamation 2008). However, Frydendall (1967) studied the diet of *S. p. morcomi* in Utah, and this perhaps sheds some light on the diet of YWAR. In Utah, yellow warblers feed exclusively on arthropods, with no individuals seen eating fruits or berries available to them (Frydendall 1967). Hymenoptera were the most numerous insects in the diet, followed by Diptera, Hemiptera, and Coleoptera (Frydendall 1967). In the Grand Canyon, aquatic midges made up 45% of the yellow warbler's diet (Yard et al. 2004).

Even though aquatic midges constituted 45% of yellow warbler diets in the Grand Canyon (Yard et al. 2004), the generalist nature of yellow warbler feeding (Reclamation 2008) suggests that aquatic insects are not a necessity for the birds. Frydendall (1967) specifically notes that the proximity to water is a main feature of yellow warbler habitat, not necessarily because of aquatic insects but because moist soils allow for the growth of lush vegetation, which in turn produces abundant insect prey. The diversity of insects therefore seems to be less important than the abundance of insects. In Riverside County, California, yellow warblers are associated with increased numbers of native arthropods (Allen et al. 2005).

Ohmart (1994) notes that because foliage volume is related to insect abundance, the greater the density of vegetation, the greater the density of most bird species in western riparian habitats. As noted above, the general consensus in the literature is that lush vegetation provides the conditions necessary to produce an abundant prey base for yellow warblers, although specific details are never presented.

GENETIC DIVERSITY AND INFECTIOUS AGENTS

Full name: **The genetic diversity of YWAR individuals and the types, abundance, and distribution of infectious agents and their vectors**. The genetic diversity component of this element refers to the genetic homogeneity versus heterogeneity of a population during each life stage. The greater the heterogeneity, the greater the possibility that individuals will have genetically encoded abilities to survive their encounters with the diverse stresses presented by their environment and/or take advantage of the opportunities presented (Allendorf and Leary 1986). Unfortunately, no genetic studies have been performed on YWAR along the LCR.

The infectious agents component refers to the spectrum of viruses, bacteria, fungi, and parasites that individual YWAR are likely to encounter during each life stage. Infectious agents and parasites of yellow warblers are poorly understood (Lowther et al. 1999). However, there is a wealth of knowledge regarding avian diseases and parasites that affect birds within North America, which indicates a large number of diseases (Morishita et al. 1999) that can be difficult to detect (Jarvi et al. 2002) and that have differing effects on different species (Merino et al. 2000; Palinauskas et al. 2008).

HUMIDITY

Full name: **The amount of moisture in a habitat patch or nest site**. This element refers to the average relative humidity in the nesting habitat. McNeil et al. (2013) suggest that higher humidity levels may reduce the potential for egg desiccation and thermal stress and is important for egg and nestling survival of yellow-billed cuckoos in the more arid landscapes of the LCR region. Humidity might likewise affect YWAR, although there do not seem to be any studies regarding humidity and site selection or breeding success of yellow warblers.

INTERMEDIATE STRUCTURE

Full name: **The density of the vegetation, including ground cover up through the mid-story**. This element refers to the visual density of vegetation (i.e., concealment) below the uppermost canopy layer. A more dense intermediate structure may support a more diverse and abundant invertebrate food supply (Ohmart 1994) as well as provide protection or concealment from predators (Latif et al. 2012). In general, intermediate structure, especially of shrubs, is associated with YWAR breeding habitat (Rosenberg et al. 1991; Wise-Gervais 2005; Reclamation 2008). For example, shrub cover was positively associated with yellow warbler habitat in California (Allen et al. 2005; Humple and Burnett 2010; Latif et al. 2012; see attachment 2), Canada (Quinlan and Green 2012), and Arizona (Brown and Trosset 1989). In Colorado, Knopf and Sedgwick (1992) (attachment 2) note that the most powerful descriptors of yellow warbler breeding habitat were those describing the density and arrangement of shrubs. Brown and Trosset (1989) also describe the volume of intermediate foliage (2–3 meters in height) to be a powerful descriptor of breeding habitat of YWAR.

Conversely, along the LCR, measures of understory and mid-story density were not significantly different between YWAR nest sites and non-use sites (GBBO 2011). In Utah, yellow warblers were associated with campgrounds with a higher density of shrub stems but the same amount of foliage density as non-campground sites (Blakesley and Reese 1988). Ruth and Stanley (2002) found that yellow warblers in Wyoming and Colorado selected larger, more open shrubs for nesting. Further, in riparian sites along the Virgin River, Utah, yellow warblers were associated with areas with lower shrub density (Whitmore 1977).

LOCAL HYDROLOGY

Full name: **The distance to standing water, or the presence of adjacent water bodies, as well as the depth to the water table and soil moisture levels**. This element refers to anything that affects soil moisture, such as the proximity of water to the nesting habitat, elevation, irrigation practices, and soil texture. In the Huachuca Mountains of Arizona, Strong and Bock (1990) note that yellow warblers are typically found in large cottonwood cienegas, which have "abundant water." Along the LCR, surface water is positively related to bird species richness (Hinojosa-Huerta et al. 2008). Wet sites seem to be important to yellow warblers, at least in part because the depth to the water table is important for the riparian vegetation upon which yellow warbler depends (Ohmart 1994), as well as to their insect prey (Frydendall 1967). Flooding might also affect the activity of yellow warbler nest predators (Cain et al. 2003).

There is broad agreement in the literature that yellow warblers prefer "wet" sites, but the measures and indices of "wetness" differ among studies. For example, along the Las Vegas Wash, YWAR were more abundant in areas with native vegetation, which had higher proportions of the landscape covered by water and greater soil moisture, than in areas with exotic vegetation (attachment 2; Shanahan et al. 2011). Work by the GBBO (2011) along the LCR suggests that YWAR prefer wet sites, as warbler territories had less upland habitat and were less often near dry washes than were non-use sites. Conversely, Brand et al. (2010) suggest that yellow warbler density is unrelated to hydrologic regime (whether a site experienced ephemeral, intermittent, or perennial flow) along the San Pedro River in Arizona.

MATRIX COMMUNITY

Full name: **The type of habitat surrounding riparian patches used by warblers**. This element refers to the types of plant communities and land-use activities surrounding the riparian habitat patches used by YWAR. The effects of the matrix community on habitat selection of YWAR are not well studied. In Santa Cruz County, California, yellow warblers were most abundant along streams adjacent to agricultural fields (Strusis-Timmer 2009), yet in Idaho, the occurrence of yellow warbler was more likely in landscapes with low percentages of agriculture (Saab 1999). Saab (1999) suggests that birds within her study site were mostly influenced by landscape attributes and stated that the matrix community should be the primary consideration in selecting riparian reserves. In the Huachuca Mountains in Arizona, yellow warblers use cottonwood cienegas that are surrounded by open grassland and some mesquite (Strong and Bock 1990). However, Rosenberg et al. (1991) ascribes the decline of YWAR along the LCR on loss of cottonwood-willow forests and subsequent breeding failures in replacement mesquite-tamarisk habitat. The GBBO (2011) showed that no landscape measures within 1 kilometer of the nesting territory were significantly different between nest and random sites. The matrix community can affect habitat selection by predators as well as the rates of predation (see Theimer et al. 2011 and references therein).

NEST PREDATOR AND COWBIRD DENSITY

Full name: **The abundance and distribution of nest predators and brood parasites**. This element refers to a set of closely related variables that affect the likelihood that different kinds of predators will encounter and successfully prey on YWAR during the egg or nestling life stages or that cowbirds or other nest parasites will lay eggs in the nest. Theimer et al. (2011) did not identify any predators specifically preying upon YWAR nests along the LCR but did note several species that might prey upon YWAR nests, including sharp-shinned hawks (*Accipiter striatus*), red-shouldered hawks (*Buteo lineatus*), western screech owls (*Megascops kennicottii*), American crows (*Corvus brachyrhynchos*), Bewick's wrens (*Thryomanes bewickii*), gray catbirds (*Dumetella carolinensis*), yellow-breasted chats (*Icteria virens*), Bullock's crioles (*Icterus bullockii*), and brown-headed cowbirds (*Molothrus ater*). Non-avian predators observed by Theimer et al. (2011) include short-tailed weasels (*Mustela frenata*), deer mice (*Peromyscus* spp.), woodrats (*Neotoma* spp.), and the common kingsnake (*Lampropeltis getula*).

PARENTAL FEEDING BEHAVIOR

Full name: **The ability of both parents to care for young post-fledging**. This element refers to the willingness and ability of the parents to feed the fledgling young once they have left the nest. Lowther et al. (1999) report that fledgling yellow warblers will remain with the parents for up to 21 days post-fledging.

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 both parents to share nesting and brood-rearing responsibilities until fledging. It is affected by the presence of predators and competitors, food availability, and the ability to thermoregulate. Brooding is performed by the female, who is fed by the male. During brooding, the female will adjust her behavior to regulate the temperature of the eggs by shading (Lowther et al. 1999; Theimer et al. 2010) or even fanning the eggs with her wings (Lowther et al. 1999). Both parents feed the nestlings (Lowther et al. 1999). The attentiveness of a brooding female is influenced by both the likelihood of cowbird parasitism and nest predation (Tewksbury et al. 2002).

PATCH SIZE

Full name: **The size of riparian habitat patches**. This element refers to the areal extent of a given patch of riparian vegetation. Although patch size is not usually listed as a factor in yellow warbler habitat selection, it is generally considered important for riparian birds in the Southwestern United States (Ohmart 1994). Patch size can also affect habitat selection by predators as well as the rates of predation (see Theimer et al. 2011 and references therein). Patch size is related to the amount of edge in a given patch, which has been shown to affect predation of yellow warbler nests (Cain et al. 2003). Saab (1999) refers to yellow warblers as small patch and edge specialists.

PREDATOR DENSITY

Full name: **The abundance and distribution of predators that affect YWAR during the post-fledging and adult stages**. This element refers to a set of closely related variables that affect the likelihood that different kinds of predators will encounter and successfully prey on YWAR during the juvenile or adult life stages. The variables of this element include the species and size of the fauna that prey on YWAR during different life stages, the density and spatial distribution of these fauna in the riparian habitat used by YWAR, and whether predator activity may vary in relation to other factors (time of day, patch size and width, matrix community type, etc.). The only predator of adult yellow warblers listed by Lowther et al. (1999) is the long-tailed weasel (*Mustela frenata*), although it is reasonable to assume that many nest predators (see section above) would also kill an adult, especially an incubating female.

