Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

2019 Updates to Least Bittern (*Ixobrychus exilis*) (LEBI) Basic Conceptual Ecological Model for the Lower Colorado River

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

August 2020

Work conducted under LCR MSCP Work Task G6

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Lower Colorado River Multi-Species Conservation Program

2019 Updates to Least Bittern (*Ixobrychus exilis*) (LEBI) Basic Conceptual Ecological Model for the Lower Colorado River

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ACRONYMS AND ABBREVIATIONS

CAP	critical biological activity or process
CEM	conceptual ecological model
CF	controlling factor
cm	centimeter(s)
ha	hectare(s)
HE	habitat element
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
LEBI	least bittern (*Ixobrychus exilis*)
LSO	life-stage outcome
m	meter(s)
pH	power of hydrogen or potential for hydrogen – a measure of how acidic/basic water is
Reclamation	Bureau of Reclamation

Symbols

ºC	degrees Celsius
>	greater than
≥	greater than or equal to
<	less than
%	percent
±	plus or minus

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 m in height.

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

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Attachment

1 Least Bittern (*Ixobrychus exilis*) Habitat Data

Foreword

This report provides an update to the original conceptual ecological model (CEM) prepared for the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) for the least bittern (*Ixobrychus exilis*) (LEBI) (Johnson and Unnasch 2015). This update incorporates information reported in publications and presentations at professional meetings since the completion of the original LEBI conceptual ecological model and also incorporates information from the professional experiences of LCR MSCP staff and other experts. An updated version of the CEM workbook incorporates the new information. This report constitutes an appendix to the original CEM. The full CEM report, including its life-stage diagrams, has not been updated.

The structure of this report follows the structure of the original CEM report. Specifically, it presents and documents updates to chapters 1–6. It does not include updates to the original Executive Summary or chapters 7–8 because they were not updated.

The updates reported in the present report do not significantly change the LEBI conceptual ecological model. Updates to names and definitions, and modifications to certain interaction strengths, improve consistency among models. New information strengthens existing discussions. This update does add a new critical biological activity or process — Chemical Stress — and changes Predation and Competition to Predation, removing Competition from the discussion, as there is insufficient information about competition and LEBI at this time. A new controlling factor, On-Site Water Management, has been added to the model to reflect important management that directly affects LEBI habitat and use of wetlands.

This update also provides a list of all literature cited in the updates to chapters 1–6. In addition, a list of all changes made to the names of the CEM components is included in order to standardize terminology across all CEMs.

This update both explicitly and implicitly identifies possible new research and monitoring questions concerning gaps in knowledge that may bear on adaptive management of LEBI. These questions may or may not reflect the current or future goals of LCR MCSP decision making and are in no way meant as a call for the Bureau of Reclamation to undertake research to fill the identified knowledge gaps.

Updates to Chapter 1 – Introduction

The information in paragraph 3 in the initial section of chapter 1 is updated as follows:

The most widely used sources of information for the least bittern (*Ixobrychus exilis*) (LEBI) conceptual ecological model (CEM) are BIO-WEST, Inc. (2005), Bureau of Reclamation (Reclamation) (2008, 2016), and Poole et al. (2020). In addition, references were used from throughout the range of LEBI to supplement the basic information from the Lower Colorado Region. These publications summarize and cite large bodies of earlier studies. Where appropriate and accessible, those earlier studies are directly cited. The CEM also integrates numerous additional sources, particularly reports and articles completed since the aforementioned publications; information on current research projects; and the expert knowledge of Lower Colorado River Multi-Species Conservation Program (LCR MSCP) biologists (Kahl, Jr. 2008, 2018a, 2018b; Ronning and Kahl, Jr. 2018; Rusk 1991). The purpose of a CEM is not to provide an updated literature review but to integrate the available information and knowledge so it can be used for adaptive management.

UPDATE TO LEAST BITTERN REPRODUCTIVE ECOLOGY

This section is updated as follows:

LEBI typically return to the lower Colorado River (LCR) to breed in April (BIO-WEST, Inc. 2005), although resident adults may begin breeding activity earlier in the season. Typically, four to five eggs are laid, with both parents sharing incubation and tending to the hatched young (Bent 1926; Weller 1961). Nestlings leave the nest at 13–15 days yet do not fledge until 29 days, and both parents continue to feed them during this time (Bogner and Baldassarre 2002; Palmer 1962 *in* Reclamation 2008). There is little information about juvenile movements post-fledging until they leave the breeding grounds in October. Most LEBI migrate farther south for winter, out of the LCR; however, some LEBI remain onsite (Reclamation 2008). There is no information about what portion of the LEBI overwintering population on the LCR consists of juveniles, year-round residents, or overwintering adults from elsewhere. LEBI feed mainly on small fishes, amphibians, and aquatic invertebrates (Poole et al. 2020).

CONCEPTUAL ECOLOGICAL MODEL PURPOSES

This update does not propose any changes to this section of chapter 1; however, when the CEMs are fully updated, chapter 1 should be revised to indicate that the CEM methodology followed here is a crucial foundation for carrying out effects analyses as described by Murphy and Weiland (2011, 2014) and illustrated by Jacobson et al. (2016).

CONCEPTUAL ECOLOGICAL MODEL STRUCTURE FOR LEBI

No change. This will not be updated for the existing CEMs.

Updates to Chapter 2 – LEBI Life-Stage Model

This update standardizes the names of LEBI life stages, by switching to the plural noun form for each name, for consistency with the other LCR MSCP conceptual ecological model updates. The names of the original life-stage outcomes are standardized as follows: (1) Survivors changes to Survival for all four life stages and (2) Offspring and Reproduction change to Fertility. This update drops the word "rate" from the names of life-stage outcomes because all life-stage outcomes are rate variables by definition. Table 1 and figure 1 are updated accordingly (see the end of this chapter).

Update to Introduction to the LEBI Life Cycle

Because most LEBI migrate, the LCR MSCP is mainly responsible for habitat management on the breeding grounds. However, there is a sizeable overwintering population on the LCR that may consist of young-of-the-year, year-round residential birds and overwintering birds that come from elsewhere in the bittern's range. Therefore, four life stages have been included as occurring within LCR MSCP lands—eggs/nestlings, juveniles, overwintering individuals, and breeding adults. Thus, the focus of this study is on management activities throughout the year as within the scope of Reclamation's responsibilities.

Both the egg and chick phases of development are included as a single life stage in the CEM even though they undergo different processes—e.g., eggs do not need to eat or molt—because both eggs and chicks occupy the same nest; therefore, management focused on the nest will cover eggs and chicks. In addition, the juveniles stage consists of two phases: (1) a non-flighted phase when the young have left the nest to forage but are unable to fly and remain dependent on parental care and (2) a post-fledging phase. Because there is insufficient information to further divide this overall timespan as it relates to survivorship, the phases have been combined for this model.

Update to LEBI Life Stage 1 – Eggs/ Nestlings

The eggs/nestlings life stage begins when the first egg is laid and ends either when the young leave the nest, prior to fledging, or if the nest fails. Typically, four to five eggs are laid over a 6-day period from mid-April to July. (*Note*: In southwest Arizona, where there are resident LEBI, nesting may begin earlier in

the season, in March [Poole et al. 2020 and references therein].) Incubation, by both parents, begins after the first or second egg is laid and lasts around 20 days (Bent 1926; Weller 1961). Although the young do not fledge until 29 days after hatching, they may leave the nest in 13–15 days and begin to forage on their own. Both parents continue to feed them until they fledge (Palmer 1962 *in* Reclamation 2008). As bitterns occasionally double brood, nestlings can be present at different times during the season. Overall nest success in a New York study in 1999–2000 was 44–52% (percent hatching combined with percent fledging) (Bogner and Baldassarre 2002). In South Carolina, 20–70% of the nests survived from laying to fledging depending on their location in the marsh (Post 1998). However, more research is needed to better understand survivorship along the LCR. The life-stage outcome from the eggs/nestlings life stage is the survival of eggs and associated nestlings. It is important to note that the outcome of the eggs/nestlings life stage is inherently tied to the behavior and condition of the parents.

