Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) (YBCU) Basic Conceptual Ecological Model for the Lower Colorado River

Life Stages, Critical Biological Activities and Processes, Habitat Elements, and Controlling Factors

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U.S. Department of the Interior
Bureau of Reclamation

December 2013

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Lower Colorado River Multi-Species Conservation Program

Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) (YBCU) Basic Conceptual Ecological Model for the Lower Colorado River

Life Stages, Critical Biological Activities and Processes, Habitat Elements, and Controlling Factors

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http://www.lcrmscp.gov

December 2013

ACRONYMS AND ABBREVIATIONS

CEM	conceptual ecological model
ERP	Sacramento-San Joaquin Delta Ecosystem Restoration Program
km	kilometer(s)
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
Reclamation	Bureau of Reclamation
YBCU	western yellow-billed cuckoo

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EXECUTIVE SUMMARY

This document presents a conceptual ecological model (CEM) for the yellow-billed cuckoo (*Coccyzus americanus occidentalis*) (YBCU). 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 YBCU ecology, the effects of specific stressors, the effects of specific management actions aimed at habitat and species restoration, and the methods used to measure YBCU habitat and population conditions.

Conceptual Ecological Models

Conceptual ecological models 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 methodology applied to the razorback sucker 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 shape the abundance, distribution, and persistence of the species in that area.

Specifically, the YBCU conceptual ecological model has four core components:

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

  Critical biological activities and processes – These consist of the activities in which the species must engage and the biological processes that must take place during each life stage to sustain an acceptable rate of transition (recruitment) to the next life stage.

- **Habitat elements** – These consist of the specific habitat conditions that are necessary or sufficient for the critical activities and processes to take place or that interfere with critical activities or processes. The abundance and distribution of habitat elements control the rates (intensities) of the activities and processes that they affect.

- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the abundance, spatial and temporal distribution, and quality of important habitat elements. Controlling factors are also called "drivers."

The CEM identifies the causal relationships among these components that affect the rate at which individuals of a species survive and transition (recruit) from one life stage to the next. Further, the model 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 status (certainty) of present a scientific understanding of the effect. CEM diagrams and a linked spreadsheet tool document all information on the model components and their causal relationships.

Structure of the YBCU Conceptual Ecological Model

The YBCU conceptual ecological model addresses the YBCU population along the river and lakes of the lower Colorado River (LCR) and in wildlife refuges and other protected areas along the LCR managed as YBCU habitat under the auspices of the LCR MSCP Habitat Conservation Plan. The model thus addresses the landscape as a whole rather than any single reach or managed area.

The basic sources of the information on the CEM summarized below include Laymon et al. (1997), Hughes (1999), Halterman (2002), McNeil et al. (2013), Reclamation (2004, 2008), and BIO-WEST (2005). These publications summarize and cite large bodies of earlier studies. The model also integrates numerous additional sources, particularly reports and articles completed since these publications; information on current research projects; and the expert knowledge of LCR MSCP biologists. Our purpose is not to simply provide an updated literature review, but to integrate the available information into a conceptual ecological model.

The YBCU conceptual ecological model distinguishes and assesses four life stages as follows:

1. Egg
2. Nestling
3. Juvenile
4. Breeding adult

The YBCU conceptual ecological model distinguishes 9 critical biological activities or processes relevant to 1 or more of 4 life stages, 20 habitat elements relevant to 1 or more of these 9 critical biological activities or processes for 1 or more life stages, and 8 controlling factors that affect 1 or more of these 20 habitat elements. Because the LCR and its refuges comprise a highly regulated system, the controlling factors exclusively concern human activities.

The nine critical biological activities and processes identified across all life stages are: disease, molt, nest site selection, foraging, nest attendance, predation, temperature regulation, eggshell thinning, and eating.

The 20 habitat elements identified across all life stages are: canopy cover, understory density, patch size, linear width of patch, food availability, community type, matrix community, local hydrology, tree density, parent nest attendance, temperature, humidity, predator density, siblings, brood size, genetic diversity and infectious agents, anthropogenic disturbance, patch phenology, distance to occupied patch, and diversity of vegetation.

The eight controlling factors identified across all habitat elements are: pesticide application, main stem water storage-delivery management, fire management, grazing, mechanical thinning, natural thinning, planting regime, and nuisance species introduction and management.

INTRODUCTION

This document presents the core components of a conceptual ecological model (CEM) for the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) (YBCU). 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 YBCU ecology, the effects of specific stressors, the effects of specific actions aimed at habitat and species restoration, and the methods used to measure YBCU 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.

The model addresses the YBCU population along the river and lakes of the lower Colorado River (LCR) and in wildlife refuges and other protected areas along the LCR managed as YBCU habitat under the auspices of the LCR MSCP Habitat Conservation Plan. The model thus addresses the landscape as a whole rather than any single reach or managed area.

The basic sources of the information on the CEM summarized below include Laymon et al. (1997), Hughes (1999), Halterman (2002), McNeil et al. (2013), Reclamation (2004, 2008), and BIO-WEST (2005). These publications summarize and cite large bodies of earlier studies. The model also integrates numerous additional sources, particularly reports and articles completed since these publications; information on current research projects; and the expert knowledge of LCR MSCP biologists. Our purpose is not to simply provide an updated literature review, but to integrate the available information into a CEM.

Conceptual Ecological Model Purposes

Adaptive management of natural resources requires a framework that helps 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. For this discussion, a resource may be a population, species, habitat, or ecological system. The best of such frameworks incorporate the combined knowledge of many professionals that has been accumulated over years of investigations and management actions. CEMs capture and synthesize this knowledge in a transparent, flexible framework (Fischenich 2008; DiGennaro et al. 2012).

Conceptual ecological models explicitly identify: (1) the parameters or attributes that best characterize resource conditions; (2) the physical and ecological 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 these factors affect this shaping or 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 we expect the characteristics of the resource to 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 see others as less so. Through the CEM, scientists and managers can identify which hypotheses – and the assumptions on which they rest – 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 and clarify the CEM – improving certainty about some aspects of the model while requiring changes to others. These changes then guide the next cycle of management action and research. The CEM, through its successive iterations, becomes the record for increasing knowledge and the ability to manage the system.

Conceptual Ecological Model Structure for the YBCU

The CEM methodology used for the YBCU 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 Kondolf et al. (2008) and Burke et al. (2009) to provide greater detail on causal linkages and outcomes. Attachment A provides a detailed description of the methodology. The model is a “life history” model, as is common for CEMs focused on individual species (Wildhaber et al. 2007), and it distinguishes the major life stages or events through which the individuals of a species must pass in order to complete a full reproductive cycle. It then identifies the factors that shape the likelihood that, within the study area, individuals in each life stage will survive to the next stage. These factors are key to maintaining the abundance, distribution, and persistence of the species in the study area.

The CEM has four core components as explained in attachment A:

- **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 reproductive cycle.

- **Critical biological activities and processes** – These consist of the activities in which the species must engage and the biological processes that must take place during each life stage to sustain an acceptable rate of transition (recruitment) to the next life stage. Examples of activities and processes for a bird species may include nesting, foraging, avoiding predators, and avoiding other specific hazards. Activities and processes may be considered "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 that are necessary or sufficient for the critical activities and processes to take place or that interfere with critical activities or processes. The abundance and distribution of habitat elements control the rates (intensities) of the activities and processes that they affect. Taken together, the suite of habitat elements for a life stage is called the "habitat template" for that life stage. Defining the habitat template also may involve estimating specific thresholds or ranges of suitable values for particular habitat elements, outside of which one or more critical life activities or processes begin to fail – if the state of the science supports such estimates.

- **Controlling factors** – These consist of environmental conditions and dynamics – including human actions – that determine the abundance, spatial and temporal distribution, and quality 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 breeding territories may depend on factors such as river flow rates and flow-path morphology, which in turn may depend on factors such as watershed geology, vegetation, and climate.