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). Thermoregulation is necessary for the survival of juveniles, adults, and nests (eggs and nestlings). Temperature can also affect the attendance behavior of adults (Lowther et al. 1999; Theimer et al. 2011).

TREE DENSITY

Full name: **The stem density of trees**. This element refers to the number of trees per acre. The greater the tree and/or shrub density, the greater the likelihood of dense vegetative cover. However, there is some disagreement in the literature regarding the effects of tree density on yellow warbler presence. The GBBO (2011) found that YWAR are positively associated with the density of tall canopy trees (> 10 meters) and large trees (> 20 centimeters diameter at breast height and > 4 meters in height) along the LCR (attachment 2). In contrast, Blakesley and Reese (1988) report that yellow warblers are positively associated with campgrounds in a riparian area in northern Utah that had fewer trees than non-campground sites. Brown and Trosset (1989) also found more yellow warblers in areas with fewer trees in the Grand Canyon, whereas Whitmore (1975, 1977) found more yellow warblers in areas with higher tree density along the Virgin River in Utah.

Chapter 5 – Controlling Factors

As noted in “Chapter 1, Introduction,” 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 nine immediate controlling factors that are within the scope of potential human manipulation. The controlling factors identified in this CEM do not constitute individual variables; rather, each identifies a category of variables (including human activities) that share specific features that make it useful to treat them together. Table 4 lists the nine controlling factors and the habitat elements they *directly* affect.

Table 4.—Habitat elements directly affected by controlling factors

Controlling factor ➔ / **Habitat element ➔**	**Fire management**	**Grazing**	**Mechanical thinning**	**Natural thinning**	**Nuisance species introduction and management**	**Pesticide/herbicide application**	**Planting regime**	**Recreational activities**	**Water storage-delivery system design and operation**
Anthropogenic disturbance			X					X	
Brood size	N/A*								
Canopy closure	X		X	X	X		X	X	
Community type	X	X			X		X	X	X
Food availability					X	X			
Genetic diversity and infectious agents	N/A*								
Humidity	N/A*								
Intermediate structure	X	X	X	X	X		X	X	
Local hydrology									X
Matrix community	X	X					X		
Nest predator and cowbird density								X	
Parental feeding behavior									
Parental nest attendance									
Patch size	X	X					X	X	
Predator density								X	
Temperature	N/A*								
Tree density	X		X	X	X		X	X	

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

FIRE MANAGEMENT

This factor addresses any fire management (whether prescribed fire or fire suppression that could affect YWAR or their habitat. Management of fire directly affects several aspects of vegetation. Hinojosa-Huerta et al. (2008) recommend that fires be avoided in riparian areas because of potential effects on establishment of cottonwoods and willows. The effects of fire may include creation of habitat that supports or excludes YWAR, a reduction in the food supply of invertebrates, or support of species that pose threats to YWAR such as predators, competitors, or carriers of infectious agents. However, there is nothing in the literature that specifically addresses these indirect impacts. Climate change is also projected to affect fire frequency along the LCR (U.S. Fish and Wildlife Service [USFWS] 2013), in part by altering rainfall patterns.

GRAZING

This factor addresses the grazing activity on riparian habitats along the LCR and its surrounding areas that could affect YWAR or their habitat. Grazing by cattle (Bovidae), burros (*Equus asinus*), or mule deer (*Odocoileus hemionus*) across the arid Southwestern United States has substantially degraded riparian habitat (see Appendix G *in* USFWS 2002b). (Note: Reclamation staff and researchers have observed mule deer browsing on LCR sites, which may become an issue if populations are not managed). Grazing may thin the understory or even prevent the establishment of cottonwood and willow seedlings (Kauffman et al. 1997). Some studies have shown a positive response in yellow warbler abundance to the removal of cattle (Taylor and Littlefield 1986; Krueper et al. 2003), although others have shown equivocal responses to grazing (Stanley and Knopf 2002; Knopf et al. 2011), and Warkentin and Reed (1999) report that yellow warblers are found most often in disturbed (mostly by grazing) birch (*Betula* sp.) and intact willow habitats.

MECHANICAL THINNING

This factor addresses the active removal of vegetation from areas within the LCR region. Effects may include creation of habitat that supports or excludes YWAR or that supports species that pose threats to YWAR such as predators, competitors, or carriers of infectious agents. This factor includes the thinning of vegetation within both riparian and matrix communities. Thinning can be implemented on a small, local scale, resembling natural thinning, or it can be implemented on a broad scale with larger and more complete transition.

NATURAL THINNING

This factor addresses the natural death of trees within a patch of riparian forest or the surrounding matrix. As overstory trees die, they leave openings in the canopy, thereby allowing light to reach lower vegetation layers and creating the diverse horizontal and vertical foliage profile needed by YWAR.

NUISANCE SPECIES INTRODUCTION AND MANAGEMENT

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

The most often mentioned nuisance species in the context of YWAR habitat is tamarisk. Some studies report yellow warblers to be negatively associated with tamarisk (Wise-Gervais 2005; Shanahan et al. 2011), and Rosenberg et al. (1991) blame the decline of YWAR along the LCR partly on nest failure in tamarisk habitat. However, YWAR will use tamarisk for nesting, and some authors suggest that any habitat contributing to nesting success is equivalent to natural habitat (Heath 2008). Along the San Pedro River in Arizona, tamarisk habitat is second only to cottonwood-willow habitat in yellow warbler density and far above densities in mesquite habitat (Brand et al. 2010). The GBBO (2011) found no correlations between tamarisk and YWAR nest sites along the LCR. In contrast, Shanahan et al. (2011) report that YWAR benefited from restoration actions that replaced tamarisk with native vegetation. Finally, yellow warblers can certainly exploit food resources in tamarisk habitats in the Grand Canyon, as demonstrated by Yard et al. (2004). There, the most common yellow warbler prey items were aquatic midges, which were most abundant in tamarisk. The complicated nature of the relationship between tamarisk and YWAR is highlighted by another introduced species—the tamarisk beetle (*Diorhabda carinulata*). The beetle was introduced to the LCR region in order to control invasive tamarisk (Bateman et al. 2013). However, defoliation of tamarisk due to beetle infestation causes decreases in humidity and cover along with increases in temperature (Bateman et al. 2013), thereby degrading areas dominated by tamarisk as habitat for YWAR.

PESTICIDE/HERBICIDE APPLICATION

This factor addresses biocide applications that may occur on or adjacent to riparian habitat of the LCR region. Pesticides/herbicides may drift into riparian areas, removing plant species important to YWAR habitat structure and composition. The effects may include sublethal poisoning of YWAR via ingestion of treated insects, pollution of runoff into wetland habitats that are toxic to the prey of YWAR, and a reduced invertebrate food supply.

PLANTING REGIME

This factor addresses the active program to restore cottonwood-willow riparian habitat along the LCR and includes both the community planted as well as the manner in which it is planted within restoration areas (e.g., density, age, and patch size). The composition of the species planted can affect not only the vertical and horizontal structure of the vegetation but also the insect community within a given patch (Bangert et al. 2013; Wiesenborn 2014).

RECREATIONAL ACTIVITIES

This factor addresses the disturbance to YWAR from recreational activities along the LCR. Even non-consumptive human activity can have negative effects on wildlife (reviewed by Boyle and Samson 1985). This is a broad category that encompasses the types of activities (e.g., boating, fishing, horseback riding, camping, off-road vehicle [ORV] use) as well as the frequency and intensity of those activities. The impacts may consist of disturbance and habitat alteration. Recreational activities have a myriad of impacts on vegetation (see table 11.1 in Cole and Landres 1995). For instance, in Utah, riparian width and tree and shrub densities were significantly different between campgrounds and non-campground sites—factors believed to affect the density of yellow warblers (Blakesley and Reese 1988). Recreational activities can influence nest predator densities by either increasing predator success rates through interfering with or distracting prey or by decreasing predator success rates through interfering with or distracting the predator (Mason 2015; Ware et al. 2015). In addition, management of recreational activities can affect noise levels, which can affect YWAR.

WATER STORAGE-DELIVERY SYSTEM DESIGN AND OPERATION

Much of the habitat currently used by YWAR along the LCR is along regulated waterways. The water moving through this system is highly regulated for storage and delivery (diversion) to numerous international, Federal, State, Tribal, and municipal users and for hydropower generation. This controlling factor includes aspects of water management such as irrigation.

This factor includes river and off-channel water management, including pumping of groundwater and diversion of river water to manage water levels in refuge ponds, as well as dewatering and flushing of marsh habitats. The amount of water, flooding frequency, water depth and stability, etc., each affect the local hydrology and, therefore, the species composition and density of the riparian plant community favored by YWAR for food, shelter, and nesting. This element also accounts for large-scale flooding regimes. Natural flooding regimes are generally considered to be beneficial to yellow warblers (Strusis-Timmer 2009), riparian forests, and the associated bird community in general (Ohmart 1994; Hinojosa-Huerta et al. 2008). However, in the short term, scouring floods can destroy yellow warbler habitat (Turley and Holthuijzen 2005).