Update to LEBI Life Stage 2 – Juveniles

The juveniles stage has two components: (1) a non-flying phase when the young first leave the nest at about 13–15 days and begin to forage on their own nearby (while receiving supplemental feeding by their parents) (Palmer 1962 *in* Reclamation 2008) and (2) after fledging, which occurs at an age of 29 days or so until they disperse (Bogner and Baldassarre 2002). Juveniles generally leave the breeding grounds in October, 1–2 weeks after the adults (BIO-WEST, Inc. 2005; Poole et al. 2020). (Some LEBI remain all year at LCR sites, and although there is no information about what portion of these overwintering individuals are young-of-the-year, it is possible that not all juvenile bitterns migrate out of the area.) There is insufficient information to further divide this overall timespan as it relates to survivorship. Pending improved information, the non-flying and flying juvenile phases have been combined. Additionally, there is no information about when LEBI reach sexual maturity. The life-stage outcome from the juveniles stage is the survival of the bird from leaving the nest and successfully fledging to become an overwintering individual along the LCR or offsite.

Update to LEBI Life Stage 3 – Overwintering Individuals

Although most LEBI are believed to migrate out of the LCR region, spending the winter months farther south, some may be year-round residents in parts of the LCR (BIO-WEST, Inc. 2005). This life stage of the model addresses the portion of the LEBI population that either remains year round onsite (including young-of-the-year that remain after fledging during the winter months) or that migrates to the LCR to spend the winter months. Little information is available about habitat use on the

wintering grounds (Poole et al. 2020). In San Diego County, California, wintering LEBI were found at the same sites that were used by bitterns during the breeding season (Unitt 2004), so LEBI likely use similar habitats throughout the year. Habitat use by LEBI during spring and fall migration in Missouri is also reported to be similar to breeding habitat (Reid 1989 *in* Poole et al. 2020). The life-stage outcome for an overwintering individual is survival to become a breeding adult.

UPDATE TO LEBI LIFE STAGE 4 – BREEDING ADULTS

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

The life-stage outcomes for breeding adults are survival and fertility. The CEM defines the latter as the rate of production of viable eggs by cohorts of breeding adults. Since LEBI eggs are not viable unless fertilized and laid in a nest that is safely constructed, safely located, and well attended, all of these contribute to breeding adult fertility. Fertility is distinguished from fecundity, which is the rate of recruitment of offspring to the next generation (Etterson et al. 2011). In the structure of the present CEM, the fecundity rate would be recognized as a function of both (1) adult survival and fertility in the breeding adult life stage and (2) egg-nestling survival in the eggs-nestlings stage, the latter of which depends significantly on nest success. Here the eggs/nestlings stage is separated from adult fecundity to more clearly display the information regarding nest success so that it can be better assessed by management. Therefore, adult reproduction (fertility in this model) involves the acts of pairing, site selection, nest building, and the production of eggs.

UPDATE TO LIFE-STAGE MODEL SUMMARY

Table 1.—(Revision of original table 1) LEBI life stages and life-stage outcomes in the LCR ecosystem

Life stage	Life-stage outcome(s)
1. Eggs/Nestlings	• Egg/nestling survival
2. Juveniles	• Juvenile survival
3. Overwintering Individuals	• Overwintering individual survival
4. Breeding Adults	• Breeding adult survival • Breeding adult fertility

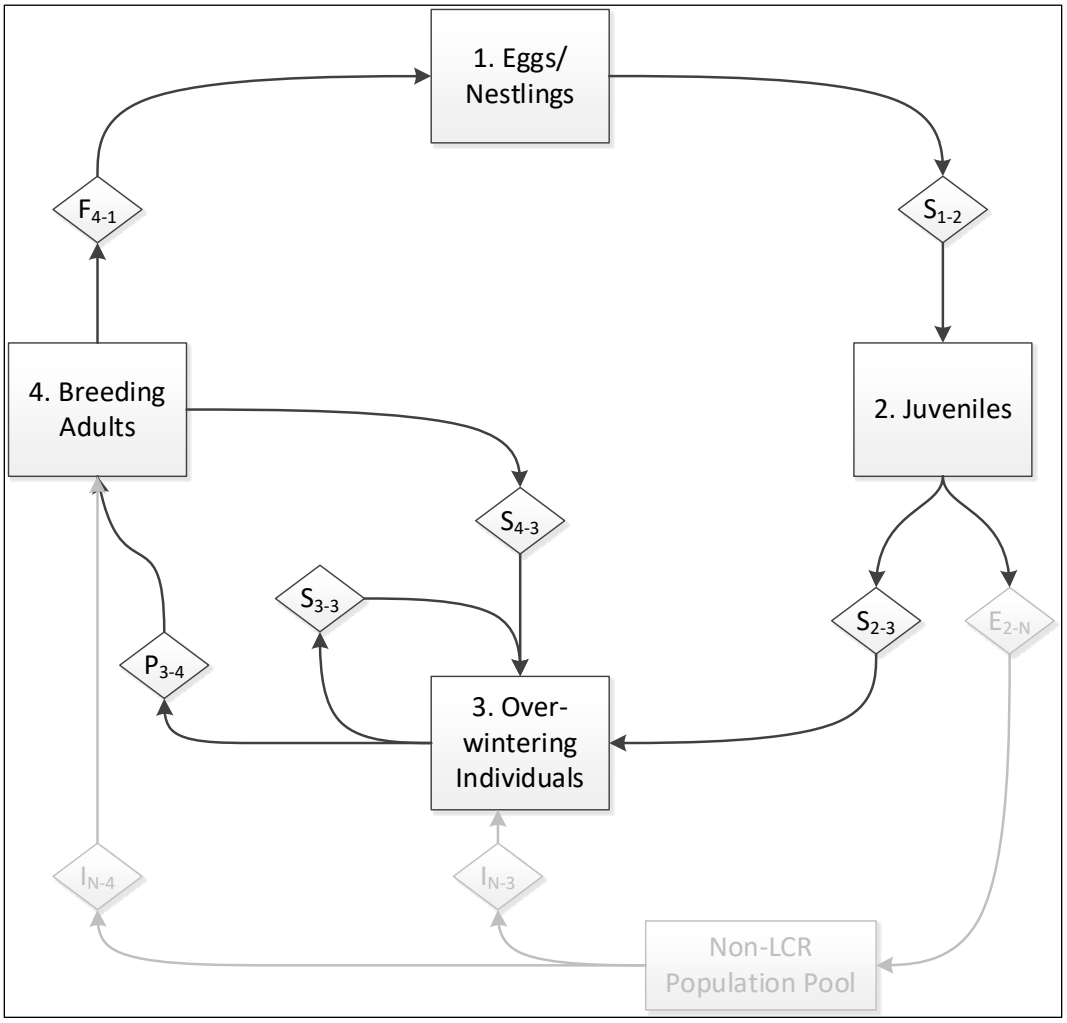

Figure 1.—(Revision of original figure 1) Proposed LEBI life history model. Squares indicate the life stage, and diamonds indicate the life-stage outcomes. S_{1-2} = survival from eggs/nestlings, S_{2-3} = survival of juveniles that stay along the LCR over winter, E_{2-N} = net emigration of juveniles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

Updates to Chapter 3 – Critical Biological Activities and Processes

This update changes the names of two critical biological activities or processes, Molt and Temperature Regulation, and replaces them with Molting and Thermal Stress for consistency with the other LCR MSCP conceptual ecological model updates. In addition, Predation and Competition has been changed to Predation. Predation and competition were addressed together in the original model and included a discussion of possible sources of competition, primarily for resources. According to Poole et al. (2020), competition for food with other bird species or fish species is unlikely, but more importantly, there is little, if any, research that demonstrates a negative effect of competition on LEBI. For this reason, competition is being removed from the model update. Competition could be addressed separately in future updates if more information becomes available.