The CEM both characterizes these four components and identifies the causal relationships among them that affect the rate at which individuals of a species survive and transition (recruit) from one life stage to the next. Further, the model assesses each causal link 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 rate of success of the life stage, support or limit the rate of each critical biological activity or process, and support or limit the quality of each habitat element (as it affects other habitat elements, or affects 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 A 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.

YBCU LIFE STAGE MODEL

A “life stage” consists of a 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. The last two parts of this definition – concerning habitats and ecological interactions – are the most crucial for the purposes of the present CEM for the LCR MSCP.

The migratory nature of the YBCU complicates its management. The LCR MSCP is mainly responsible for management on the breeding grounds, and we therefore focus on four life stages occurring within LCR MSCP lands—egg, nestling, juvenile, and adult. YBCU management during migration and winter are certainly important, but outside of the scope of Reclamation’s responsibilities.

YBCU Life Stage 1 – Egg

We consider the egg stage to be the first in the life cycle of the YBCU. It begins when the egg is laid and ends at hatching. Incubation begins with the first egg laid and usually lasts 10 to 12 days, with eggs hatching asynchronously (Halterman 2002; Reclamation 2008).

YBCU Life Stage 2 – Nestling

The nestling stage lasts from the time the egg hatches until fledging, usually 5 to 8 days for YBCU, with most chicks fledging on day six (Halterman 2002;

Reclamation 2008). The entire nestling period from the time eggs are laid until fledging lasts roughly 17 days, among the shortest nestling periods of any bird, with nestlings gaining 4.9 grams per day (Hughes 1999).

YBCU Life Stage 3 – Juvenile

The juvenile stage begins at fledging and ends when the bird returns to the breeding grounds the next year. After fledging, juveniles are dependent on adults for food for 2 weeks (Laymon and Halterman 1985), although adults may feed the young for 3 to 4 weeks after fledging (Halterman 1991; McNeil et al. 2013).

YBCU Life Stage 4 – Breeding Adult

The 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. Generally, adults arrive on breeding grounds during mid to late-May (Halterman 2002; Reclamation 2008). Nesting can begin as early as late May (Halterman 2002) and continue into September, but generally peaks during July and early August (Halterman 2002; Reclamation 2008; McNeil et al. 2013).

Pair formation occurs from late June to mid-July (Halterman 1991). Both parents participate in the placement and building of the nest as well as incubation and feeding of young (Halterman 1991; Hughes 1999). YBCU may double or even triple brood if sufficient resources exist (Reclamation 2008; McNeil et al. 2013).

Although YBCU are known to be intra- and interspecific brood parasites, the frequency of brood parasitism is poorly understood (Hughes 1999; Wiggins 2005), and it likely occurs more often than assumed (McNeil et al. 2013). YBCU are mostly monogamous; however, approximately 30 percent of nests may have helpers, which are typically young, unrelated males that feed nestlings (Laymon 1998; Hughes 1999). YBCU populations along the LCR likely contain an abundance of "floaters" or adult birds that do not breed (McNeil et al. 2013). We have included breeding males and females as well as floaters and helpers in the breeding adult life stage because they have similar habitat requirements—especially for foraging—and therefore management directed at breeding adults will likely benefit all demographics present on the breeding grounds.

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 of some species may prospect for potential future breeding areas or move into habitat types that differ from breeding areas but provide good conditions for migratory staging (Vega Rivera et al. 2003). However, 83 percent of YBCU captured along the LCR remain on their territories until they leave the area (McNeil et al. 2013), suggesting that habitat use by YBCU is constant while they are present along the LCR.

Life Stage Model Summary

Based on this information, the YBCU conceptual ecological model distinguishes four life stages as follows and as shown on figure 1. The life stages are numbered sequentially beginning with the gametes and eggs.

1. Egg
2. Nestling
3. Juvenile
4. Breeding adult

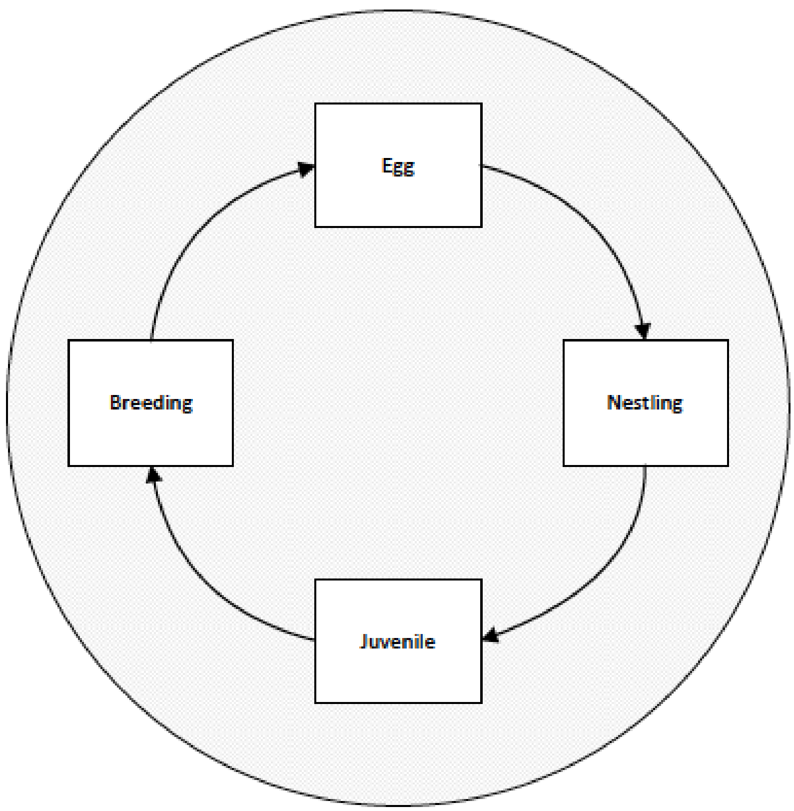

Figure 1.—Proposed CEM for the YBCU.

CRITICAL BIOLOGICAL ACTIVITIES AND PROCESSES

Critical biological activities and processes consist of the activities in which the species must engage and the biological processes that must take place during each life stage to sustain an acceptable rate of transition (recruitment) to the next life stage. Critical activities and processes may be considered critical "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).

This section identifies a set of nine critical activities and processes that affect one or more YBCU life stages. Some of these activities or processes differ in their details between life stages. For example, YBCU of different life stages differ in their ability to thermoregulate. 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 1 lists the nine critical activities and processes and their distribution across life stages.

Table 1.—Distribution of YBCU 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	**Egg**	**Nestling**	**Juvenile – Breeding grounds**	**Adult – Breeding**
Disease	X	X	X	X
Molt		X	X	X
Nest site selection				X
Foraging			X	X
Nest attendance				X
Predation			X	X
Temperature regulation	X	X	X	X
Eating		X		
Eggshell thinning	X			

Disease

This process refers to diseases caused either by lack of genetic diversity or by infectious agents. Little is known about disease prevalence or its effects on YBCU populations along the LCR. All life stages are conceivably susceptible to disease.

Molting

Nestling, juvenile, and adult YBCU must molt during their time along the LCR. Molting is an energetically costly process that may make nestlings more susceptible to death when resources are scarce.

Nest Site Selection

Both breeding males and females select a nest site (Halterman 1991; Hughes 1999). Nest site selection is important for reproductive success because nest success varies spatially (McNeil et al. 2013).

Foraging

YBCU are primarily gleaning insectivores, although they will also sally from a perch to catch insects on the wing (Hughes 1999; Reclamation 2008). Their primary diet is large insects, but they will sometimes take small vertebrates such as tree frogs (Hughes 1999; Reclamation 2008). Foraging is done by juveniles and adults, but it is important to note that foraging by the parents affects the provisioning rate to nestlings and nest attendance by adults.