Chapter 6 – Conceptual Ecological Model by Life Stage

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

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

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

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

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

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

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

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

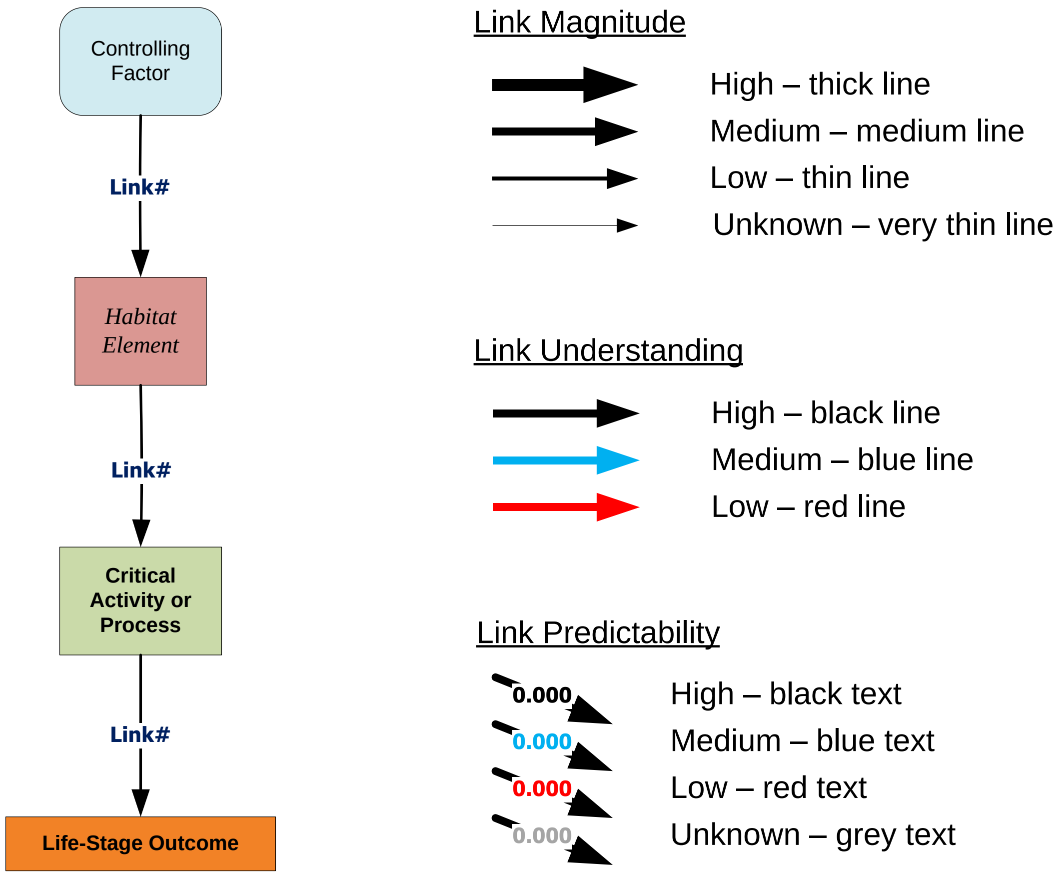

Figure 2.—Diagram conventions for LCR MSCP conceptual ecological models.

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

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

YWAR LIFE STAGE 1 – NEST

The nest stage lasts from when the egg is laid until either the young fledge or the nest fails. Success during this life stage – successful transition to the next stage – involves organism survival, maturation, molt, and fledging. The organisms actively interact with their environment.

The CEM (figures 3 and 4) recognizes five (of nine) critical biological activities and process for this life stage. Foraging, nest attendance, nest site selection, and predation are not included, as they are part of other life stages. The critical biological activities and process 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 YWAR, we still feel that disease bears mentioning. Diseases and parasites are prevalent in avian populations, so it is safe to assume they have an impact on YWAR (Morishita et al. 1999; Lachish et al. 2011). Disease and parasite impacts along the LCR is recommended as an area of potential research.

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

2. **Eating** – The nestling must eat to maintain metabolic processes and relies on its parents to provide food.

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

3. **Molt** – The nestling must molt into juvenile plumage, and molt directly affects survival.

   The CEM does not recognize any habitat elements as directly affecting molt. Other critical biological activities influencing molt include those affecting energy resources, such as disease and eating.

4. **Nest Predation and Brood Parasitism** – Both nest predation and brood parasitism affect the survival of a nest and are affected by similar habitat elements. We have combined nest predation and brood parasitism into one process for this stage.

   The CEM recognizes canopy closure, community type, intermediate structure, nest predator and cowbird density, parental nest attendance, patch size, and tree density as habitat elements affecting predation and brood parasitism. Note that the effects of anthropogenic disturbance on this element are not well known.

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

   The CEM recognizes humidity and temperature as the primary habitat elements directly affecting temperature regulation. Other habitat elements affecting temperature regulation include canopy closure, intermediate structure, and parental nest attendance.

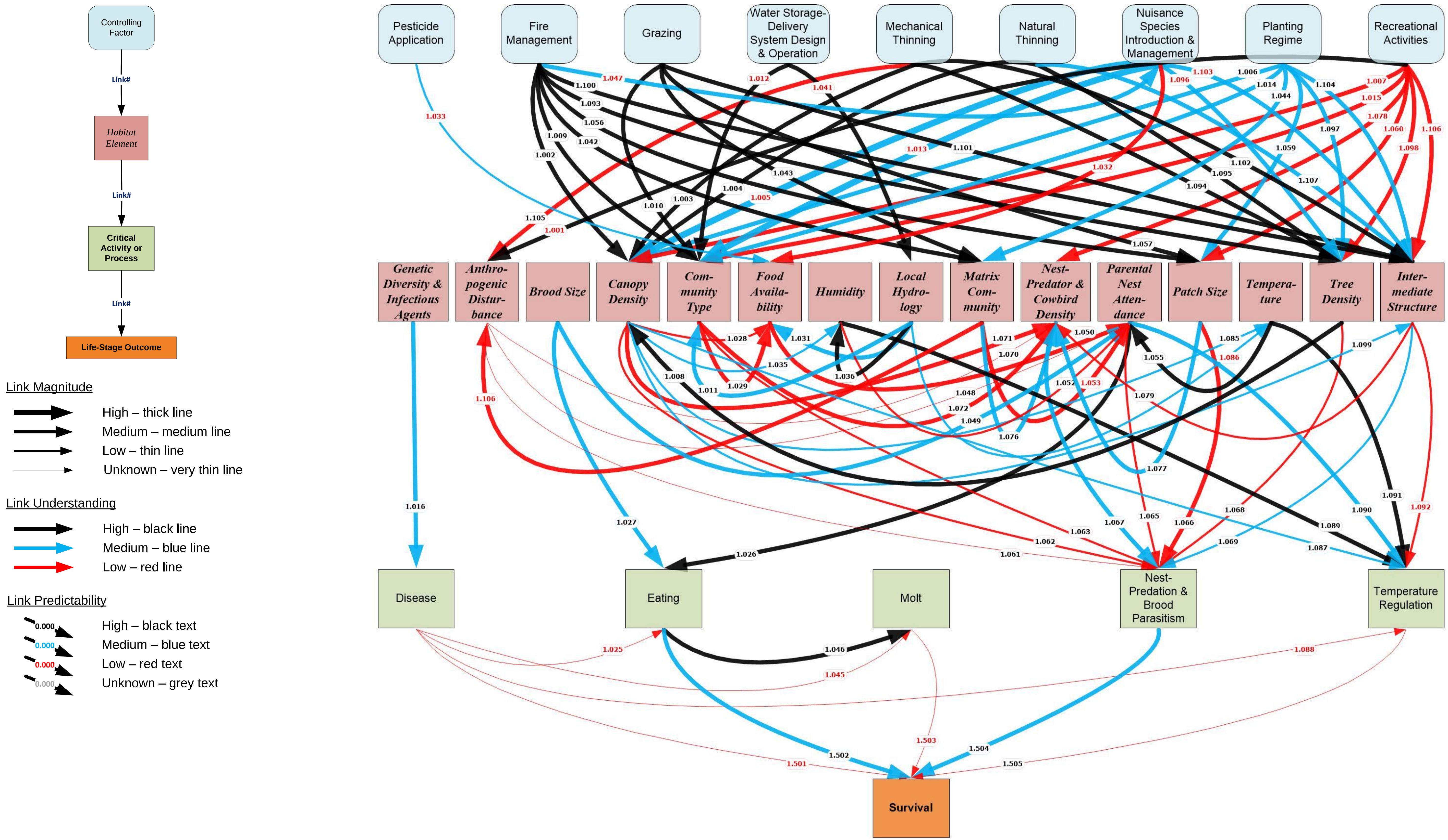

Figure 3.—YWAR life stage 1 – nest, basic CEM diagram.

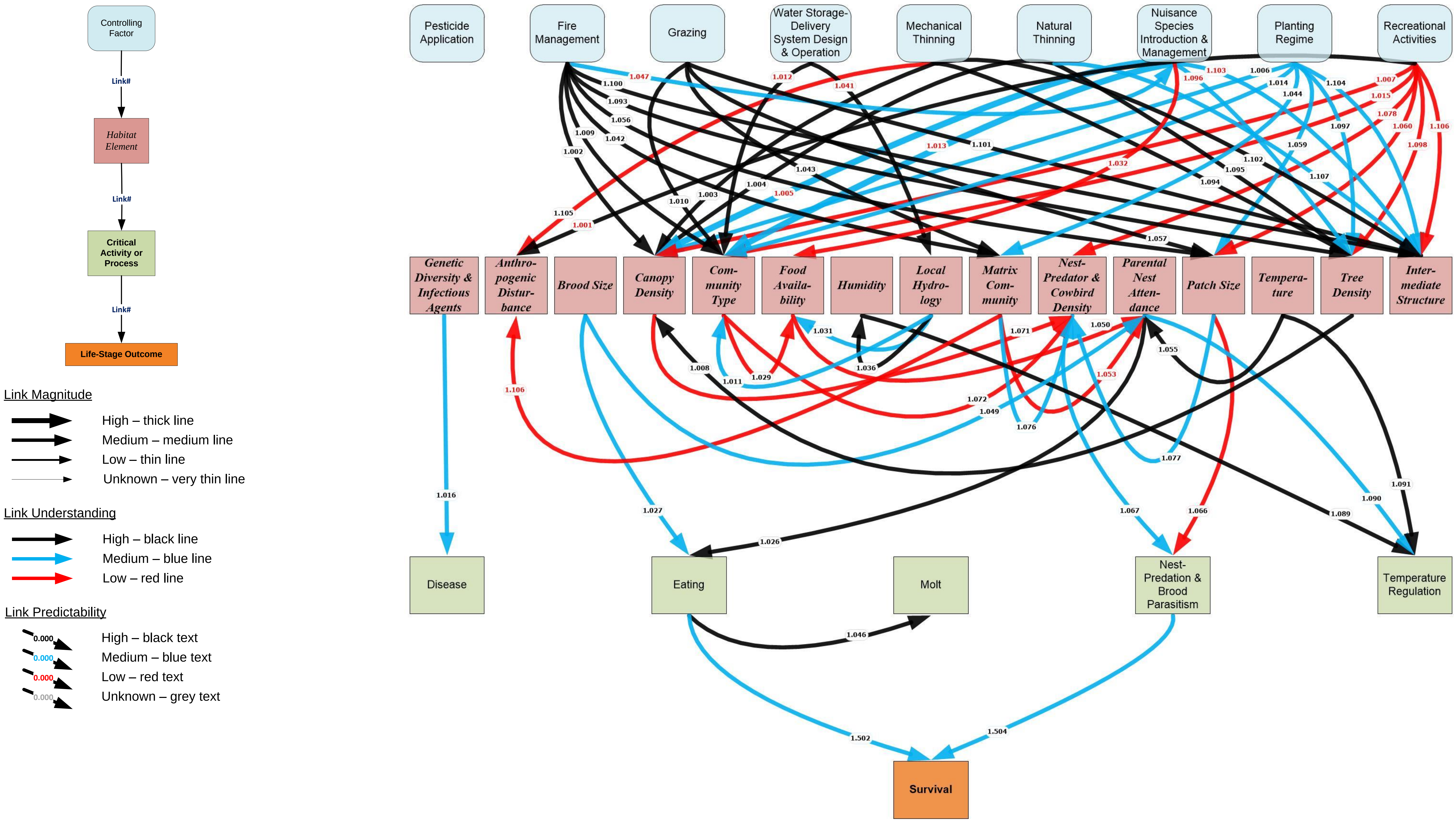

Figure 4.—YWAR life stage 1 – Nest, high- and medium-magnitude relationships.