Two new critical biological activities or processes were also added: (1) Nest Predation for the eggs/nestlings life stage and (2) Chemical Stress for all life stages. The addition of nest predation will better align with how predation has been addressed in other bird models. Chemical stress has been added to better reflect the issue of contamination in wetland birds that are susceptible to harm from chemical contaminants, including agricultural chemicals and LCR-wide pollutants such as selenium and mercury, the former of which the LCR MSCP has explicitly recognized as a management concern for its marsh birds (see Work Task 59). As a result, the LEBI conceptual ecological model now has 10 critical biological activities and processes. Seven critical biological activities or processes have been updated: Disease, Eating, Foraging, Molting, Nest Attendance, Predation, and Thermal Stress.

Updates to table 2 and details follow below.

Table 2.—(Revision of original table 2) Distribution of LEBI critical biological activities or 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 ➓**	**Eggs/nestlings**	**Juveniles**	**Overwintering individuals**	**Breeding adults**
Chemical stress (*new*)	X	X	X	X
Disease	X	X	X	X
Eating	X			
Foraging		X	X	X
Molting (*renamed*)	X	X		X
Nest attendance				X
Nest predation (*new*)	X			
Nest site selection				X
Predation		X	X	X
Thermal stress (*renamed*)	X	X		X

CHEMICAL STRESS

This critical biological activity or process is a new addition to the CEM, defined as follows:

LEBI in every life stage are vulnerable to stress and mortality due to exposure to harmful chemicals such as pesticides or to natural chemicals at extreme concentrations. Pesticide use on agricultural fields adjacent to wetlands could result in contamination of LEBI habitat either through wind transport of sprayed chemicals, through chemical leaching into shallow groundwater, or directly via agricultural runoff. The pesticides used may be toxic to prey of LEBI, reducing food availability and/or causing sublethal poisoning of LEBI via ingestion of treated insects or fishes that bioaccumulate toxins. Pesticide use was listed as

a potential threat to LEBI and their invertebrate food supply (Poole et al. 2020), with high concentrations of insecticide residues (e.g., dieldrin) found in LEBI eggs in Louisiana (see Causey and Graves 1969) and in feathers in Ontario birds (Sandilands and Campbell 1988 *in* COSEWIC 2009).

Mercury contamination is widespread, though patchy, in the Western United States (Eagles-Smith et al. 2016) and is known to negatively affect wetland birds, especially those that are piscivorous (Ackerman et al. 2016). In a study of California clapper rails (*Rallus obsoletus*), exposure to mercury resulted in reduced reproductive success and increased fetal deformities and other embryonic abnormalities (Schwarzbach et al. 2006). LEBI could exhibit a similar response to mercury contamination; however, mercury's effects on LEBI in the LCR have not been evaluated.

Selenium is a naturally occurring element that can reach potentially biologically harmful concentrations in LCR surface waters. Rusk (1991) measured selenium concentrations along the LCR in sediment, invertebrates, Virginia rails (*Rallus limicola*), and LEBI. She concluded that adult marsh bird species (and presumably juveniles) along the LCR were at low risk for mortality but moderate to high risk of teratogenicity—reproductive failure or deformities in young.

DISEASE

The discussion of this critical biological activity or process is updated as follows:

This process refers to diseases caused either by lack of genetic diversity or by infectious agents. Although there is little information available about LEBI in relation to disease susceptibility (Poole et al. 2020), LEBI in all life stages are conceivably susceptible to diseases, particularly those that affect other wading birds (see Friend and Franson 1999). There is reference to susceptibility to a parasitic fish nematode (*Eustrongilides*) (see Poole et al. 2020 and references therein). Also, in a California study of West Nile Virus, LEBI were one of the nine most frequently infected bird species (Wheeler et al. 2009).

EATING

The discussion of this critical biological activity or process is updated as follows:

This process only applies to the eggs/nestlings life stage because nestlings must eat to stay alive and develop but do not actively forage within their environment in the same way as juveniles and adults. A nestling's ability to eat during the first weeks of life is determined by the foraging and provisioning rate of its parents. (Juveniles may still be fed by adults for some time after leaving the nest and possibly after fledging [see the habitat element of Parental Care].)

FORAGING

The discussion of this critical biological activity or process is updated as follows:

LEBI are generalist feeders, preying mainly on small fishes, amphibians, and aquatic invertebrates (Poole et al. 2020; Reclamation 2008, 2016). Foraging is done by juveniles and adults, but it is important to note that foraging by the parents affects the provisioning rate to nestlings (and somewhat to juveniles) and nest attendance by adults.

MOLTING

This critical biological process, formerly named Molt, is renamed Molting for consistency with other CEMs. Further, the discussion of this critical biological activity or process is updated as follows:

Molting is one of the most significant biological activities and processes undertaken by bird species, and successful completion of various molts during a birds' lifetime is critical (Howell 2010). Nestling LEBI undergo a 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 (Gill et al. 2019; Howell 2010). Juveniles then undergo an incomplete pre-basic (pre-formative) molt beginning in September. Adults undergo a complete pre-basic molt on the summer grounds from July to August every subsequent year of their lives (Poole et al. 2020). There is some suggestion that the LEBI adult pre-basic molt is synchronous, consisting of all flight feathers (wing and tail), resulting in a flightless period of undetermined length (Howell 2010; Poole et al. 2020).

NEST ATTENDANCE

The discussion of this critical biological activity or process is updated as follows:

Nestlings rely on their parents to provide food, protection from predators, and thermoregulation. In the case of LEBI, both males and females incubate, brood, and feed young chicks (Palmer 1962 *in* Poole et al. 2020; Poole et al. 2020; Weller 1961). Nest attendance is performed by breeding adults (and is dependent in part on their survivorship) and affects the eggs/nestlings life stage (egg hatching and the provisioning rate to nestlings).

NEST PREDATION

This critical biological activity or process is a new addition to the CEM, added for consistency with other bird models. It only applies to the eggs/nestlings life stage. The discussion is updated as follows:

Nest predation is a threat to LEBI and obviously affects nestling survival to varying degrees. Although some common nest predators of LEBI are known (see the habitat element Nest Predators), the rate of predation at the eggs/nestlings life stage is not known.

NEST SITE SELECTION

The definition of this habitat element remains unchanged. No new information was located on LEBI nest site selection in the Lower Colorado River Valley or elsewhere.

PREDATION

This critical biological activity or process, formerly named and described as Predation and Competition, is renamed Predation. Competition and the associated discussion have been removed from the description, as there is little information about competition's effects on LEBI. The discussion is updated as follows:

Predation is a threat to LEBI at all life stages and obviously affects survival to varying degrees. Little is known about predators of LEBI juveniles, overwintering individuals or breeding adults (see the habitat element Predators),

nor are the rates of predation at any LEBI life stage known. There are few, if any, records in the literature of predation on adults, other than by snapping turtles (*Chelydra serpentina*) (Trautman 1940 *in* Poole et al. 2020) and red-tailed hawks (*Buteo jamaicensis*) (Weller 1961). For this model, nest predation is treated as a separate critical biological activity or process at the eggs/nestlings life stage (see above).

THERMAL STRESS

This critical biological activity or process, formerly named Temperature Regulation, is renamed Thermal Stress for consistency with other CEMs and to clarify its meaning.

Avoiding thermal stress is important for any organism inhabiting a region with temperatures as high as that of the LCR. Although overheating is possible during all life stages, most of the concern has been directed at eggs and nestlings (Rosenberg et al. 1991). The optimal temperature for egg development generally is 37–38 degrees Celsius (ºC), with exposure to temperatures greater than 40.5 ºC potentially lethal (Gill et al. 2019). However, adults can influence the temperature regulation of eggs and nestlings through their own behavior (incubation, brooding, or shading) and through nest placement and construction (e.g., LEBI will bend vegetation over the nest to form a protective canopy) (Poole et al. 2020). In this update, we have not included thermal stress for the overwintering life stage; however, if further information becomes available, it can be included in future revisions.