Nest Attendance

Both males and females participate in incubation and feeding young (Halterman 1991; Hughes 1999). Breeding adults attend the nest, and this affects the survival of nestlings and eggs.

Predation

Predation is a threat in all life stages, and it obviously affects survival. The predators of and rates of predation upon eggs and nestlings are much better understood (McNeil et al. 2013) than predation upon adults and juveniles, although it has been suggested that Cooper's hawk may be the primary predator of adult YBCU (Reclamation 2008).

Temperature Regulation

Temperature regulation is important for any organism inhabiting a region with temperatures as high as the LCR. Although overheating is possible in all life stages, most of the concern has been toward eggs and nestlings (Hunter et al. 1987a, 1987b; Rosenberg 1991). Adults can affect the temperature regulation of eggs and nestlings through their own behavior (incubation or shading) and through nest placement.

Eating

This process only applies to the nestling stage because they must eat to stay alive and develop, but do not actively forage within their environment in the same way as the juveniles and adults. A nestling's ability to eat is determined by the foraging and provisioning rate of its parents.

HABITAT ELEMENTS

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

This section identifies 20 habitat elements that affect 1 or more critical biological activities or processes across the four YBCU life stages. Some of these habitat elements apply to multiple spatial scales. For example, canopy cover could act at the patch and microhabitat scales, with YBCU choosing patches with heterogeneous vegetation density and nest sites within those patches with enough canopy cover 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 2 lists the 20 habitat elements and their distribution across the 4 YBCU life stages.

Table 2.—Distribution of YBCU habitat elements among life stages

Life stage ➔ / 🡻 Critical activity or process	Egg	Nestling	Juvenile – Breeding grounds	Adult – Breeding
Canopy cover	X	X	X	X
Understory density	X	X	X	X
Patch size	X	X	X	X
Linear width	X	X	X	X
Food availability	X	X	X	X
Community type	X	X	X	X
Matrix community	X	X	X	X
Local hydrology	X	X	X	X
Tree density	X	X	X	X
Parent nest attendance	X	X		
Temperature	X	X	X	X
Humidity	X	X	X	X
Predator density			X	X
Siblings		X	X	
Brood size				X
Genetic diversity and infectious agents	X	X	X	X
Anthropogenic disturbance	X	X	X	X
Patch phenology	X	X	X	X
Distance to occupied patch				X
Diversity of vegetation				X

The diagrams and other mentions of habitat elements elsewhere in this document identify the habitat elements by a short name of mostly one or two words such as predator density.” However, each name in fact refers to some variant of a longer phrase such as abundance and distribution of predators. The definitions below document this full name and meaning.

Canopy Cover

Defined as: **The density of foliage in the overstory.** This element refers to the percent canopy closure/density of canopy vegetation in the vicinity of the YBCU nest site. Canopy cover of riparian vegetation, especially higher density in the upper canopy, has been shown to be important to YBCU (Laymon et al. 1997; Halterman 2004). Dense vegetation around the nest may provide more optimal microclimate for thermal regulation (Rosenberg 1991; but see Balluff 2012; McNeil et al. 2013) and camouflage from nest predators, although heterogeneity in canopy cover within a given patch or landscape may also be desirable (see the

"Diversity of Vegetation" section below). Canopy cover may also affect the availability of food (Smith et al. 2006). Canopy cover is often related to tree density (James 1971; Rudnicki et al. 2004).

Understory Density

Defined as: **The density of the understory layer.** This element refers to the visual density of vegetation (i.e., concealment) below the uppermost canopy layer. This has been shown to be a factor in YBCU nest site selection (Gaines 1974; Gaines and Laymon 1984; Halterman and Laymon 1994). A more dense understory may support a more diverse and abundant invertebrate food supply as well as provide protection or camouflage from predators.

Patch Size

Defined as: **The size of riparian habitat patches.** This element refers to the area of a given patch of riparian vegetation. Patch size affects the number of breeding pairs that an area can support (Laymon et al. 1989; Launer et al. 1990; Halterman 2002) as well as the density of predators.

Linear Width of Patch

Defined as: **The width of a patch of riparian habitat.** This element refers to the width of riparian habitat along a corridor. Habitat width has been shown to influence cuckoo distribution and abundance (Gaines 1974), with wider habitat patches supporting cuckoo breeding. Patch width may also affect the presence of nest parasites and other predators.

Food Availability

Defined as: **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 YBCU will encounter during each life stage as well as the density and spatial distribution of the food supply in proximity to the nest. Cuckoos primarily feed on larger bodied insects such as caterpillars and katydids (Laymon 1980), and in some areas of their range, their nesting activity coincides with cicada emergences (Hughes 1999). The abundance and condition of the food supply affects adult health as well as the growth and development of the young during nestling and juvenile stages.

Community Type

Defined as: **The abundance and distribution of habitat with a suitable species composition.** This element refers to the species composition of riparian habitat used for breeding by YBCU. Research shows the ideal habitat to be composed primarily of cottonwood and willow (Gaines 1974; Laymon et al. 1989; Rosenberg 1991). We note here that Johnson et al. (2012) found that terrain roughness was useful in predicting site use by YBCU, but stated that this association was likely because it was a surrogate for areas containing the best patches of cottonwood-willow. Further, the data examined by Johnson et al. (2012) were mostly collected along the Bill Williams River, potentially limiting the extrapolation of their results to other areas along the LCR. We therefore did not include terrain roughness in our CEM, but recognize that it might be used to identify areas containing a community type appropriate for YBCU or areas suitable for revegetation.

Matrix Community

Defined as: **The type of habitat surrounding riparian patches used by cuckoos.** This element refers to the types of plant communities and land-use activities surrounding riparian habitat patches used by YBCU. For example, adjacent agricultural landscapes may have elevated pesticide loads, which may affect foraging by adult and juvenile birds. Further, Launer et al. (1990) suggested YBCUs would use orchards planted outside of riparian areas, and Halterman (2002) observed YBCUs foraging within mesquite areas surrounding riparian forests.

Local Hydrology

Defined as: **Aspects such as 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. Western YBCU are riparian obligates (Hunter et al. 1987b), typically found within 100 meters of water (Gaines 1974). The presence of moist soil or standing water affects food availability (e.g., supporting more and a greater diversity of invertebrates), and may provide cooler temperatures and more humid conditions that are necessary for egg and chick survival in these desert systems (Hunter et al. 1987a, 1987b; Laymon and Halterman 1987; Balluff 2012).

Tree Density

Defined as: **The 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 denser vegetative cover. Further, YBCU may use basal area as a criterion for site selection (Laymon et al. 1997).

Parent Nest Attendance / Parent Feeding Behavior

Defined as: **The ability of both parents to care for young during the egg/incubation and nestling stages at the nest or care for juvenile (post-fledging) young.** This element refers to the capacity for both parents to share nesting and brood rearing responsibilities until fledging. It is affected by the presence of predators, food availability, and the ability to thermal regulate.

Temperature

Defined as: **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). Thermal regulation/maintaining optimal temperatures is necessary for survival of chicks and adults. High temperatures typical of the LCR region in the summer can kill eggs and stress young in the nest (Hunter et al. 1987b; Rosenberg 1991).

Humidity

Defined as: **The amount of moisture in a habitat patch or nest site.** This element refers to the average relative humidity in the nesting habitat. Higher humidity levels may reduce the potential for egg desiccation and thermal stress and is important for egg and nestling survival in the more arid landscapes of the LCR region (McNeil et al. 2013).

Predator Density

Defined as: **The abundance and distribution of predators that affect YBCU during post-fledgling 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 YBCU during the juvenile or adult life stages. The variables of this element include the species and size of the fauna that prey on YBCU during different life stages, the density and spatial distribution of these fauna in the riparian habitat used by cuckoos, and whether predator activity may vary in relation to other factors (e.g., time of day, patch size and width, matrix community type, etc.).