YWAR LIFE STAGE 2 – JUVENILE

The juvenile stage begins at fledging and ends when the bird returns to the breeding grounds the next year. Success during this life stage – successful transition to the next stage – involves 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 nine) critical biological activities and processes for this life stage. Eating, nest attendance, nest predation and brood parasitism, 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 YWAR, we still feel that disease bears mentioning. Diseases and parasites are prevalent in avian populations, so it is safe to assume they have an impact on YWAR (Morishita et al. 1999; Lachish et al. 2011). Disease and parasite impacts along the LCR is recommended as an area of potential research.

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

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.

   The CEM recognizes canopy closure, community type, food availability, intermediate structure, matrix community, and parental feeding behavior as habitat elements affecting foraging. Note that the effects of anthropogenic disturbance on this element are not well known.

3. **Molt** – The nestling must molt into juvenile plumage, and molt directly affects survival.

   The CEM does not recognize any habitat elements as directly affecting molt. Other critical biological activities influencing molt include those affecting energy resources, such as disease and eating.

4. **Predation** – Brood parasitism is no longer a threat to the survival of YWAR; therefore, it is no longer included with predation.

   The CEM recognizes canopy closure, community type, intermediate structure, parental feeding behavior, patch size, predator density, and tree density as habitat elements affecting predation. Note that the effects of anthropogenic disturbance on this element are not well known.

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

   The CEM recognizes canopy closure, humidity, intermediate structure, and temperature as habitat elements directly affecting temperature regulation.

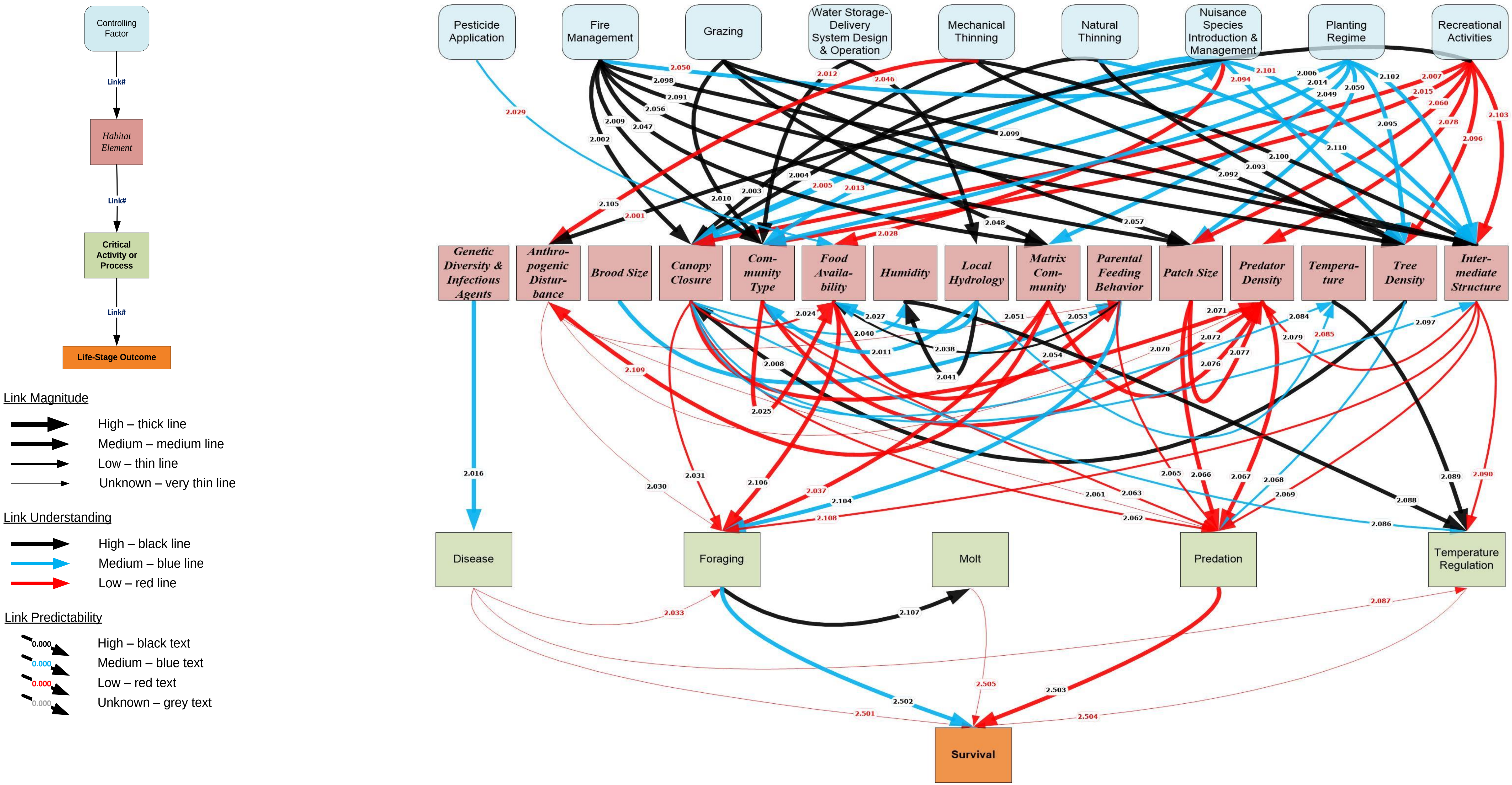

Figure 5.—YWAR life stage 2 – juvenile, basic CEM diagram.

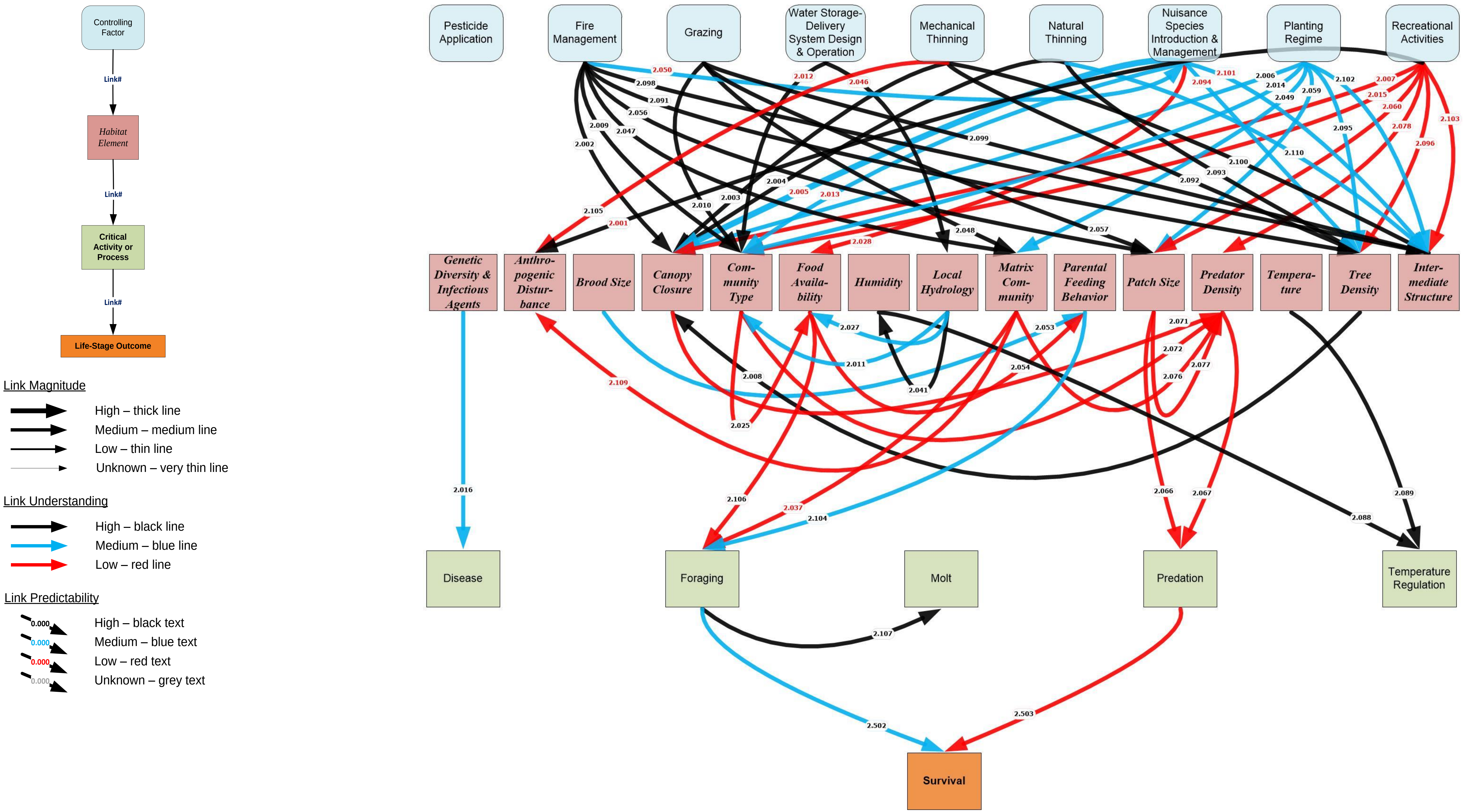

Figure 6.—YWAR life stage 2 – juvenile, high- and medium-magnitude relationships.