Updates to Chapter 4 – Habitat Elements

This update standardizes the name of four habitat elements, with Brood Size becoming Brood/Litter Size, Predator Density becoming Predators, Water Quality becoming Water Chemistry, and Water Turbidity becoming Turbidity. A new habitat element has been created, Nest Predators, and two habitat elements (Parental Nest Attendance and Parental Feeding Behavior) have been combined to form a new element, Parental Care, for consistency with other bird models. The definitions of two habitat elements have been revised for clarity and for consistency with other models (see "Anthropogenic Disturbance" and "Infectious Agents," below). Eight habitat elements have been updated with additional information: Anthropogenic Disturbance, Emergent Vegetation Assemblage, Food Availability, Infectious Agents, Marsh Size, Predators, Water Depth, and Woody Vegetation Assemblage. Table 3 has been updated to reflect these changes. Table 3 also lists the 15 habitat elements and the critical biological activities or processes that they *directly* affect across all LEBI life stages.

Table 3.—(Revision of original table 3) Distribution of LEBI habitat elements and the critical biological activities or 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 ⬇**	**Chemical stress**	**Disease**	**Eating**	**Foraging**	**Molting (*renamed*)**	**Nest attendance**	**Nest predation**	**Nest site selection**	**Predation**	**Thermal stress (*renamed*)**
Anthropogenic disturbance				X		X				
Brood/litter size (*renamed*)			X	X		X				
Density of conspecifics								X		
Emergent vegetation assemblage				X				X	X	X
Food availability				X						
Infectious agents		X								
Marsh size								X		
Nest predators (*new*)							X			
Parental care (*new*)			X	X					X	
Predators (*renamed*)								X	X	
Temperature						X		X		X
Turbidity (*renamed*)				X						
Water chemistry (*renamed*)	X									
Water depth				X				X	X	
Woody vegetation assemblage									X	

* *Note*: There is no habitat element that directly affects molting. (Infectious agents would affect molting via disease.)

ANTHROPOGENIC DISTURBANCE

The discussion of this habitat element is updated as follows:

Full name: **Human activity within or surrounding a given habitat patch, including noise, pollution, and other disturbances associated with human activity.** Whether due to recreational, land management, or scientific research activities, the presence of humans can disturb LEBI, causing changes in behavior that might ultimately affect survival. Most problematic would be disturbances during the nesting season that would discourage nesting or cause nest abandonment. Noise might mask conspecific cues such as songs or calls, making it more difficult for LEBI, with their quiet dove-like calls, to attract or find mates or defend territories. Further, noise might mask cues used in conspecific attraction, making it difficult for LEBI to find appropriate habitat. Noise can shift the foraging/vigilence tradeoff – either putting an individual at higher risk due to starvation or to predation (Ware et al. 2015). Noise can cause behavioral changes, physiological changes, and species diversity changes within an area. Anthropogenic disturbance and its effect on birds has been reviewed by Barber et al. (2010) and Francis and Barber (2013).

Anthropogenic disturbance is considered to be a habitat element, as it is an environmental characteristic with which a nesting, foraging, or overwintering bittern must contend. Although disturbances, particularly from recreational activities, have been reported to reduce nest success in closely related herons (Kushlan and Hancock 2005 *in* COSEWIC 2009) according to Poole et al. (2020), LEBI may be tolerant of some human presence if the habitat remains "undisturbed."

BROOD/LITTER SIZE

This habitat element replaces the original, Brood Size, with a slightly updated definition as follows:

Full name: **The number of young in the nest.** This element refers to the number of young that the parents must rear per nest. Brood/litter size is a life-stage outcome for breeding adults (fertility) that acts as a habitat element for eggs/nestlings and juveniles. Clutch size is related to maternal health, and the well-being of both parents depends in part on the availability of sufficient food resources in close proximity to the breeding territory (during incubation, bitterns forage directly from the nest [Weller 1961]) in addition to other factors, including predator density. Brood size affects the likelihood that all siblings will survive

the nest stage, as the youngest hatchling (LEBI have asynchronous hatching) may starve due to competition with their larger siblings for food (Ehrlich et al. 1988; Poole et al. 2020 and references therein).

DENSITY OF CONSPECIFICS

The description of this habitat element is updated as follows:

Full name: **The density of conspecifics, specifically of other LEBI in the same habitat patch.** LEBI are typically solitary nesters, with nest densities less than 1 per hectare (ha) (Poole et al. 2020; Rosenberg et al. 1991). However, LEBI will nest in higher densities (as close as 10 meters [m] apart and up to 15 nests per ha) in marshes that are very productive in terms of food (Kushlan 1973; Poole et al. 2020; Weller 1961).

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

EMERGENT VEGETATION ASSEMBLAGE

The description of this habitat element is updated as follows:

Full name: **The species diversity, abundance/density, spatial and temporal distributions, and vertical structure of emergent vegetation.** LEBI usually nest over water and prefer nest sites with dense emergent vegetation (preferably of cattails (*Typha* spp.), sedges, or rushes [BIO-WEST, Inc. 2005; Bogner and Baldassarre 2002; Corman 2005; Lor and Malecki 2006; Poole et al. 2020; Rosenberg et al. 1991]) interspersed with open water and occasional scattered woody shrubs. LEBI will also use giant cutgrass (*Zizianopsis miliacea*) (Arnold 2005; Winstead and King 2006). (*Note*: LEBI will occasionally nest or forage in other vegetation such as common reed (*Phragmites*) or tamarisk (*Tamarix* sp.) [Patten et al. 2003 *in* Sterling 2008; Poole et al. 2020]). Dense vegetation conceals nests and provides a microclimate needed for egg and nestling development. Tall emergent vegetation also provides essential materials for nest and forage platform construction as well as habitat structure for aquatic prey and for other species that may compete with or prey upon LEBI. Open water areas facilitate foraging, as bitterns forage from the edge of vegetation into open water.

Although dense foliage is a classic characteristic of LEBI habitat, LEBI generally prefer marshes that contain a mix of both dense areas for nest placement and open water areas for foraging. The distance to open water from nest sites is usually less than 10 m (Poole et al. 2020). Lor and Malecki (2006) found that LEBI preferred a 50:50 vegetation cover-to-water ratio in western New York State marshes. Similarly, in Iowa, a hemi-marsh, with approximately equal extents of vegetated areas and open water areas that were well interspersed, was found to support the most bitterns (Weller and Spatcher 1965 *in* Bogner and Baldassarre 2002). Interspersion was also found to be important to LEBI in upper Midwest wetlands (Bolenbaugh et al. 2011). Rehm and Baldassarre (2007) suggest that increased and more complex interspersion (or edge density) may reduce visibility, helping breeding birds to avoid intra- and inter-species confrontations and enabling them to nest in greater densities in such wetlands. Greater numbers and diversity of aquatic invertebrates have also been observed in hemi-marsh systems in Iowa (Voights 1976).

FOOD AVAILABILITY

The definition of this habitat element has been changed for consistency with other bird models, and the discussion is updated as follows:

Full name: **The abundance of food available for adults and their young.** This element refers to the availability of food resources, whether fishes, amphibians, or invertebrates that individual LEBI will encounter during each life stage, as well as the density and spatial and temporal distributions of the food supply in proximity to the nest. LEBI feed on crustaceans, leeches, other aquatic invertebrates, as well as fish and amphibians (Palmer 1962 *in* Poole et al. 2020; Poole et al. 2020; Reclamation 2016). LEBI will nest in higher densities (as close as 10 m apart/up to 15 nests per ha) in marshes that are more productive in relation to food (Kushlan 1973; Poole et al. 2020; Weller 1961); otherwise, they are solitary nesters with nest densities less than 1 per ha (Poole et al. 2020; Rosenberg et al. 1991).