Siblings

Defined as: **The presence of siblings in the nest.** This element refers to the number of siblings in the nest or that fledge, requiring ongoing parental care. The greater the number of young, the less food may be available for each, potentially affecting growth and survival of individual chicks.

Brood Size

Defined as: **The number of young in the nest.** This element refers to the number of young that the parents must rear. Clutch size is related to maternal health, and the wellbeing 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 “Predator Density” section).

Genetic Diversity and Infectious Agents

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

Anthropogenic Disturbance

Defined as: **Human activity within or surrounding a given habitat patch, including noise, pollution, and other disturbances associated with human activity.** An anthropogenic disturbance such as noise (reviewed by Barber et al. 2010; Francis and Barber 2013), and even non-consumptive human activity, can have negative effects on wildlife (reviewed by Boyle and Samson 1985).Activities such as hunting may also be affecting YBCU populations (McNeil et al. 2013).

Patch Phenology

Defined as: **The seasonal timing of changes in vegetation structure due to monsoons or irrigation.** The timing and intensity of changes in the vegetation structure of a given patch of riparian forest are affected by the spatial and temporal variation in seasonal monsoons (Wallace et al. 2013). This seasonal and spatial variation of "greening up" affects site use by YBCU (Wallace et al. 2013).

Diversity of Vegetation

Defined as: **Either horizontal or vertical diversity of the vegetation structure at the patch or microhabitat scales or diversity of community types at the landscape scale.** The diversity of vegetation affects site use by many animals (MacArthur and MacArthur 1961; Erdelen 1984; Wiens et al. 1993). YBCU prefer sites with dense shrub and canopy cover, which likely have high foliage height diversity. Horizontal diversity—or variation in vegetation density within a patch—also has been shown to positively affect site use by YBCU (Johnson et al. 2012). However, at a landscape scale, YBCU avoid sites surrounded by a high diversity of vegetation types—a measure of habitat fragmentation (Johnson et al. 2012).

CONTROLLING FACTORS

As noted in the "Introduction" section, controlling factors consist of environmental conditions and dynamics – both natural and anthropogenic – that determine the abundance, spatial and temporal distribution, and quality of the conditions that comprise the habitat template. A hierarchy of such factors exists, with long-term dynamics of climate and geology at the top. However, this CEM focuses on more 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.

Pesticide Application

This factor addresses pesticide applications that may occur on or adjacent to riparian habitat of the LCR region. Effects may include sublethal poisoning of

YBCU via ingestion of treated insects, pollution of runoff into wetland habitats that are toxic to prey of the YBCU, and a reduced invertebrate food supply (Laymon and Halterman 1987).

Main Stem Water Storage-Delivery Management

The LCR consists of a chain of reservoirs separated by flowing reaches. The water moving through this system is highly regulated for storage and delivery (diversion) to numerous international, Federal, State, Tribal, and municipal users and for hydropower generation. In addition, the dams along and above the LCR trap essentially all of the sediment that would have flowed past their locations prior to their construction. This combination of flow regulation, impoundments, and sediment trapping has created a river in which water management is the overwhelmingly dominant force that affects hydraulic and hydrogeomorphic dynamics (Reclamation 2004). The dynamic nature of a free-flowing river creates a mosaic of riparian habitats, and thus, a natural flow regime may be beneficial to the YBCU (Launer et al. 1990; Halterman and Laymon 1994).

Fire Management

This factor addresses any fire management (whether prescribed or suppression) that may occur along the LCR that could affect YBCU or their habitat. Effects may include creation of habitat that supports or excludes YBCU, a reduction in the food supply of invertebrates with soil stage (katydids, sphinx moths, cicadas) affected by hot fire (Smith et al. 2006), or support of species that pose threats to YBCU as predators or carriers of infectious agents.

Grazing

This factor addresses the grazing activity on riparian habitats along the LCR that could affect YBCU or their habitat. Grazing may thin the understory or even prevent the establishment of cottonwood and willow seedlings (Kauffman et al. 1997).

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 YBCU or support of species that pose threats to YBCU as predators or carriers of infectious agents. This factor includes the thinning of vegetation within both riparian and matrix communities.

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, patch size). Restoration areas are generally successful in providing habitat for YBCU (Rosenberg 1991; McNeil et al. 2013).

Nuisance Species Introduction and Management

This factor addresses the intentional or unintentional introduction of nuisance species (animals and plants) and their control that affects YBCU survival and reproduction. The nuisance species may infect, prey on, compete with, or present alternative food resources for YBCU during one or more life stages; cause other alterations to the riparian food web that affect YBCU; or affect physical habitat features such as canopy or shrub cover. For example, sites dominated by invasive salt cedar (*Tamarix* spp.) are generally considered as poor quality nesting habitat for YBCU (Gaines and Laymon 1984; Corman and Magill 2000; Johnson et al. 2012).

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 horizontal and vertical foliage profile needed by YBCU.

CONCEPTUAL ECOLOGICAL MODEL BY LIFE STAGE

The following four sections summarize the CEM for each YBCU 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 activities and processes, the controlling factors that determine the abundance and quality of these habitat elements, and the causal links among them. The model sections specifically refer to wildlife refuges and other protected areas managed as YBCU habitat, and thus address the landscape as a whole rather than any single reach or managed area.

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

- **Character and direction** categorizes a causal relationship as positive, negative, involving a threshold response, or complex. Positive means that an increase (or decrease) in the causal agent results in an increase (or decrease) in the affected element, and negative means that an increase (or decrease) in the agent results in a decrease (or increase) in the affected element. Thus, positive or negative here do *not* mean that a relationship is beneficial or detrimental. The terms only provide information analogous to the sign of a correlation coefficient. Threshold means that change in the causal agent must cross some value before we see an effect. Complex means that there is more going on than a simple positive, negative, or threshold effect.

- **Magnitude** refers to "…the degree to which a linkage controls the outcome relative to other drivers. While the models are designed to encompass critical drivers, linkages, and outcomes, this concept recognizes that some are more important than others in determining how the system works" (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.

- **Predictability** refers to the consistency with which the causal agent shapes the affected condition. The more variable the relationship, or the more the relationship depends on the interactions and effects of other factors, the less predictable the relationship (DiGennaro et al. 2012).

- **Scientific 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.

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

The diagrams for the life stages use a common set of conventions for identifying the controlling factors, habitat elements, critical biological activities and processes, and life stage success. Figure 2 illustrates these conventions. The diagrams also use a common set of conventions for displaying information about the causal links. Figure 2 also illustrates these latter conventions. The full methodology involves the assessment of the above four properties for each causal link; however, displaying the information on character and predictability results in extremely confusing diagrams. For this reason, the model diagrams for the individual life stages only display information on the magnitude and scientific understanding of each causal link. A separate spreadsheet tool records the assessment of all four properties for each causal link, along with the underlying rationale and citations. The CEM diagrams for the four life stages follow.

The causal relationships between controlling factors and habitat elements are essentially the same across all four life stages. For this reason, this section reserves the discussion of controlling factor-habitat element linkages to a separate section, covering all four life stages together.