YWAR LIFE STAGE 3 – BREEDING ADULT

The breeding adult stage begins when the bird returns to the breeding grounds after its first or subsequent winter and ends when it departs the breeding grounds during fall migration. Success during this life stage – successful transition to the next stage – involves organism survival and breeding. Individuals that do not successfully find a territory and floaters, even though they do not breed, are also included in this category. The organisms actively interact with their environment.

The CEM (figures 7 and 8) recognizes seven (of nine) critical biological activities and process for this life stage. Eating and nest predation and brood parasitism are not included, as they are part of other life stages. The critical biological activities and process 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 YWAR, we still feel that disease bears mentioning. Diseases and parasites are prevalent in avian populations, so it is safe to assume they have an impact on YWAR (Morishita et al. 1999; Lachish et al. 2011). Disease and parasite impacts along the LCR is recommended as an area of potential research.

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

2. **Foraging** – The breeding adult must forage to feed itself and its young. The survival of adults and their young are dependent upon the foraging rate, which can be influenced by a number of factors.

   The CEM recognizes canopy closure, community type, food availability, intermediate structure, and the matrix community as habitat elements affecting foraging.

3. **Molt** – The breeding adults molt each year. This activity takes resources, which must be directed from other biological processes. Molt requires food (through foraging) and is impacted by disease. The result is that other aspects of survival may be affected, but flight capability should improve.

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

4. **Predation** – Adults must avoid predation to survive.

   The CEM recognizes canopy closure, community type, intermediate structure, patch size, predator density, and tree density as habitat elements affecting predation. Note that the effects of anthropogenic disturbance on this element are not well known.

5. **Nest Attendance** – The breeding adult must attend the nest to incubate eggs, brood young, and feed young, thus directly affecting reproductive output.

   The CEM recognizes brood size, food availability, humidity, predator density, and temperature as habitat elements affecting nest attendance. Note that the effects of anthropogenic disturbance on this element are not well known.

6. **Nest Site Selection** – This process includes both territory establishment and the placement of nests. Territory establishment is especially important because if a bird fails to establish a territory (or find a male with a territory in the case of females), the bird will be a floater and is unlikely to breed during that season. The breeding adult must choose where to place territories and nests, thereby affecting breeding success.

   The CEM recognizes canopy closure, community type, humidity, intermediate structure, the matrix community, patch size, predator density, temperature, and tree density as habitat elements affecting nest site selection. Note that the effects of anthropogenic disturbance on this element are not well known.

7. **Temperature Regulation** – The adult must maintain an optimum temperature to survive.

   The CEM recognizes canopy closure, humidity, intermediate structure, and temperature as habitat elements directly affecting temperature regulation.

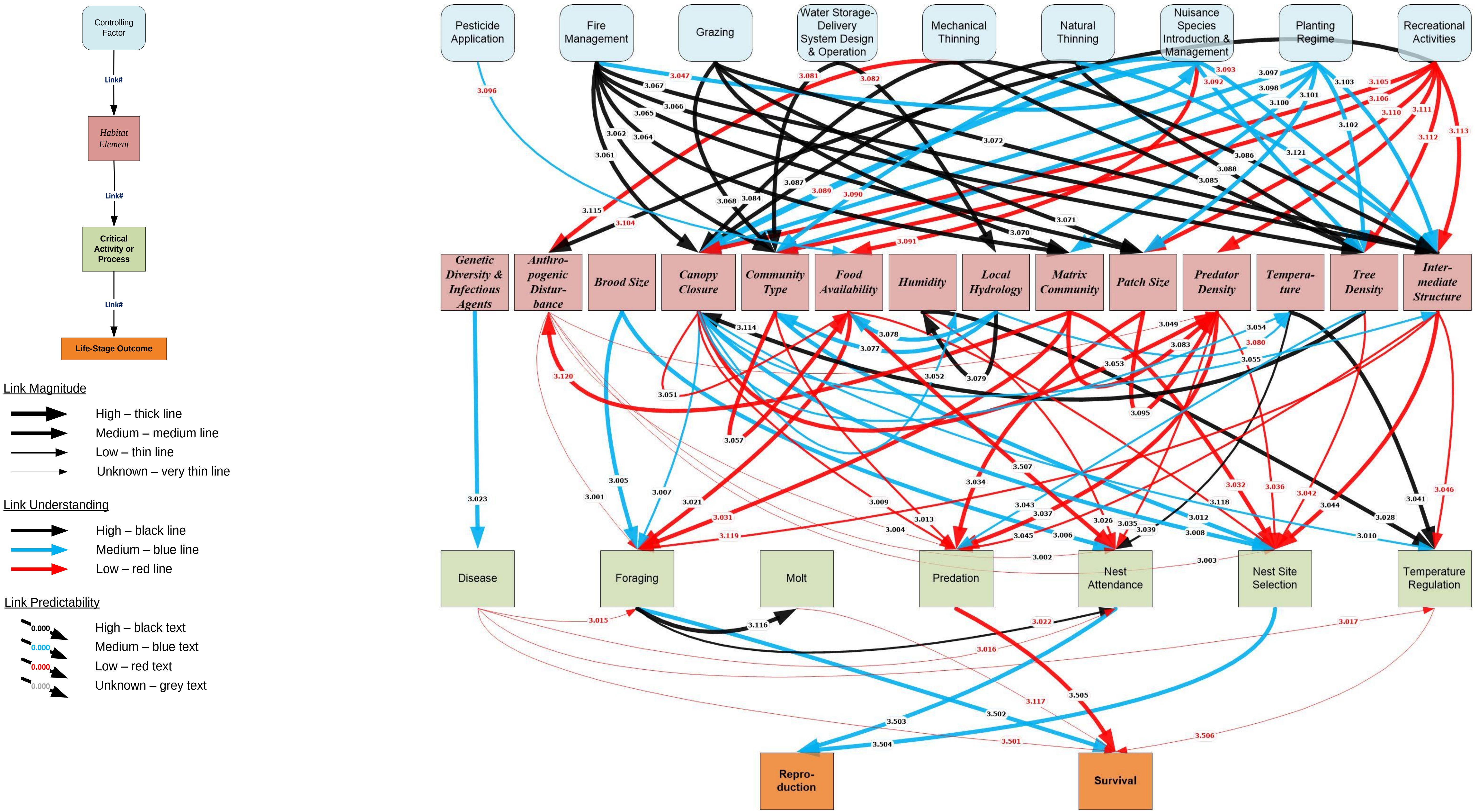

Figure 7.—YWAR life stage 3 – breeding adult, basic CEM diagram.

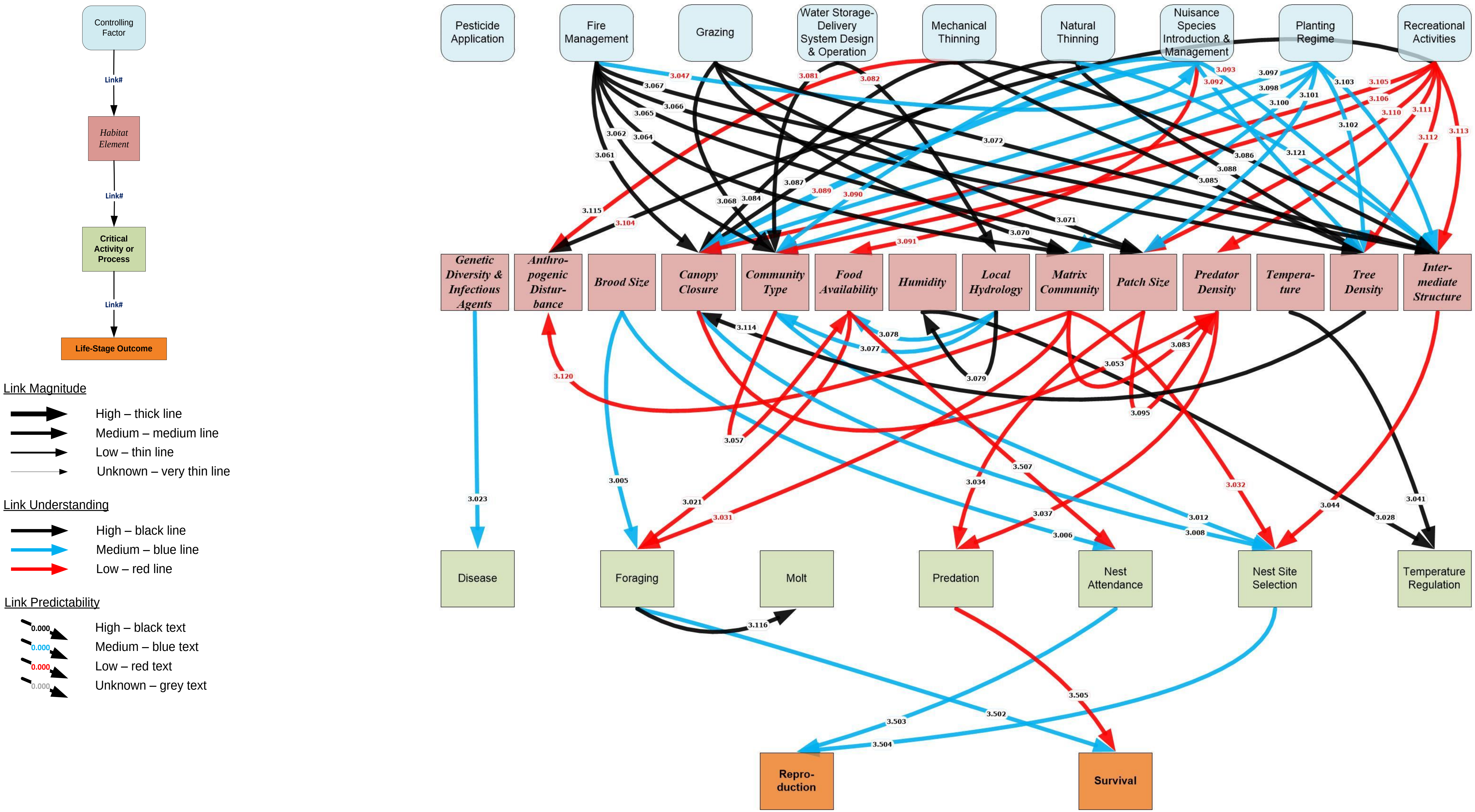

Figure 8.—YWAR life stage 4 – breeding adult, high- and medium-magnitude relationships.