INFECTIOUS AGENTS

The discussion of this habitat element is updated as follows:

Full name: **The types, abundance, and distribution of infectious agents and their vectors.** The infectious agent habitat element refers to the spectrum of

viruses, bacteria, fungi, and parasites that individual LEBI are likely to encounter during each life stage. The effects of disease and other infectious agents are poorly understood, although there is reference to susceptibility to a parasitic fish nematode (*Eustrongilides*) in other parts of their range (see Poole et al. 2020 and references therein). Also, in a California study of the West Nile Virus, LEBI were one of the nine most frequently infected bird species (Wheeler et al. 2009). However, the virus has been detected annually in the Southwest since 2003, but there have not been any indications of impacts to LEBI detection rates during annual breeding bird surveys (B. Raulston 2018, personal communication; C. Ronning 2019, personal communication).

MARSH SIZE

The discussion of this habitat element is updated as follows:

Full name: **The areal extent of marsh habitat.** Although an average marsh size may differ between riverine and reservoir systems, marsh size likely affects the number of breeding pairs that an area can support as well as the density of predators. Brown and Dinsmore (1986) found bitterns using Iowa marsh lands of more than 5 ha, and Harms and Dinsmore (2013) detected 36% of the LEBI in their study in marshes greater than 30–40 ha in size. Tozer et al. (2010) observed LEBI breeding in Ontario wetlands ≥ 6.8 ha and ≥ 25.2 centimeters (cm) deep. Poole et al. (2020) recommend a marsh size of > 10 ha as optimal, although territorial individuals were found on a marsh only 0.4 ha in size (Gibbs and Melvin 1990 *in* Poole et al. 2020). According to the Ohio Breeding Bird Atlas, although LEBI can use a variety of marsh sizes, they rarely use small marshes or narrow strips of cattails along the water's edge (Peterjohn and Rice 1991); see Sterling (2008) for information about LEBI nesting in cattail patches in California.

The home range of LEBI may also affect and reflect selected marsh size. Mean home ranges have been calculated in two studies. Bogner and Baldassarre (2002) determined a mean home range for nesting adult LEBI of 9.7 ha in New York wetlands. Griffin et al. (2009) determined home ranges of LEBI in northwestern Missouri wetlands to have a mean home range of 223.2 ± 47.9 ha and a mean core range of 37.6 ± 9.4 ha. More research is needed.

NEST PREDATORS

This habitat element is a new addition to the CEM, added for consistency with other bird models, and it is defined as follows:

Full name: **The abundance and distribution of species that depredate LEBI during the eggs/nestlings life stage.** This element refers to a set of closely related variables that affect the likelihood that different kinds of nest predators will encounter and successfully prey on LEBI during the eggs/nestlings life stage. The variables of this element include the species and size of the fauna that prey on LEBI during this life stage, the density and spatial distribution of these fauna in the marsh habitat used by bitterns, and the ways in which predator activity may vary in relation to other factors (e.g., emergent vegetation assemblage, matrix community type, patch size and width, time of day, vegetation diversity, water depth, etc.) (Thompson, III 2007).

Susceptibility to predation is related to emergent vegetation cover and nest location (e.g., depth of water at the nest or distance from land). The location of bittern nests in dense vegetation over water reduces the impact of most terrestrial predators, but all nests are vulnerable to raptors, snakes, turtles, and some mammals (e.g., raccoons [*Procyon lotor*] and mink [*Neovison vison*]) (Arnold 2005; Poole et al. 2020). There have also been reports of marsh wrens (*Cistothorus palustris*) puncturing the eggs of LEBI (Arnold 2005; Bent 1926).

PARENTAL CARE

This habitat element replaces the former elements, Parental Feeding Behavior and Parental Nest Attendance, with a slightly updated definition as follows:

Full name: **The ability and behavior of parents to provide care to eggs, nestlings, and juveniles after they fledge from the nest.** This element refers to the capacity of both parents to share nesting and brood-rearing responsibilities until fledging and to provision food for recently fledged birds. The care provided by one or both parents can include providing shelter and warmth, providing food, warding off predators, and teaching the young necessary life skills. The better the quality of the parental care, the healthier the condition and, therefore, the higher the rate of survival of the offspring, other things being equal. Parental care is affected by food availability, the presence of predators and competitors, and the ability to thermoregulate.

The length of time that juvenile LEBI are fed once they leave the nest and then after fledging is unknown in this species. The feeding rate is dependent upon food availability and the number of young in the brood. This rate influences the amount of food and time spent foraging by the juvenile birds.

PREDATORS

This habitat element replaces the original, Predator/Competitor Density, for consistency with other bird models, and the definition is updated as follows:

Full name: **The abundance and distribution of species that depredate LEBI during the juveniles, overwintering individuals, and breeding adults life 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 LEBI during the juveniles, breeding adults, and overwintering individuals life stages. The variables of this element include the species and sizes of the fauna that prey on LEBI during different life stages and the density and spatial distribution of these fauna in the marsh habitat used by bitterns. Susceptibility to predation is related to emergent vegetation cover and nest location (e.g., depth of water at the nest or distance from land). Snapping turtles (Trautman 1940 *in* Poole et al. 2020) and red-tailed hawks (Weller 1961) have been reported as predators of adults. In addition, a northern harrier (*Circus hudsonius*) was observed at Topock Marsh during the winter months (J. Kahl, Jr. 2019 and B. Raulston 2018, personal communications), and these raptors are known to prey on small mammals and marsh birds such as LEBI and rails (Smith et al. 2020). Little is known about depredation rates of juveniles or adults generally (Massachusetts Natural Heritage Endangered Species Program 2010). The effect of predator density can have impacts more subtle than survival by altering breeding behavior, foraging behavior, nest site selection, and prey behavior (Lima 1998, 2009).

TEMPERATURE

The definition of this habitat element is updated as follows:

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

TURBIDITY

This habitat element replaces the original, Water Turbidity, with a slightly updated definition as follows:

Full name: **The turbidity of water in a marsh, including its magnitude and spatial and temporal distributions.** Bitterns are visual predators, stalking prey while perched among the reeds, and they need relatively clear water in order to locate their food (COSEWIC 2009; Poole et al. 2020). Water turbidity can have many causes (e.g., dredging and other construction, maintenance, or water management activities, recreation [motorboat disturbances of shallows—see Asplund 2000], substrate characteristics, dense algal blooms that block sunlight from penetrating the water column, and invasive common carp (*Cyprinum carpio*) that churn the benthic substrate during feeding and spawning [Cucherousset and Olden 2011; Lougheed et al. 1998]). Note that the density and arrangement of emergent marsh vegetation can also affect water turbidity caused by weather-related factors such as wind.

WATER CHEMISTRY

This habitat element replaces the original, Water Quality, with a slightly updated definition as follows:

Full name: **The water chemistry at sites potentially used by LEBI in each life stage, including the way that water chemistry can vary over time and space.** This element covers parameters such as dissolved oxygen, pH, salinity, naturally occurring dissolved substances, and the presence of chemical pollutants, including pesticide residue. Pesticide runoff may harm prey populations and bioaccumulate, with repercussions for nesting success. Chemical runoff may alter plant species diversity and marsh vegetation structure and hence suitability for nesting bitterns. Although LEBI are reported to use brackish water habitats to some degree (Poole et al. 2020), high salinity concentrations due to the source of inflow and lack of circulation may become too high to support appropriate emergent vegetation such as cattails (Garnett 2012). In addition, runoff and resulting eutrophication coupled with higher salinity may lead to the development of algal blooms, in particular those of golden algae (*Prymnesium parvum*). Toxins produced by golden algae affect gill-breathing organisms, including fishes, bivalves, and crayfish, and they can lead to extensive fishkills under certain conditions (Sallenave 2010), reducing the food supply for LEBI. In the LCR, there was a golden algae bloom in 2013 at Beal Lake. During the 2012 bird survey pre-bloom, 12 LEBI were counted at the lake. From 2013 to 2019, the

numbers of LEBI were 5, 3, 2, 11, 7, 12, 12 each year, respectively. Prey population numbers were not monitored during those years (J. Kahl, Jr. 2019, personal communication).