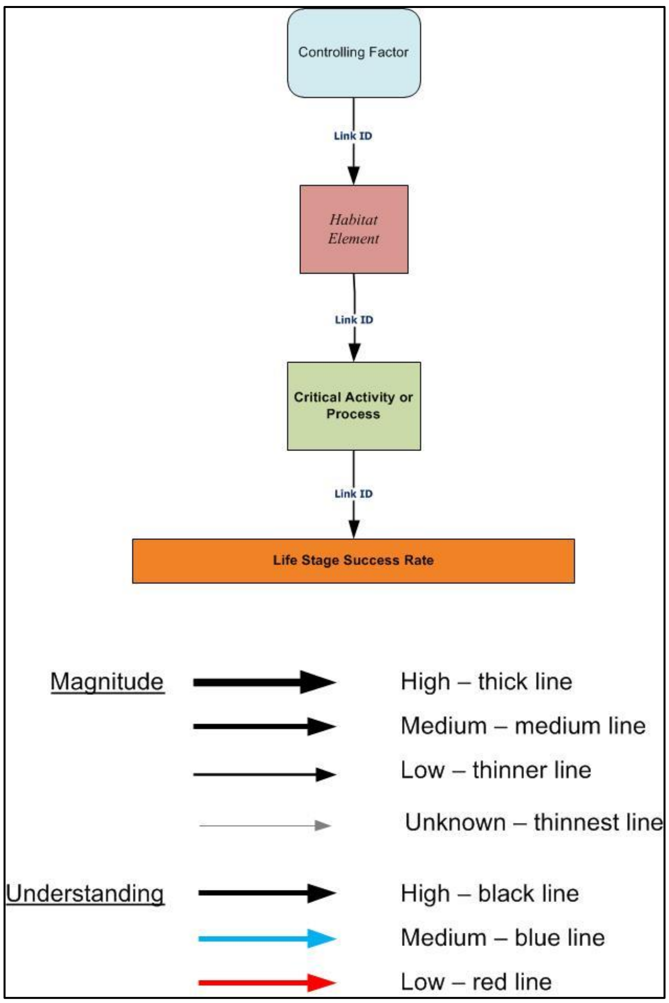

Figure 2.—Diagram conventions for LCR MSCP conceptual ecological models.

YBCU Life Stage 1 – Egg

We consider the egg stage to be the first in the life cycle of the YBCU. It begins when the egg is laid and ends at hatching. Success during this life stage – successful transition to the next stage – involves egg survival, maturation, and hatching. Since the eggs do not actively interact with their environment, critical biological activities and processes consist only of critical processes, which include:

1. **Temperature regulation** – The embryo must maintain an optimum temperature to develop within the egg.

   The CEM recognizes temperature and humidity as primary habitat elements directly affecting temperature regulation. Secondary habitat elements include parent nest attendance, canopy cover, and understory density.

2. **Predation** – Predation affects the survival of an egg.

   The CEM recognizes community type, linear width of patch, parent nest attendance, patch size, predator density, canopy cover, anthropogenic disturbance, understory density, and tree density as secondary habitat elements affecting predation.

3. **Disease** – Although the literature does not emphasize disease as affecting population levels of YBCU, we still feel that disease bears mentioning.

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

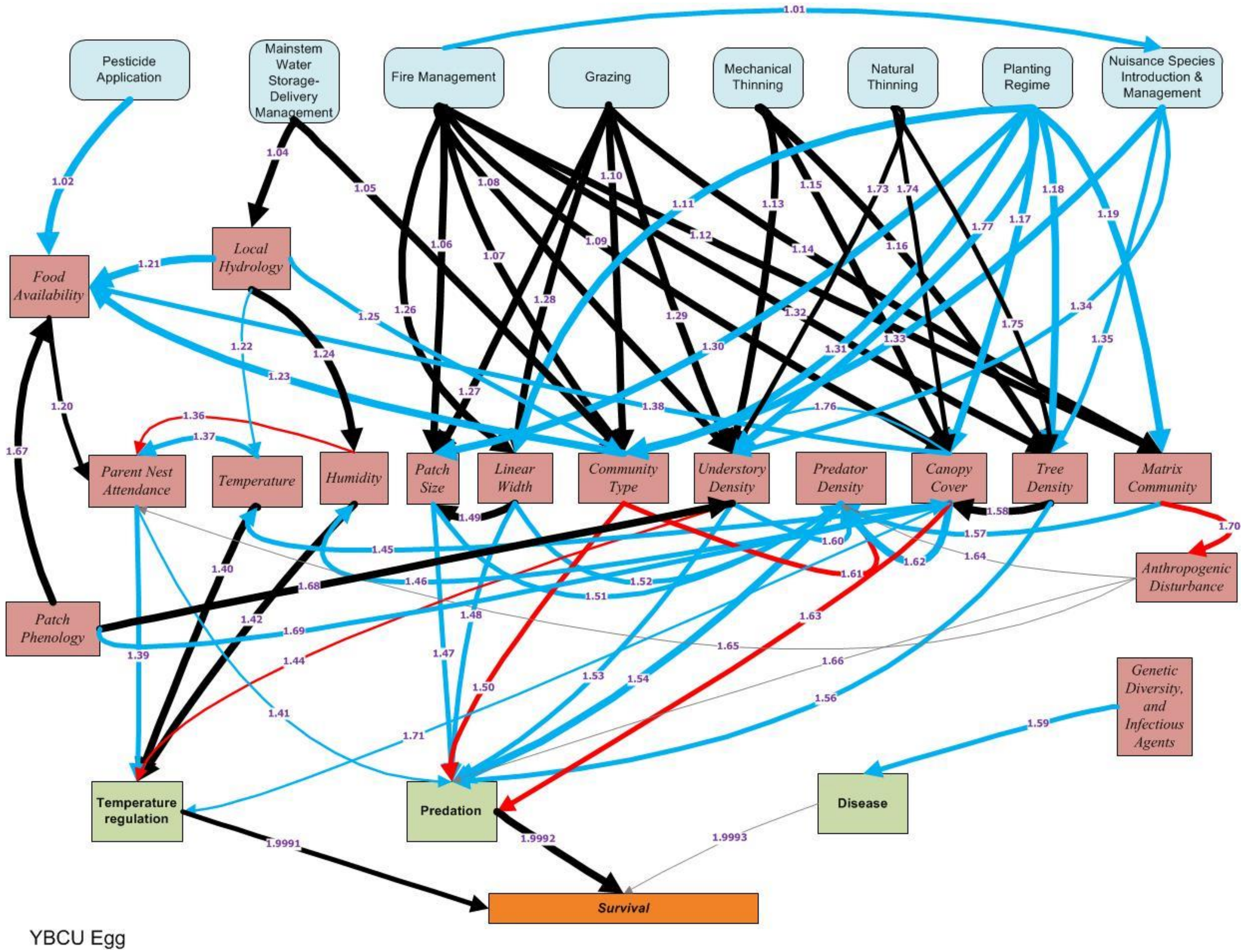

Figure 3.—Basic CEM diagram for life stage 1 – egg.

YBCU Life Stage 2 – Nestling

The nestling stage lasts from the time the egg hatches until fledging. 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. Critical biological activities and processes therefore consist of both activities and processes, which include:

1. **Temperature regulation** – The nestling must maintain an optimum temperature to develop and survive.

   The CEM recognizes temperature and humidity as the primary habitat elements affecting temperature regulation. Secondary habitat elements affecting temperature regulation include parent nest attendance, canopy cover, and understory density.

2. **Predation** – Predation affects the survival of a nestling.

   The CEM recognizes community type, linear width of patch, parent nest attendance, patch size, predator density, canopy cover, anthropogenic disturbance, understory density, and tree density as secondary habitat elements affecting predation.

3. **Disease** – Although the literature does not emphasize disease as affecting population levels of YBCU, we still feel that disease bears mentioning.

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

4. **Eating** – The nestling must eat to maintain metabolic processes.

   The CEM recognizes parent nest attendance as a primary habitat element affecting eating. Secondary habitat elements affecting eating include siblings and anthropogenic disturbance.