Chapter 7 – Causal Relationships Across All Life Stages

The 9 controlling factors discussed in chapter 5 directly affect some of the 17 habitat elements as shown in table 5. The influence of these controlling factors is the same across all life stages for which those habitat elements matter. Table 5 shows the magnitudes of *direct* influence of the 9 controlling factors on the 11 habitat elements that they affect. 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 following paragraphs discuss the relative effects of the different controlling factors on each habitat element.

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

Controlling factor ➔ / **Habitat element ➔**	**Fire management**	**Grazing**	**Mechanical thinning**	**Natural thinning**	**Nuisance species introduction and management**	**Pesticide/herbicide application**	**Planting regime**	**Recreational activities**	**Water storage-delivery system design and operation**
Anthropogenic disturbance			**Med.**					**Med.**	
Brood size	N/A*								
Canopy closure	**Med.**		**Med.**	**Med.**	**High**		**Med.**	**Med.**	
Community type	**Med.**	**Med.**			**Med.**		**Med.**	**Med.**	**Med.**
Food availability					**Med.**	**Low**			
Genetic diversity and infectious agents	N/A*								
Humidity	N/A*								
Intermediate structure	**Med.**	**Med.**	**Med.**	**Med.**	**Med.**		**Med.**	**Med.**	
Local hydrology									**Med**
Matrix community	**Med.**	**Med.**					**Med.**		
Nest predator and cowbird density								**Med.**	
Parental feeding behavior	N/A*								
Parental nest attendance	N/A*								
Patch size	**Med.**	**Med.**					**Med.**	**Med.**	
Predator density								**Med.**	
Temperature	N/A*								
Tree density	**Med.**		**Med.**	**Med.**	**Med.**		**Med.**	**Med.**	

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

ANTHROPOGENIC DISTURBANCE

Mechanical thinning and recreational activities are the main controlling factors that affect anthropogenic disturbance. Mechanical thinning can involve the use of loud machines onsite or in the matrix community, but all activities involving humans, including recreational activities such as ORV use, increase anthropogenic noise, a major component of anthropogenic disturbance.

The scale and scope of the influences of mechanical thinning or recreational activities depend upon the scale and scope of the activity. In general, most activities are of narrow scope and short duration; however, systematic influences can cause repeated noise or other disturbances (e.g., campsites, ORV trails, or nearby roads). Decisions regarding management of recreational activities can affect large areas.

CANOPY CLOSURE

The controlling factors that directly affect canopy closure include fire management, mechanical thinning, natural thinning, nuisance species introduction and management, planting regime, and recreational activities. Fire, recreational activities, and mechanical/natural thinning will generally reduce canopy closure, whereas the effects of planting regime and nuisance species introduction and management depend on the management actions and species involved.

Fire affects many aspects of vegetation structure and composition (Naiman and Decamps 1997) and can destroy riparian habitat. Fire management can have great effects on vegetation structure, and is usually implemented over large areas. However, the dynamic nature of both fire and riparian communities means that the effects of fire management will likely last less than a decade.

Mechanical thinning would be done at the patch level, with effects lasting until vegetation grows back, and can be as intense as managers wish.

Although natural thinning affects canopy closure, it works on small scales, creating forest gaps. The effect only lasts until the vegetation grows back.

Nuisance species can change the structure of entire communities, with lasting effects. Although the effects are experienced at a patch level, invasive species can spread across entire regions, and their effects can last decades.

Planting regimes have the ability to greatly affect vegetation. However, planting decisions are made at the scale of the individual restoration site. Despite the dynamic nature of riparian communities, restoration sites are heavily managed, so the effects are likely medium or even long term.

The potential impact of recreational activities on YWAR habitat is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activities and riparian communities mean that effects of recreational activities will likely last less than a decade.

COMMUNITY TYPE

The controlling factors that directly affect community type include fire management, grazing, nuisance species introduction and management, planting regime, recreational activities, and water storage-delivery system design and operation. It is not possible to state whether the effects of controlling factors are positive or negative, as community type is not a numeric variable.

Fire affects many aspects of vegetation structure and composition (Naiman and Decamps 1997). Fire management can have great effects on vegetation structure and is usually implemented over large areas. However, the dynamic nature of both fire and riparian communities means that effects of fire management will likely last less than a decade.

Grazing affects many aspects of riparian vegetation structure and composition (Taylor and Littlefield 1986; Kauffman et al. 1997; Krueper et al. 2003; Knopf et al. 2011). Grazing activity can have great effects on community composition and is often implemented over large and long scales. However, the dynamic nature of riparian communities means that the effects of grazing will likely last less than a decade.

Nuisance species can change the structure of entire communities, with lasting effects. In addition, invasive species can spread across entire regions, and their effects can last decades.

Planting regimes have the ability to greatly affect vegetation. However, planting decisions are made at the scale of individual restoration sites. While riparian communities along unmanaged rivers tend to be dynamic, restoration sites are heavily managed, so the effects of water management are likely medium or even long term.

The USFWS (2002a) states that recreational activities can affect the species composition of riparian forests. The potential impact of recreational activities on YWAR habitat is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activity and riparian communities means that effects of recreation will likely last less than a decade.

Water storage and flow regimes can affect vegetation communities (Launer et al. 1990; Halterman and Laymon 1994), and nuisance species can change the structure of entire communities (Sogge et al. 2008; USFWS 2011), with lasting effects. The effects of water storage-delivery system design and operation are spread over large spatial and long scales.

FOOD AVAILABILITY

The controlling factors that directly affect food availability to YWAR include nuisance species introduction and management and pesticide/herbicide application.

Nuisance species can change arthropod communities; however, other factors also affect arthropod availability, and most arthropods are agile and can immigrate from other areas (Wiesenborn and Heydon 2007). The effects of nuisance species can spread across entire regions and last for decades.

The magnitude of the effect of pesticides/herbicides depends on many factors, but the potential magnitude is great. The most likely scenario involves herbicide/pesticide applications at individual agricultural fields affecting nearby patches and the effects dissipating less than a decade after application. However, pesticides/herbicides have been—and in the future may be—applied to habitat conservation areas; in those cases, its effect on food availability is probably higher than if it is only used on nearby agricultural fields. Because YWAR are generalists (Lowther et al. 1999; Reclamation 2008), a change in the arthropod community composition might not signify a change in the availability of prey.

INTERMEDIATE STRUCTURE

The controlling factors that directly affect intermediate structure include fire management, grazing, mechanical thinning, natural thinning, nuisance species introduction and management, planting regime, and recreational activities. Fire management, mechanical thinning, and recreational activities will generally reduce the intermediate structure, whereas the effects of nuisance species introduction and management and the planting regime depend on the management actions and species involved.

Fire affects many aspects of vegetation structure and composition (Naiman and Decamps 1997). Fire management can have great effects on vegetation structure and is usually implemented over large areas. However, the dynamic nature of both fire and riparian communities means that effects of fire management will likely last less than a decade.

Grazing affects many aspects of riparian vegetation structure and composition (Taylor and Littlefield 1986; Kauffman et al. 1997; Krueper et al. 2003; Knopf et al. 2011). Grazing activity can have great effects on community composition, and is often implemented over large and long scales. However, the dynamic nature of riparian communities means that effects of grazing will likely last less than a decade.

Mechanical thinning would be done at the patch level, with the effects lasting until vegetation grows back, and can be as intense as managers wish.

Although natural thinning affects canopy closure, it works on small scales, creating forest gaps. The effect only lasts until the vegetation grows back.

Nuisance species can change the structure of entire communities, with lasting effects. Although the effects are experienced at a patch level, invasive species can spread across entire regions, and their effects can last decades.

Planting regimes have the ability to greatly affect vegetation. However, planting decisions are made at the scale of individual restoration sites. Although riparian communities tend to be ephemeral, restoration sites are heavily managed, so the effects are likely medium or even long term.

The potential impact of recreational activities on YWAR habitat is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activity and riparian communities means that effects of recreation will likely last less than a decade.

LOCAL HYDROLOGY

The only controlling factor affecting local hydrology is water storage-delivery system design and operation—it is not possible to put a direction on the effect. The amount of water released or stored affects water levels and therefore distance to water, soil moisture, and other hydrological conditions. Water storage and flow regimes can affect vegetation communities and food abundance (Nilsson and Svedmark 2002). The effects of water storage spreads over large scales, but the effects of changes in flow regimes likely will be short term in nature unless a complete transformation of the habitat occurs.

MATRIX COMMUNITY

The controlling factors that directly affect the matrix community include fire management, grazing, and planting regime. Because of the wide range of possible outcomes of these controlling factors, it is not possible to describe any as strictly positive or negative.

Fire affects many aspects of vegetation structure and composition (Naiman and Decamps 1997) and can destroy YWAR habitat. Fire management can have great effects on vegetation structure and is usually implemented over large areas. However, the dynamic nature of both fire and riparian communities means that the effects of fire management will likely last less than a decade.

Grazing affects many aspects of riparian vegetation structure and composition (Taylor and Littlefield 1986; Kauffman et al. 1997; Krueper et al. 2003; Knopf et al. 2011). Grazing activity can have great effects on community composition and is often implemented over large and long scales. However, the dynamic nature of riparian communities means that the effects of grazing will likely last less than a decade.

Planting regimes have the ability to greatly affect vegetation. However, planting decisions are made at the scale of individual restoration sites. Restoration sites are heavily managed, so the effects are likely medium or even long term.

NEST PREDATOR AND COWBIRD DENSITY

The controlling factor that directly affects the density of nest predators and cowbirds is recreational activities, although the direction and size of these effects are difficult to quantify. Recreational activities can increase the density of nest predators in an area (USFWS 2002a). In addition, recreational activities can influence nest predator densities by either increasing predator success rates through interfering with or distracting prey or by decreasing predator success rates through interfering with or distracting the predator (Mason 2015; Ware et al. 2015). The potential impact of recreational activities on YWAR habitat and nest predator density is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activity and riparian communities means that the effects of recreational activities will likely last less than a decade.

PATCH SIZE

The controlling factors that directly affect patch size include fire management, grazing, planting regime, and recreational activities. Fire management, grazing, and recreational activities will generally reduce the size of a given patch, whereas the effects of the planting regime depend on the management actions and species involved.

Fire affects many aspects of vegetation structure and composition (Naiman and Decamps 1997). Fire management can have great effects on vegetation structure and is usually implemented over large areas. However, the dynamic nature of both fire and riparian communities means that effects of fire management will likely last less than a decade.