Contaminants in the LCR arrive from both point and non-point sources (see "Updates to Chapter 5 – Controlling Factors"). Wastewater and other contaminant inflows and water storage-delivery system design and operations (see updates to chapter 5) also affect water chemistry, including salinity and dissolved oxygen concentrations, through effects on reservoir operations and releases, diversions and flow management for off-channel wetlands and ponds, and well-water supply to ponds.

WATER DEPTH

The definition of this habitat element is updated as follows:

Full name: **The range of water depth in marshes used by bitterns.** Bitterns typically build their nests over water that is between 25 and 60 cm deep (Poole et al. 2020 and references therein). Deep, open water areas are also important for foraging as long as there is adjacent vegetation from which they can forage. Additionally, LEBI are often associated with stable water regimes, especially at managed impoundments (Gibbs and Melvin 1990 *in* Poole et al. 2020; Jobin et al. 2009). Arnold (2005) and Environment Canada (2014) recommend the maintenance of water levels that reflect that natural hydrologic regime, yet with relatively stable water levels throughout the LEBI breeding season (COSEWIC 2009). High water levels may flood nests (McVaugh 1975 *in* Poole et al. 2020), whereas lowered water levels may allow greater access by predators and negatively affect LEBI foraging (Arnold 2005).

WOODY VEGETATION ASSEMBLAGE

The discussion of this habitat element is updated as follows:

Full name: **The stem density and spatial distribution of woody vegetation in a marsh.** LEBI predominantly use marsh habitat dominated by herbaceous emergent vegetation, selecting wetlands with only scattered shrubs or other woody vegetation (Poole et al. 2020). In southern Manitoba marshes, Hay (2006) observed that LEBI selected wetlands with some cover of tall shrubs. A 2004–06 Statewide New York secretive marsh bird survey also found LEBI using wetlands

with shrub cover. The authors (Osborne et al. 2011) recommend a wetland scrub/shrub cover of between 5–15% when managing for LEBI in New York wetlands.

Although wetlands with shrubby vegetation are used by LEBI, extensive cover of woody trees or shrubs may preclude bittern use. Kirk et al. (2001) found that the presence of trees and shrubs was a negative predictor when modeling habitat for LEBI in the Great Lakes Basin. Gibbs and Melvin (1990 *in* Poole et al. 2020) also observed a negative association between LEBI and extensive shrub coverage in Maine wetlands. Scattered trees or shrubs can provide perches for predators (Bolenbaugh et al. 2011). There is no data regarding optimal percent cover of woody vegetation for LEBI, as the presence and extent of shrub cover in wetlands used by LEBI varies across the bittern's range.

Updates to Chapter 5 – Controlling Factors

This update changes the names of four controlling factors, Fisheries Management, Marsh Management and Restoration, Off-Site Land Use, and Wastewater and Other Contaminant Input, and replaces them with Fishing Activity and Fisheries Management, Habitat Management and Restoration, Off-Site Land Management and Use, and Wastewater and Other Contaminant Inflows, respectively. A new controlling factor, On-Site Water Management, has been added. All controlling factors also have been updated, as well as table 4, as follows:

Table 4.—(Revision of original table 4) Habitat elements directly affected by controlling factors

Controlling factor ➔ / **Habitat element ⬇**	**Fire management**	**Fishing activity and fisheries management (*renamed*)**	**Habitat management and restoration (*renamed*)**	**Nuisance species introduction and management**	**Off-site land management and use (*renamed*)**	**On-site water management (*new*)**	**Recreational activities**	**Wastewater and other contaminant inflows (*renamed*)**	**Water storage-delivery system design and operation**
Anthropogenic disturbance		X					X		
Brood/litter size (*new*)	N/A*								
Density of conspecifics	N/A*								
Emergent vegetation assemblage	X		X	X					
Food availability		X		X					
Infectious agents				X				X	
Marsh size			X						
Nest predators (*new*)		X		X			X		
Parental care (*new*)	N/A*								
Predators (*renamed*)		X		X			X		
Temperature	N/A*								
Water depth			X			X	X		X
Water chemistry (*renamed*)	X		X	X	X		X	X	X
Turbidity (*renamed*)	X		X	X	X	X	X		X
Woody vegetation assemblage	X		X	X					

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

FIRE MANAGEMENT

The discussion of this controlling factor is updated as follows:

This factor addresses any fire management (whether prescribed fire or fire suppression) that could affect LEBI or their habitat. Effects may include creation of habitat that supports or excludes LEBI, a reduction in the food supply of invertebrates, or support of species that pose threats to LEBI such as predators, competitors, or carriers of infectious agents.

Prescribed fire has been used as a marsh management tool for Yuma clapper rails (*Rallus longirostris yumanensis*) at sites that also support LEBI. Conway and Nadeau (2011) report that application of winter burns did not adversely affect numbers of LEBI detected in those marsh systems the following spring. In fact, fire may have a positive effect, "as LEBI numbers were higher in several of the post-burn years." The removal of residual cattail vegetation by burning creates more openings in a marsh, thereby improving habitat for LEBI.

Conversely, fire may affect water chemistry and turbidity through the release of soluble and insoluble materials into the water after a burn; however, the effect will vary depending on the severity and intensity of the fire (and whether wildfire or prescribed burn), season of the year, type of aquatic system, surrounding upland habitat, and subsequent precipitation events that increase runoff from burned areas if offsite (Bixby et al. 2015; Meixner and Wohlgemuth 2004; New Mexico Environment Department 2014; Tecla and Neary 2015). This may not be a concern in the wetland habitats under management for LEBI in the LCR. As Conway and Nadeau (2011) explain, a healthy marsh system filters out sediments such that fire on adjacent land should not be an issue.

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

FISHING ACTIVITY AND FISHERIES MANAGEMENT

The definition of this habitat element remains unchanged. No new information was located on fishing activity or fisheries management effects on LEBI in the Lower Colorado River Valley or elsewhere.

This factor includes activities involved in managing habitat for rare native fishes that might affect habitat or prey of LEBI either positively or negatively. Examples of such activities include fish monitoring, seining, electroshocking (may disturb nesting/feeding bitterns if present), or

construction of riprap shoreline cover (depending on the location) (see LCR MSCP research and monitoring fisheries activities reports at http://www.lcrmscp.gov/fish/fish_res_mon.html). Fisheries management may alter the species composition of the aquatic community and introduce competitors into the system (e.g., stocked bonytail [*Gila elegans*] may compete with LEBI for the same prey). Improvement of backwater habitats and water quality for fishes would benefit LEBI that also use these habitats. However, use of rotenone to remove non-native fish species would clearly be detrimental to the LEBI prey base. (See "Nuisance Species Introduction and Management," below.)

Habitat Management and Restoration

The discussion of this controlling factor is updated as follows:

This factor addresses the active restoration program to restore marsh habitat within the LCR and includes not only mechanical or chemical clearing of existing vegetation but also the vegetation community planted and the pattern in which it is planted within restoration areas (e.g., density, interspersion with open water, etc.). This factor also includes other management activities, such as grading of the land surface, pond deepening, removal of decadent vegetation, etc., that may be part of any marsh management and restoration plan. (See updates to chapter 5, "Fire Management," for additional information about the use of prescribed fire in marsh management.)