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

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

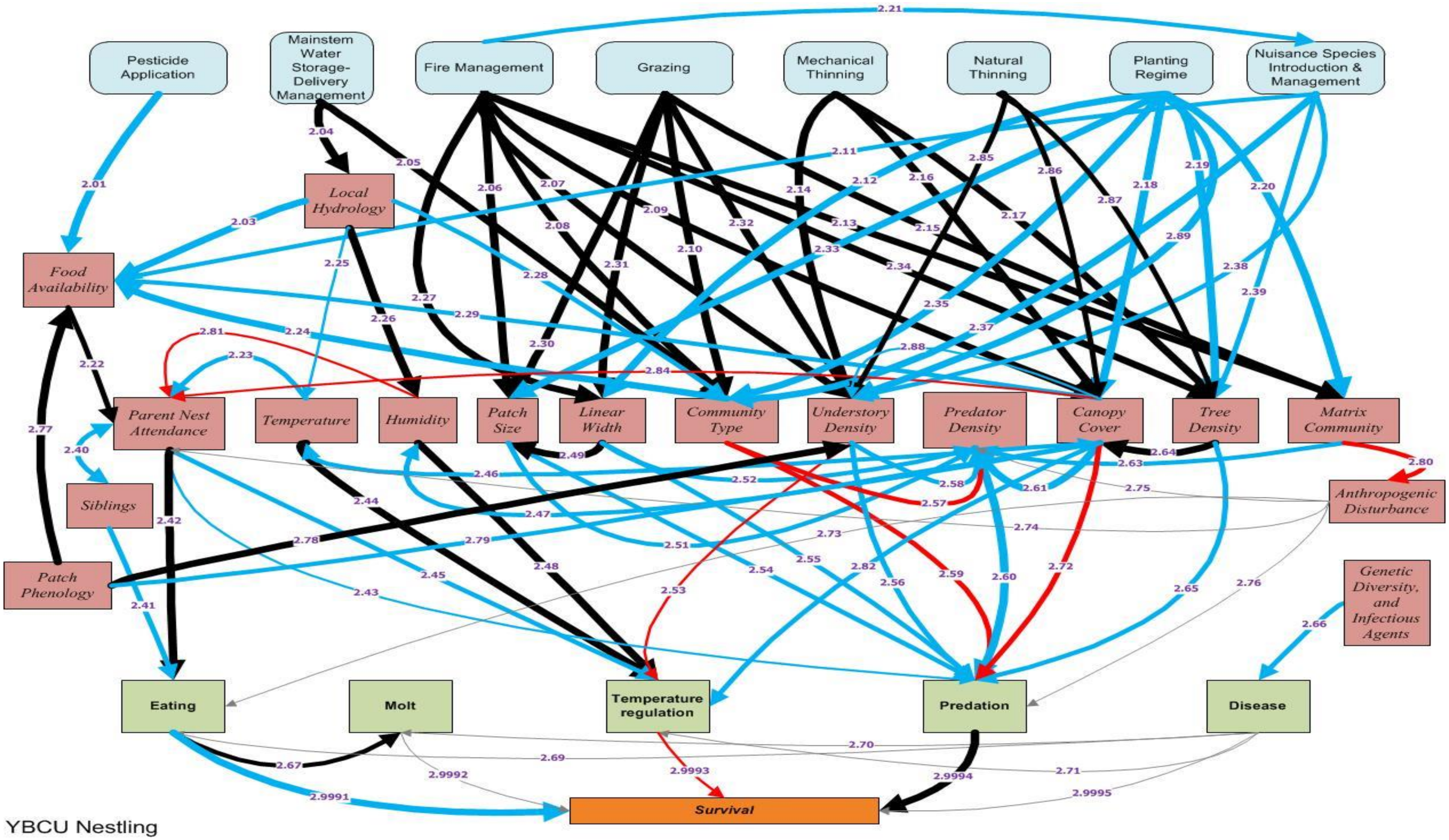

Figure 4.—Basic CEM diagram for life stage 2 – nestling.

YBCU Life Stage 3 – 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, maturation, and molt. The organisms actively interact with their environment. Critical biological activities and processes therefore again consist of both activities and processes, which include:

1. **Temperature regulation** – The juvenile must maintain an optimum temperature to survive.

   The CEM recognizes temperature and humidity as primary habitat elements affecting temperature regulation. Secondary habitat elements affecting temperature regulation include canopy cover and understory density.

2. **Predation** – Predation affects the survival of a juvenile.

   The CEM recognizes community type, linear width of patch, parent nest attendance/parent feeding behavior, patch size, predator density, canopy cover, anthropogenic disturbance, understory density, and tree density as secondary habitat elements affecting predation.

3. **Disease** – Although the literature does not emphasize disease as affecting population levels of YBCU, we still feel that disease bears mentioning.

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

4. **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 parent nest attendance/parent feeding behavior, food availability, anthropogenic disturbance, and canopy cover as secondary habitat elements affecting foraging.

5. **Molt** – The juvenile must molt into basic plumage, and the process begins on breeding grounds.

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

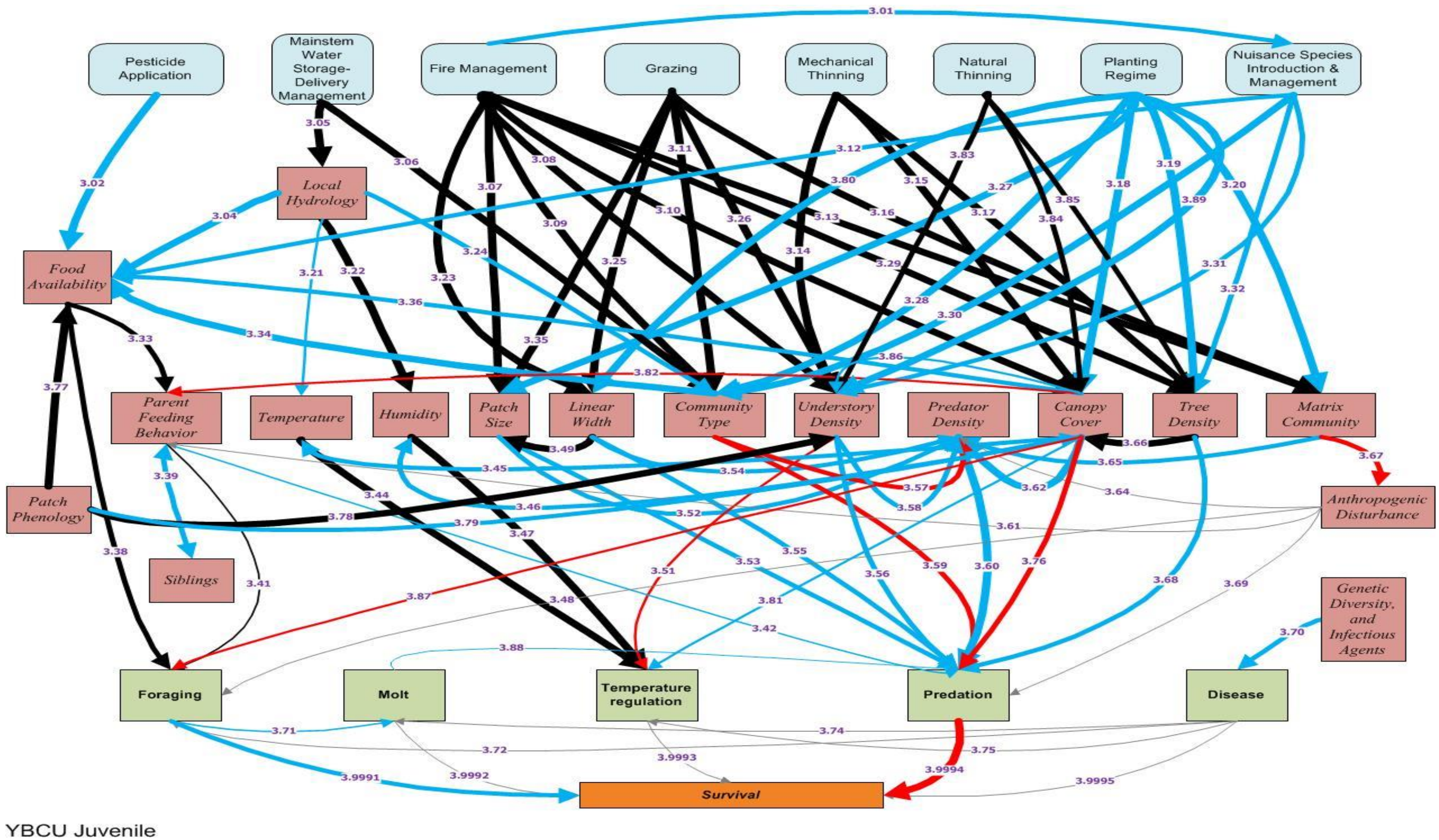

Figure 5.—Basic CEM for life stage 3 – juvenile.