Grazing affects many aspects of riparian vegetation structure and composition (Taylor and Littlefield 1986; Kauffman et al. 1997; Krueper et al. 2003; Knopf et al. 2011). Grazing activity can have great effects on community composition and is often implemented over large and long scales. However, the dynamic nature of riparian communities means that effects of grazing will likely last less than a decade.

Planting regimes have the ability to greatly affect vegetation. However, planting decisions are made at the scale of individual restoration site. Although riparian communities tend to be ephemeral, restoration sites are heavily managed, so the effects are likely medium or even long term.

The potential impact of recreational activities on YWAR habitat is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activities and riparian communities means that effects of recreation will likely last less than a decade.

PREDATOR DENSITY

The controlling factor that directly affects predator density is recreational activities, although the direction and size of its effects are difficult to quantify. Recreational activities can increase the density of predators in an area (USFWS 2002a). In addition, recreational activities can influence predator densities by either increasing predator success rates through interfering with or distracting prey or by decreasing predator success rates through interfering with or distracting the predator (Mason 2015; Ware et al. 2015). The potential impact of recreation on YWAR habitat and predator density is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activity and riparian communities means that effects of recreational activities will likely last less than a decade.

TREE DENSITY

The controlling factors that directly affect tree density include fire management, mechanical thinning, natural thinning, nuisance species introduction and management, planting regime, and recreational activities. Fire management, mechanical/natural thinning, and recreational activities will generally reduce tree density, whereas the effects of nuisance species introduction and management and the planting regime depend on the management actions and species involved.

Fire affects many aspects of vegetation structure and composition (Naiman and Decamps 1997) and can destroy YWAR habitat. Fire management can have great effects on vegetation structure and is usually implemented over large areas. However, the dynamic nature of both fire and riparian communities means that effects of fire management will likely last less than a decade.

Mechanical thinning is generally performed at the patch level, with effects lasting until the vegetation grows back, and it can be as intense as managers deem necessary.

Although natural thinning affects tree density, it works on small scales, creating forest gaps. The effect only lasts until the vegetation grows back.

Nuisance species can change the structure of entire communities, with lasting effects. Although the effects are experienced at a patch level, nuisance invasive species can spread across entire regions, and their effects can last decades if not resulting in a permanent transformation.

Planting regimes have the ability to greatly affect vegetation. However, planting decisions are made at the scale of individual restoration sites. Restoration sites are heavily managed, so the effects are likely medium or even long term.

The USFWS (2002a) states that recreational activities can affect the density of riparian vegetation. The potential impact of recreational activities on YWAR habitat is great, although it depends on the activity. Decisions regarding management of recreational activities can affect large areas, but the dynamic nature of both human activity and riparian communities means that effects of recreation will likely last less than a decade.

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

- Predation and foraging/eating are likely the most important critical biological activities and processes affecting survival of YWAR in all life stages. Depredation of nests can be high (Theimer et al. 2011). The effects likely act at the landscape scale, and the effects of a change in rates of predation probably last less than a decade. Other processes, such as disease, molt, and temperature regulation can be very important, but are less understood, especially within the LCR.

- Only two processes affect reproduction—nest attendance and nest site selection. These two critical biological activities and processes are especially important because they also affect the survival of the nestlings.

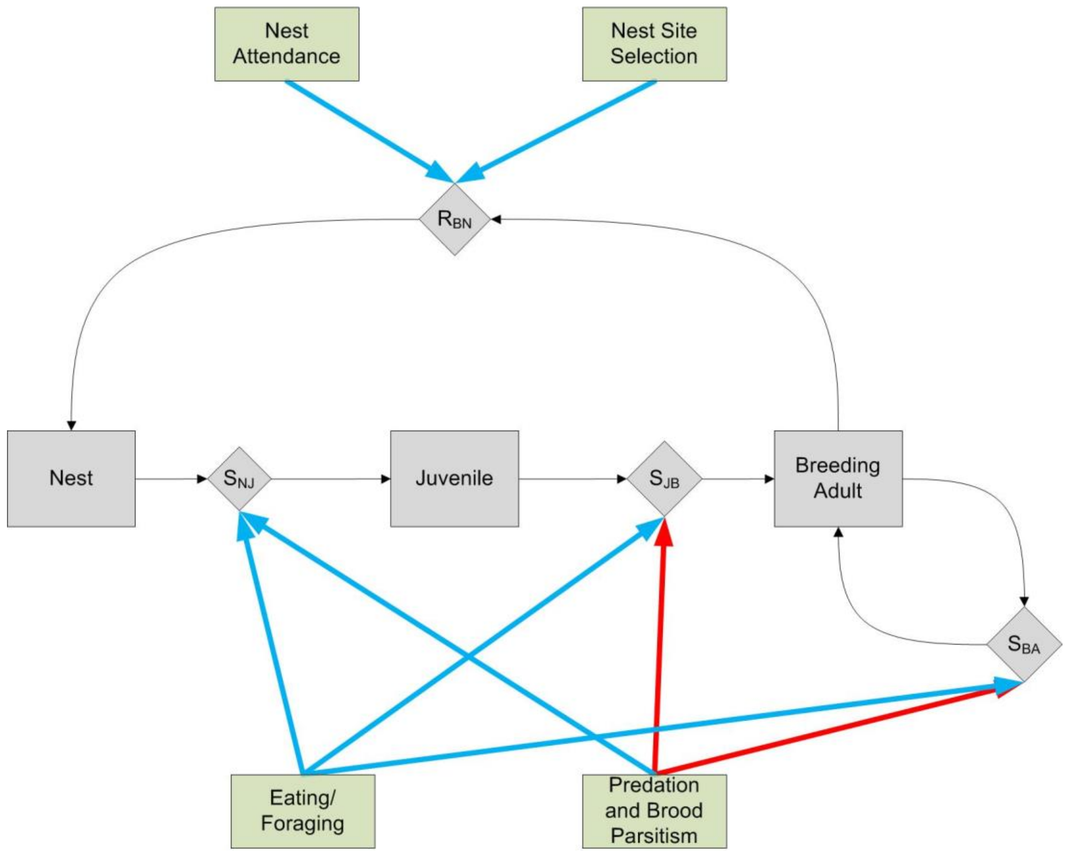

Figure 9.—Most influential biological activities and processes affecting each life stage. Only elements with high- or medium-magnitude connections are presented. The legend is provided on figure 2.

POTENTIALLY PIVOTAL ALTERATIONS TO HABITAT ELEMENTS

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

- Nest site selection is reported to be affected by the largest number of habitat variables likely because this critical biological activity is the most researched among those on figure 10.

- Nest predation/predation is only strongly affected by two habitat elements—patch size and predator density. Patch size affects predation rates because of its effects on the proportion of edge (Yahner 1988; Cain et al. 2003, 2006; Theimer et al. 2011). Predator density also affects predation rates (Schmidt and Whelan 2005).

- Parental nest attendance is only strongly affected by brood size. Brood size affects the amount of time adult YWAR must spend foraging versus attending the nest.

- Foraging is affected strongly by food availability and the matrix community. The reason the matrix community is scored as a medium magnitude effect is because of the medium spatial and temporal scales of the effect and not because we believe this is an intense effect.

GAPS IN UNDERSTANDING

Figures 9 and 10 use the conventional color coding of individual causal relationships to identify relationships that the CEM identifies as having high, intermediate, or low levels of scientific confirmation. As noted in attachment 1, "Low" scientific understanding of a relationship means that it is "… subject to wide disagreement or uncertainty in peer-reviewed studies from within the ecosystem of concern and in scientific reasoning among experts familiar with the ecosystem." In many cases, the scientific principles are well understood, but the factual details are insufficiently understood within the LCR. The two figures show large numbers of red arrows, indicating relationships that the assessment identifies as having a low level of scientific understanding. Each

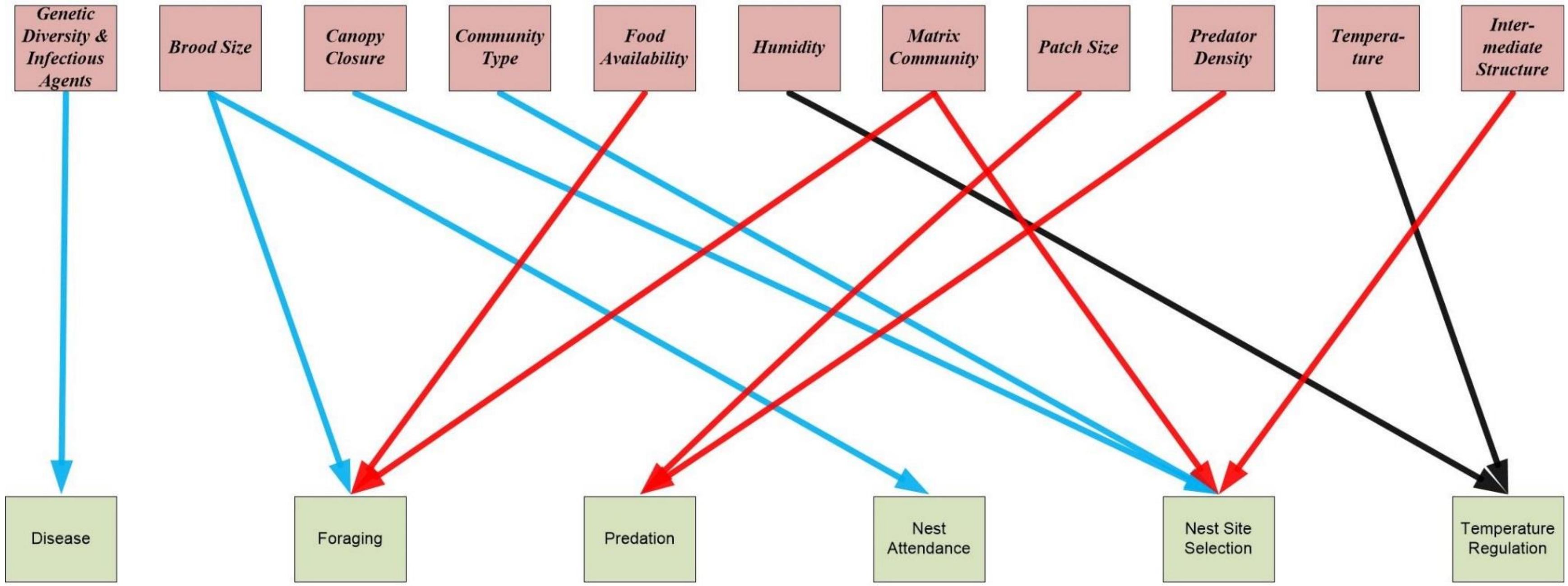

Figure 10.—Habitat elements that directly or indirectly affect the most influential biological activities and processes of YWAR. Note that eating and nest predation and brood parasitism only apply to the nest stage and are not shown, but they are affected by roughly the same processes as foraging and predation. The legend is provided on figure 2.

of these red arrows identifies a causal relationship that may warrant further field, laboratory, or literature investigation. The following paragraphs highlight some potentially important areas of low understanding.