Nuisance Species Introduction and Management

The discussion of this controlling factor is updated as follows:

This factor addresses the intentional or unintentional introduction of nuisance species (animals and plants as well as microbes) and/or their control that affect LEBI survival and reproduction. The nuisance species may poison, infect, prey on, compete with, or present alternative food resources for LEBI during one or more life stages; cause other alterations to the riparian food web that affect LEBI; or affect physical habitat features such as vegetation cover and nesting substrate. For example, largemouth bass (*Micropterus salmoides*), introduced by sport fishermen, may remove smaller fishes and aquatic insects that LEBI depend upon, as has been reported for the yellow bittern (*I. sinensis*) (Sawara 2013). Encroachment of non-native species such as common reed or tamarisk can alter marsh vegetation structure, as will the use of herbicides to control these invasive

plants. Clearing vegetation without replanting will make a marsh system unsuitable for longer time periods than if replanted with native emergents. Use of algicides to control golden algal blooms may affect other organisms in aquatic systems (Sallenave 2010). (*Note*: Under certain environmental conditions, blooms of golden alga may produce a toxin harmful to many gilled aquatic organisms [Brooks et al. 2011; Roelke et al. 2011; Sallenave 2010].)

OFF-SITE LAND MANAGEMENT AND USE

The discussion of this controlling factor is updated as follows:

This factor addresses activities occurring on lands adjacent to marshes that may affect nesting or year-round resident LEBI. Agricultural and other land use activities on adjacent lands may result in erosion and sediment deposition into wetlands utilized by LEBI. Increased nutrient loads may lead to eutrophication, altering water chemistry and reducing water quality and increasing turbidity. Poole et al. (2020) mention the potential threat of roads, power lines, and barbed wire fencing to low-flying bitterns during migration or movement to other marsh lands; however, these are considered localized threats (COSEWIC 2009) and have not been identified as a specific concern for the LCR (J. Kahl, Jr. 2019 and B. Raulston 2018, personal communications).

The use of pesticides was listed as a potential threat to LEBI and their invertebrate food supply (Poole et al. 2020), with high concentrations of insecticide residues (e.g., dieldrin) found in LEBI eggs in Louisiana (see Causey and Graves 1969). Wetlands often accumulate toxins from surrounding watershed lands (Eddleman et al. 1988). Drainage waters from agricultural lands that include pesticides may be toxic to prey of LEBI, reducing food availability. The effects may include sublethal or lethal poisoning of LEBI via ingestion of treated insects or fishes that bioaccumulate toxins.

ON-SITE WATER MANAGEMENT

This controlling factor is a new addition to the CEM, and it is described as follows:

This factor addresses the types, frequencies, and durations of official activities that affect the delivery and distribution of regulated water within sites managed to support LEBI habitat. In particular, this addresses water management for ponds and marshes maintained by the LCR and includes areas such as Hart Mine Marsh

at the Cibola National Wildlife Refuge, the ponds at the Imperial Ponds National Wildlife Refuge, and Yuma East Wetlands, all of which consistently support LEBI (Kahl, Jr. 2018b; Ronning and Kahl, Jr. 2018).

LEBI rely on consistent water levels during the breeding season (COSEWIC 2009), and the abundance of bitterns at a site will vary over time depending on water levels. Jobin et al. (2009) observed a reduction in bittern numbers with a lowering of the water level in Quebec impoundments after a breach in a dike. Numbers rebounded the following year after water levels were restored.

On-site water management in the LCR may include actions to reduce or terminate water applications at a site (e.g., to reallocate water to other sites within the limits of Reclamation or other agency's water rights). The amount and consistency of water provided through pond and marsh water level management directly affects water depth, water chemistry, vegetation density and species composition, and the overall suitability of a wetland for nesting LEBI.

Recreational Activities

The discussion of this controlling factor is updated as follows:

This factor addresses the disturbance to LEBI from recreational activity – in particular, the use of motor boats and jet skis that may swamp nests with their wake (BIO-WEST, Inc. 2005; Poole et al. 2020) or otherwise disturb nesting bitterns (Asplund 2000 and references therein). In addition, the use of motorized watercraft can affect turbidity and water chemistry (Asplund 2000). In the LCR, the backwaters of the Havasu National Wildlife Refuge and Topock Marsh, as well as the river waters at the Bill Williams River National Wildlife Refuge, are closely regulated to protect nesting waterbirds from boat wake (https://www.fws.gov/refuge/Havasu/activities/boating.html). Increased recreational use of an area may attract predators if resulting garbage is not managed properly.

Wastewater and Other Contaminant Inflows

The discussion of this controlling factor is updated as follows:

This factor includes contamination from main stem diversions that may include contaminants such as high concentrations of selenium. Rusk (1991) detected high

selenium levels in LEBI from three separate locations in the LCR: Imperial Reservoir, Cibola Lake, and Topock Marsh. In other studies, bitterns collected from the Imperial National Wildlife Refuge had high selenium concentrations in their livers (higher than the toxic threshold) (King et al. 2000; Martinez 1994) that may have reproductive consequences. Selenium monitoring is a component of the current LCR marsh and backwater restoration program.

WATER STORAGE-DELIVERY SYSTEM DESIGN AND OPERATION

The discussion of this controlling factor is updated as follows:

Much of the habitat used by LEBI is along regulated waterways. The water moving through these systems is highly managed to allow for storage and delivery (diversion) to numerous international, Federal, State, Tribal, and municipal users and for hydropower generation. This factor includes river and off-channel water management, including pumping of groundwater and diversion of river water to manage water levels in refuge ponds as well as dewatering and flushing of marsh habitats. The amount of water, flooding frequency, water depth and stability, etc., all affect development and maintenance of backwater habitats and fringing marshes with sufficient water depth, water chemistry, vegetation density, and species composition for LEBI. Marsh bird surveys have identified the fringing marshes of Topock Gorge, Beal Lake (Kahl, Jr. 2018a), and Butler Lake (Kahl, Jr. 2008) as LEBI habitats directly connected to mainstem riverflow (or seepage from the river, in the case of Butler Lake [Kahl, Jr. 2008]).

Updates to Chapter 6 – Conceptual Ecological Model by Life Stage

The following sections identify all changes made to the LEBI conceptual ecological model workbook other than changes that involve only updates to names. These latter changes are listed separately in table 5 (see "Summary of Standardization of Terms," at the end of this chapter). The items in each section of this chapter are arranged alphabetically. The abbreviations, CF for controlling factor, HE for habitat element, CAP for critical activity or process, and LSO for life-stage outcome, are provided to identify component types where needed. Each item also identifies the life stage(s) to which the item applies.

NEW LINKS WITH CONTROLLING FACTORS AS CAUSAL AGENTS

- On-Site Water Management effect on Water Depth (HE): Water level manipulations of wetlands and ponds will directly affect the depth of water in these aquatic habitats. However, effects may be short term and/or small scale depending on the frequency of manipulations, and whether water is added or removed, as well as the climate. The link is hypothesized to be complex and bi-directional with proposed high intensity and low spatial scale and temporal scale, medium predictability, and high understanding. *Applies to all life stages*.

- On-Site Water Management effect on Turbidity (HE): Water level manipulations of wetlands and ponds can affect turbidity especially during times of active management. However, the effects should be short term and/or small scale depending on the frequency of manipulations. The link is hypothesized to be complex and unidirectional with proposed medium intensity and low spatial and temporal scale, low predictability, and low understanding. *Applies to all life stages.*

- Water Supply-Delivery System Design and Operation effect on On-Site Water Management (CF): On-site water management is only possible with appropriate water storage delivery and operation. While on-site water management is critically dependent on water delivery, the exact water management regime that results is difficult to predict well in advance partly because LEBI populations occur on lands with various landowners and water management capacity. Note also that LEBI may not be the intended beneficiaries of the on-site water management of interest but only secondary beneficiaries of water management aimed primarily at

benefiting other Habitat Conservation Plan species (e.g., rails or fishes). The link is hypothesized to be complex and unidirectional with proposed high intensity, medium spatial, and medium temporal scale; medium predictability; and high understanding. *Applies to all life stages*.

- Water Supply-Delivery System Design and Operation effect on Water Chemistry (HE): The link is hypothesized to be complex and unidirectional with proposed high intensity, medium spatial, and medium temporal scale; high predictability; and high understanding. *Applies to all life stages*.