YBCU Life Stage 4 – Breeding Adult

The 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. Success during this life stage – successful transition to the next stage –involves organism survival, breeding, and molt. The organisms actively interact with their environment. Critical biological activities and processes therefore again consist of both activities and processes, which include:

1. **Temperature regulation** – The adult must maintain an optimum temperature to survive.

   The CEM recognizes temperature and humidity as the primary habitat elements affecting temperature regulation. Secondary habitat elements affecting temperature regulation include canopy cover and understory density.

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

   The CEM recognizes community type, linear width of patch, patch size, predator density, canopy cover, anthropogenic disturbance, and tree density as secondary habitat elements affecting predation.

3. **Disease** – Although the literature does not emphasize disease as affecting population levels of YBCU, we still feel that disease bears mentioning.

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

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

   The CEM recognizes community type as a primary habitat element directly affecting foraging. Brood size, food availability, diversity of vegetation, canopy cover, matrix community, patch phenology, and anthropogenic disturbance are secondary habitat elements directly affecting foraging.

5. **Molt** – The adult must molt into basic plumage, and the process begins on breeding grounds.

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

6. **Nest site selection** – The breeding adult must choose where to place the nest, nest placement will affect breeding success.

   The CEM recognizes community type as a primary habitat element affecting nest site selection. Humidity, linear width of patch, matrix community, patch size, predator density, understory density, temperature, anthropogenic disturbance, patch phenology, diversity of vegetation, and tree density are secondary habitat elements affecting nest site selection.

7. **Nest attendance** – The breeding adult must attend the nest to incubate eggs, brood young, and feed young.

   The CEM recognizes brood size, humidity, predator density, anthropogenic disturbance, and temperature as secondary habitat elements affecting nest attendance.

Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) (YBCU)
Basic Conceptual Ecological Model

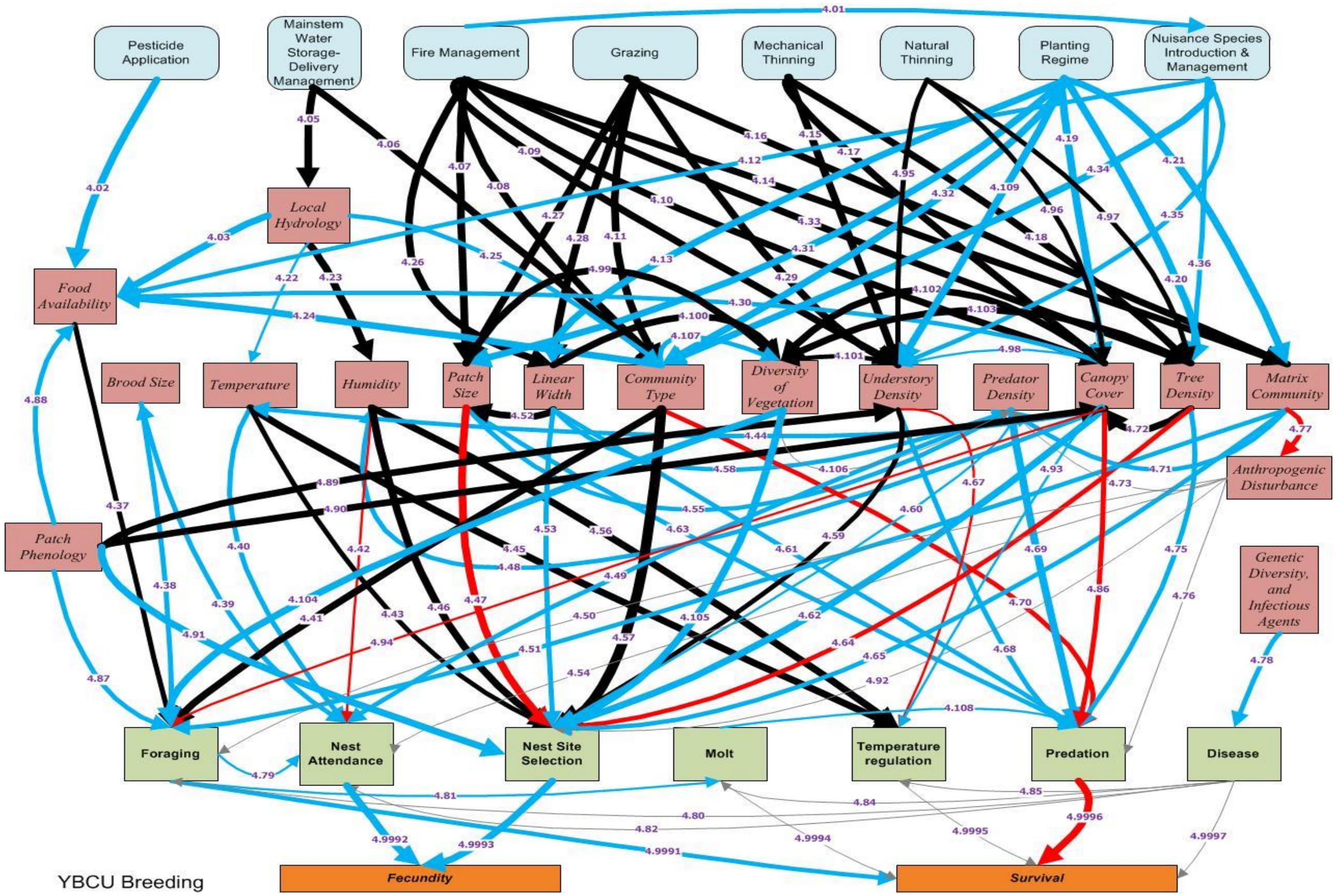

Figure 6.—Basic CEM diagram for life stage 4 – breeding adult.

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ATTACHMENT 1

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

OVERVIEW OF METHODOLOGY FOR BUILDING CONCEPTUAL ECOLOGICAL MODELS

The conceptual ecological models (CEMs) for species covered by the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) 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 the National Marine Fisheries Service. The Bureau of Reclamation participates in this program.

The ERP methodology for building CEMs incorporates common best practices for presenting these models for species covered by the LCR MSCP and identified in Habitat Conservation Plan (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 transitions from one stage/event to the next.

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

- It characterizes these interrelationships using a "*driver-linkage-outcomes*" approach. Linkages are cause-and-effect relationships between drivers and outcomes. Outcomes are the transition rates and their associated metrics (such as larval production or mortality).

- 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 status (certainty) of present scientific understanding of the effect. Below, we present the draft definitions for these four variables, after DiGennaro et al. (2012).

The LCR MSCP conceptual ecological models will expand this ERP methodology, incorporating the recommendations of Kondolf et al. (2008) and Burke et al. (2009) for a more hierarchical approach. This expanded approach provides greater detail on causal linkages and outcomes by dividing outcomes into two types: (1) activities and processes and (2) habitat elements. This expansion therefore calls for identifying **three** model components for each life stage or transition, and the causal linkages among them, as follows:

- **Critical biological activities and processes** – These consist of the activities in which the species must engage and the biological processes that must take place during each life stage to sustain an acceptable rate of transition (recruitment) to the next life stage. Examples of activities and processes include mating, foraging, avoiding predators, avoiding other specific hazards, egg maturation, and seed germination.