- Nest site selection is by far affected by the most habitat variables and is likely one of the most well-studied processes. However, conflicting study results indicate that more research is needed, especially regarding intermediate structure.

- The effects of predation on juveniles and adults are poorly understood, whereas nest predation is better studied. In addition, the effects of habitat on rates of predation are also poorly understood. This likely reflects the relative ease of studying depredation of nests versus predation of free-flying birds. Studies of predation would likely be expensive and, therefore, would only be a priority if the persistence or population growth of YWAR populations along the LCR is considered sensitive to the survival of adults and juveniles.

- The effects of the matrix community on foraging and nest site selection are not well understood. The lack of understanding of the matrix community highlights the need to study the effects of certain habitat attributes at multiple scales. The literature on specifically studying scales of site selection for yellow warblers is reviewed in chapter 3, "Nest Site Selection." The LCR MSCP might consider conducting studies similar to Saab's (1999) along the LCR.

- The results of quantitative and qualitative studies of the effects of food availability on foraging are conflicting. Therefore, there is uncertainty regarding the importance of food availability on the persistence of YWAR subpopulations. In addition, although the effect of food availability on nest site selection is considered to be of low magnitude, there is major uncertainty. Therefore, studies of insect abundance at used versus non-used sites and of the effects of local hydrology and vegetation characteristics on insect abundance might be informative.

This list of uncertainties is not meant to be exhaustive but only to highlight topics the literature identifies as potentially pivotal to YWAR 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 LCR MSCP, nor are these knowledge gaps expected to be addressed under the program.

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ACKNOWLEDGMENTS

The authors would like to acknowledge Chris Dodge and Laura Sabin, biologists with Reclamation, LCR MSCP; Carrie Ronning, Wildlife Group Manager, LCR MSCP; and Sonja Kokos, Adaptive Management Group Manager, LCR MSCP, who provided invaluable technical feedback and guidance during the development of the model process and production of this report. We would also like to acknowledge John Swett, Program Manager, LCR MSCP, for his leadership and support of this modeling effort that will guide and inform the work of the LCR MSCP well into the future.

ATTACHMENT 1

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

OVERVIEW OF METHODOLOGY

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

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

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

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

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

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

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

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

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

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

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

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

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

(1) The effect of one controlling factor on another

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

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

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

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

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

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

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

Conceptual Ecological Models as Hypotheses

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

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

Characterizing Causal Relationships

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

(1) The character and direction of the effect

(2) The magnitude of the effect

(3) The predictability (consistency) of the effect

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

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

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

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

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

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

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

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

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

Conceptual Ecological Model Documentation

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

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

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

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

Link Attribute Ratings, Spreadsheet Fields, and Diagram Conventions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

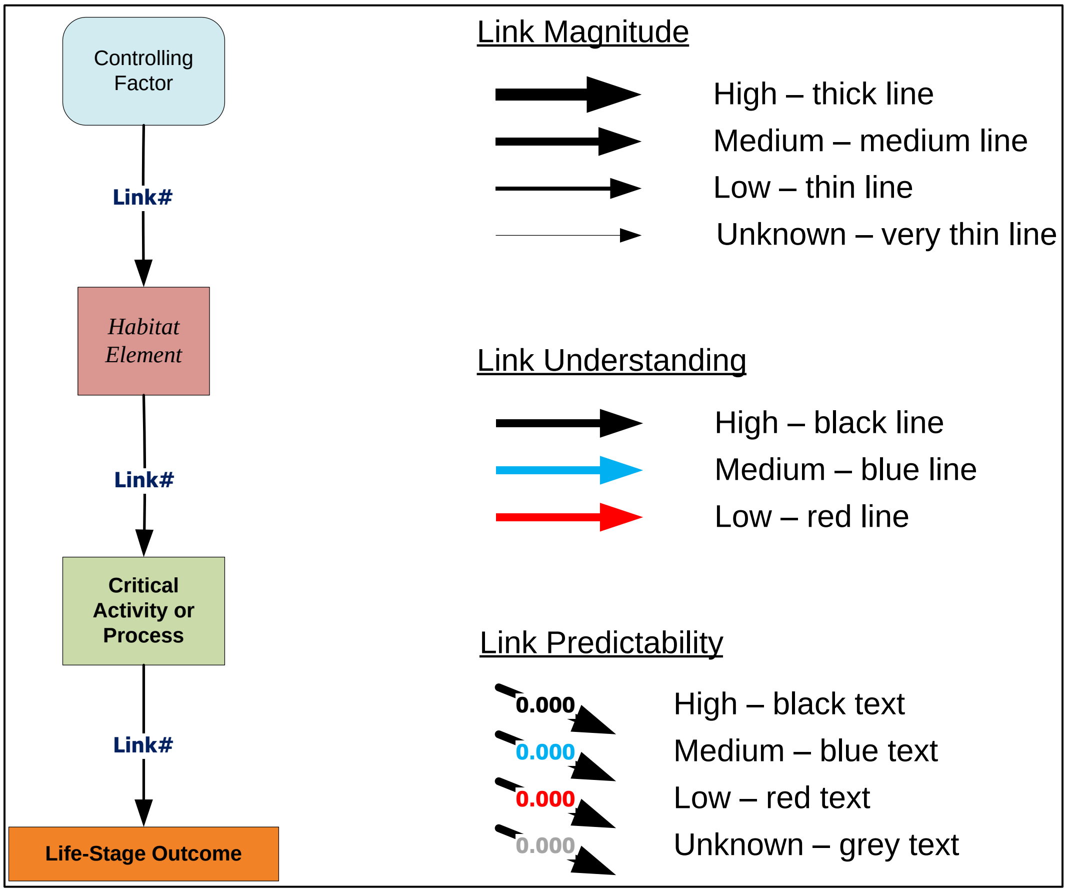

Figure 1-1.—Conventions for displaying cause and effect nodes, linkages, link magnitude, link understanding, and link predictability.

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ATTACHMENT 2

Sonoran Yellow Warbler Habitat Data

Table 2-1.—Sonoran yellow warbler (YWAR) habitat data

Habitat element	Value or range	Location	Reference
Anthropogenic disturbance	< 55 a-weighted decibels * During migration	Idaho	McClure et al. 2013
Canopy closure	Territories = 19.6%, confidence interval (CI) = 14.4–24.8%; random = 25.5%, CI = 17.8–33.2% * Canopy closure	British Columbia	Quinlan and Green 2012
	Use = 12.3, range = 0.9–72; non-use = 4.3, range = 0–16 * Canopy closure	Lower Colorado River	Great Basin Bird Observatory (GBBO 2011)
Community type	Percent of use sites = 11; percent of non-use sites = 19 * Mesquite (*Prosopis* sp.) present in territory	Lower Colorado River	GBBO 2011
	Use = 7.7, range = 0–32; non-use = 0.3, range = 0–4 * Number of large Goodding's willow (*Salix gooddingii*) (> 20 centimeters diameter at breast height (DBH) and > 4 meters tall)	Lower Colorado River	GBBO 2011
	Use = 2.3, range = 0–39; non-use = 0.4, range = 0–5 * Number of large tamarisk (*Tamarix ramosissima*) (> 20 centimeters DBH and > 4 meters tall)	Lower Colorado River	GBBO 2011

Table 2-1.—Sonoran yellow warbler (YWAR) habitat data

Habitat element	Value or range	Location	Reference
Intermediate structure	Use = 46.3, CI = 34.6–58.0; non-use = 36.8, CI = 25.6–48.0 * Cover < 5 meters measured using a densiometer	British Columbia	Quinlan and Green 2012
	Use = 249, CI = 214–284; non-use = 120, CI = 95–145 * Number of deciduous stems < 8 centimeters DBH	British Columbia	Quinlan and Green 2012
	30–80% * Natural concealment range, predation worse when < 30%	California	Latif and Rotenberry 2012
	Use = 1.6, random = 15.2 * Distance to closest bush in any quadrant	Colorado	Knopf and Sedgwick 1992
	Use = 34.4, random = 52.5 * Calculated value radius for the five bushes	Colorado	Knopf and Sedgwick 1992
	Use = 15.8, random = 81.8 * Distance to nearest bush in each quadrant	Colorado	Knopf and Sedgwick 1992
	Present = 40%, standard error (SE) = 2.3; absent = 22%, SE = 0.6 * Shrub cover	California	Humple and Burnett 2010
	Suppressed = 9.61, SE = 3.15; released = 21.42, SE = 3.29; previously tall = 60.39, SE = 3.15 * Horizontal cover; YWAR absent from suppressed areas	Yellowstone National Park	Baril et al. 2011
	Campground = 52.5; non-campground = 109.6 * Shrub/sapling stems, YWAR most abundant in camp-grounds	Utah	Blakesley and Reese 1988

Table 2-1.—Sonoran yellow warbler (YWAR) habitat data

Habitat element	Value or range	Location	Reference
Local hydrology	Native = 0.10, SE = 0.04; non-native = 0.04, SE = 0.02 * Proportion of site covered with water; YWAR most abundant at native sites	Lower Colorado River	Shanahan et al. 2011
	Native = 42.4, SE= 8.9; exotic = 14.5, SE = 4.1 * Soil moisture; YWAR most abundant at native sites	Lower Colorado River	Shanahan et al. 2011
Tree density	Use = 12.5, range = 0–108; non-use = 0.4, range = 0–5 * High canopy trees (> 10 meters)	Lower Colorado River	GBBO 2011
	Use = 16.3, range = 0–53; non-use = 5.1, range = 0–105 * Large trees (> 20 centimeters DBH and > 4 meters in height)	Lower Colorado River	GBBO 2011
	Campground= 19.9; non-campground = 28.3 * Total number of trees; YWAR most abundant in campgrounds	Utah	Blakesley and Reese 1988

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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