- **Habitat elements**– These consist of the specific habitat conditions that are necessary or sufficient for the critical activities and processes to take place or that interfere with critical activities or processes. Defining the full "template" of these elements for each life stage or transition also requires identifying habitat conditions that can interfere with these critical activities and processes. The abundance and distribution of habitat elements control the rates (intensities) of the activities and processes that they affect. Defining the habitat template also may involve estimating specific thresholds or ranges of suitable values for particular habitat elements, outside of which one or more critical life activities or processes begin to fail – if the state of the science supports such estimates.

- **Controlling factors** – These consist of environmental conditions and dynamics –including human actions – that determine the abundance, spatial and temporal distribution, and quality 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 breeding territories may depend on factors such as river flow rates and flow-path morphology, which in turn may depend on factors such as watershed geology, vegetation, and climate.

This expanded approach permits the consideration of five possible types of causal linkages on which management actions may focus for each life stage of a species: (1) from one controlling factor to another, (2) from controlling factors to elements of the habitat template, (3) from one element of the habitat template to another, (4) from elements of the habitat template to critical biological activities and processes, and (5) from one critical biological activity or process to others. Each controlling factor may affect more than one element of the habitat template, and each element of the habitat element may be affected by more than one controlling factor. Similarly, each habitat element may affect more than one biological activity or process, and each biological activity or process may be affected by more than one habitat element. 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 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.

Expanding the ERP methodology with this added level of detail will ensure that the CEMs explicitly identify the habitat conditions that support or impede the rates of success of each critical biological activity or process for each life stage and therefore the rate of recruitment from each life stage to the next. Such explicit consideration of habitat conditions is crucial for identifying critical monitoring and research questions and guiding habitat restoration for the species addressed by the LCR MSCP.

Conceptual Ecological Models as Hypotheses

The CEM for each species produced with this methodology will constitute a collection of hypotheses for that species. These hypotheses will concern: (1) the species' life history; (2) the species' habitat requirements and constraints; (3) the factors that control the abundance, spatial and temporal distribution, and quality of these habitat conditions; and (4) the causal relationships among these. Knowledge about these elements and relationships may vary, ranging from well settled to very tentative. Such variation in the degree of 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 these three CEMs will document the degree of certainty of current knowledge concerning each element of the model for each species as indicated in part by the degree of agreement/disagreement among the experts. In some cases, it will be possible also to represent differences in the interpretations or arguments offered by different experts in the form of alternative hypotheses. Categorizing the degree of agreement/disagreement concerning the elements of the CEM will help to more easily identify the topics of greatest uncertainty or controversy.

Documentation and Diagrams

The CEM for each species will include the definition and rationale for each of the following:

1. Species life cycle, identifying all life stage/events and their transitions.

2. The critical biological activities and processes for each life stage and transition.

3. The critical habitat conditions that support or impede each critical biological activity or process.

4. The controlling factors affecting the abundance, spatial and temporal distribution, and quality of the conditions that comprise the habitat template.

5. The causal linkages among (2), from (3) to (2), among (3), from (4) to (3), and among (4).

The CEM will also include an assessment of each causal linkage based on the four variables noted above 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 spreadsheet and text will present the rationale for the assessment findings for each of these four variables. The definitions for these four variables will follow those of the ERP methodology.

The CEM for each species will include two types of diagrams: (1) a summary diagram of the species life cycle and the controlling factors affecting each stage and transition and (2) a more detailed diagram for individual life stages that shows the individual elements of the model for that stage (critical biological activities and processes, habitat elements, controlling factors) and their causal relationships. The more detailed diagrams will use many of the conventions of the ERP conceptual ecological models (Williams 2010; DiGennaro 2012), expanded as suggested by Kondolf et al. (2008) and Burke et al. (2009).

Methods for Characterizing Causal Relationships

The following information is adapted from DiGennaro et al. (2012). It incorporates the ERP methodology for assessing causal links among the four dimensions of: (1) the character and direction of the effect, (2) the importance of the effect, (3) the predictability (consistency) of the effect, and (4) the status (certainty) of present scientific understanding of the effect.

- **Character and direction** categorizes a causal relationship as positive, negative, or involving a threshold response. Positive means that an increase (or decrease) in the causal agent results in an increase (or decrease) in the affected element, and negative means that an increase (or decrease) in the agent results in a decrease (or increase) in the affected element.

- **Magnitude** refers to "…the degree to which a linkage controls the outcome relative to other drivers. While the models are designed to encompass critical drivers, linkages, and outcomes, this concept recognizes that some are more important than others in determining how the system works." 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. For purposes of the LCR MSCP conceptual ecological models, the score for magnitude will be calculated as the average of the scores for intensity, spatial scale, and temporal scale (tables 1–3).

- **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 is based on understanding of the driver, and the nature of how it is linked to the outcome, and thus captures variability. For example, understanding of processes may be high, but there may be natural variability either on an inter-annual and/or a seasonal basis that is unpredictable. Or the strength of relationships and the magnitude of effects may vary so much that properly measuring and statistically characterizing inputs to the model are difficult." Table 4 presents the scoring framework for predictability.

- **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 5 presents the scoring framework for understanding.

The ERP methodology applies a consistent approach to characterize these linkage attributes by rating magnitude, predictability, and understanding on a scale of high, medium, or low. The following tables provide the rating definitions for these four increments to assess linkage magnitude, predictability, and understanding.

Table 1.—Criteria for scoring the intensity of a cause-effect relationship, one of three variables averaged to produce the overall score for “magnitude” (after DiGennaro et al. 2012, Table 2)

Intensity – The strength of the effect, either positive or negative, on the population or habitat of a given species. Intensity takes into account the complete driver-linkage-outcome chain leading to the effect of interest.	
High	Expected major effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics at the places and times where the effect occurs.
Medium	Expected moderate effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics at the places and times where the effect occurs.
Low	Expected minor effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics at the places and times where the effect occurs.

Table 2.—Criteria for scoring the spatial scale of a cause-effect relationship (after DiGennaro et al. 2012, Table 1)

Spatial scale – The spatial scale of the effect on the population or habitat of a given species. Spatial scale takes into account the complete driver-linkage-outcome chain leading to the effect of interest.	
High	Effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics occurs at a large spatial scale – landscape or basin scale.
Medium	Effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics occurs at a moderate spatial scale – regional or reach scale.
Low	Effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics occurs at a small spatial scale – local or site scale.

Table 3.—Criteria for scoring the temporal scale of a cause-effect relationship (after DiGennaro et al. 2012, Table 1)

Temporal scale – The time scale of the effect on the population or habitat of a given species. Temporal scale takes into account the complete driver-linkage-outcome chain leading to the effect of interest.	
High	Effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics emerges, persists, or can be reversed only over a very long time scale – decades or longer.
Medium	Effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics emerges, persists, or can be reversed over a time scale of one or two decades.
Low	Effect on natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity), habitat quality, spatial configuration, and/or dynamics emerges, persists, or can be reversed over a time-scale of less than a decade.

Table 4.—Criteria for scoring the predictability of a cause-effect relationship (after DiGennaro et al. 2012, Table 3)

Predictability – The likelihood that a given causal agent will produce an effect of interest.	
High	Magnitude of effect is largely unconstrained by variability (i.e., predictable) in ecosystem dynamics or other external factors.
Medium	Magnitude of effect moderately depends on other highly variable ecosystem processes or uncertain external factors.
Low	Magnitude of effect greatly depends on other highly variable ecosystem processes or uncertain external factors.

Table 5.—Criteria for scoring the 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 and in scientific reasoning among experts familiar with the ecosystem.
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 or uncertainty in peer-reviewed studies from within the ecosystem of concern and in scientific reasoning among experts familiar with the ecosystem.