- Wastewater and Other Contaminant Inflows effect on Infectious Agents (HE): Polluted water affects water chemistry, but it may also introduce bacteria or viruses or other disease-causing microorganisms. The link is hypothesized to be positive (more contamination, greater chance for infectious agents) and unidirectional with proposed unknown intensity, unknown spatial, and unknown temporal scale; low predictability; and low understanding. *Applies to all life stages*.

Deleted Links with Controlling Factors as Causal Agents

No change.

Updated Links with Controlling Factors as Causal Agents

- Fire Management effect on Emergent Vegetation Assemblage (HE): The link is now hypothesized to be complex (although fire removes vegetation, plants and plant communities respond differently, as do land managers, and there are many other factors involved) and unidirectional (fire managers must take vegetation into account when deciding if/when/how to manage) with proposed medium intensity, low spatial, and low temporal scale; medium predictability; and high understanding. (Fire will remove vegetation. The effects depend on the type of fire, season of year, intensity of burn, and hydrological condition of the wetland; however, most prescribed fires are applied during the winter months and are tightly controlled.) *Applies to all life stages.*

- Fire Management effect on Woody Vegetation Assemblage (HE): The link is now hypothesized to be complex (similar to Fire Management effect on Emergent Vegetation Assemblage above) and unidirectional with proposed medium intensity, low spatial, and low temporal scale; low predictability; and high understanding. (Fire will remove vegetation. The effects depend on the type of fire, season of year, intensity of burn, and hydrological condition of the wetland. It usually takes a hotter fire to remove woody vegetation, and most prescribed fires are applied during the winter months.) *Applies to all life stages.*

- Fishing Activity and Fisheries Management effect on Predators (HE): The original CEM featured a link between fisheries activity and fisheries management to predator/competitor density. However, due to a lack of information about competition and its effects on LEBI, competition has been removed from the definition of this habitat element, and it is now called predators. Although references consulted for this CEM did not list any specific fish species as predators of LEBI, fisheries management activities can affect entire aquatic communities, which may affect the predator assemblage more broadly.

- Nuisance Species Introduction and Management effect on Nest Predators (HE): The original CEM had a link from nuisance species introduction and management to predators. For continuity with other models, predators was changed to nest predators in the eggs/nestlings life stage; however, all link interactions remain the same. *Applies to the eggs/nestlings life stage.*

- Recreational Activities effect on Nest Predators (HE): The original CEM had a link from recreational activities to predators. For continuity with other models, Predators was renamed Nest Predators for the eggs/nestlings life stage; however, all link interaction strengths and directions remain unchanged. *Applies to the eggs/nestlings life stage.*

- Fishing Activity and Fisheries Management effect on Nest Predators (HE): The original CEM had a link from fishing activity and fisheries management to predators in the eggs/nestlings life stage. For continuity with other models, Predators was renamed Nest Predators for the eggs/nestlings life stage. All link interactions remain the same. *Applies to the eggs/nestlings life stage.*

New Links with Habitat Elements as Causal Agents

- Water Chemistry effect on Chemical Stress (CAP): The natural and toxic chemicals in water (e.g., selenium and mercury as well as pesticide residues) can result in stress in LEBI, affecting health, fertility, and even survival. The link is hypothesized to be negative and unidirectional with proposed high intensity and low spatial scale and medium temporal scale, medium predictability, and high understanding. *Applies to all life stages.*

Deleted Links with Habitat Elements as Causal Agents

- Temperature effect on Thermal Stress (CAP). The link in the overwintering individuals life stage has been removed, as there is no indication that temperatures during this time period cause thermal stress. As defined in the model, most concern is related to high summer temperatures and effects on thermal stress of eggs/nestlings, juveniles, and breeding adults. *Applies to the overwintering individuals life stage.*

Updated Links with Habitat Elements as Causal Agents

- Nest Predators effect on Nest Predation (CAP): The original CEM had a link between predators and predation for all life stages. In the update for the eggs/nestlings life stage, Predators, has been renamed Nest Predators, and Predation has been renamed Nest Predation. All link interactions remain the same; only the names of the habitat element and the critical biological activity or process have been updated. *Applies to the eggs/nestlings life stage.*

- Emergent Vegetation Assemblage effect on Thermal Stress (CAP): Temperature regulation was changed to Thermal Stress. The link character type has been changed to negative (tall emergent vegetation in proximity to open water provides shade and humidity, reducing thermal stress), and the link and link character reasons have been updated. *Applies to all life stages.*

- Temperature effect on Thermal Stress (CAP): Temperature Regulation was changed to Thermal Stress. The link character type has been changed to positive (higher temperatures make it more difficult to regulate internal temperature, increasing thermal stress), and the link and link character reasons have been updated. *Applies to all life stages.*

- Brood/Litter Size effect on Nest Attendance (CAP): The link character direction has been changed from bi-directional to uni-directional (the bigger the brood, the more demand is placed on the parents to provision young), but there is a threshold placed on the birds by foraging ability and food availability. *Applies to the breeding adults life stage.*

- Infectious Agents effect on Disease (CAP): The link intensity, spatial scale, and temporal scale have been changed from high, unknown, and unknown to low, low, and low. Infectious agents do cause disease and are a potential concern that would act at small temporal and spatial scales; however, no pathogens have been identified as a current concern. Predictability is medium (the prevalence of certain pathogens should predictably correlate with certain diseases) and understanding low, as little research has been done on disease and LEBI in the LCR. *Applies to all life stages.*

New Links with Critical Activities/ Processes as Causal Agents

- Chemical Stress effect on Survival (LSO): Depending on the amount and type of chemical, individual LEBI can be weakened, and survival may be reduced. The link is hypothesized to be negative (more chemical stress, reduced survival) and unidirectional with proposed low intensity and low spatial scale and temporal scale, low predictability, and low understanding. *Applies to all life stages.*

- Chemical Stress effect on Fertility (LSO): Chemical stress caused by selenium, mercury, and pesticide residue can affect LEBI fertility. The link is hypothesized to be negative (greater chemical stress, reduced fertility) and unidirectional with proposed medium intensity and low spatial scale and low temporal scale, low predictability, and low understanding. *Applies to the breeding adults life stage.*

Deleted Links with Critical Activities/ Processes as Causal Agents

- Thermal Stress effect on Overwintering Individual Survival (LSO). The link in the overwintering individuals life stage has been removed, as there is no indication that temperatures during this time period cause thermal stress that affects LEBI survival. As defined in the model, most concern is related to high summer temperatures and effects on thermal stress of eggs/nestlings, juveniles, and breeding adults. *Applies to the overwintering individuals life stage.*

Updated Links with Critical Activities/ Processes as Causal Agents

- Nest Predation effect on Survival (LSO): In the original CEM, predation linked to survival in all life stages. In the update for the eggs/nestlings life stage, Predation has been renamed Nest Predation. The interaction links between nest predation and survival remain the same as the original predation to survival link. *Applies to the eggs/nestlings life stage.*

- Disease effect on Thermal Stress (CAP): Temperature Regulation was changed to Thermal Stress. Therefore, the character type has been changed to bi-directional (disease may increase physiological vulnerability to thermal stress and vice versa), and the link and character reason have been updated. *Applies to all life stages.*

- Thermal Stress effect on Survival (LSO): Temperature Regulation was changed to Thermal Stress. The link character type was changed from positive to negative (an increase in thermal stress may reduce survival of individual). The link character reason was also updated. *Applies to all life stages.*

New Links with Life-Stage Outcomes as Causal Agents

No change.

SUMMARY OF STANDARDIZATION OF TERMS

(Blue indicates new or revised items; orange indicates replaced items; and italicized entries are explanatory comments.)

CEM updated terms, 2018	CEM original terms, 2015–16
Life stages	
Eggs/Nestlings (*renamed*)	Nest
Juveniles (*renamed*)	Juvenile
Overwintering Individuals (*renamed*)	Overwintering Individual
Breeding Adults (*renamed*)	Breeding Adult
Life-stage outcomes	
Survival (*renamed*)	Survivors
Fertility (*renamed*)	Offspring
	Reproduction
Critical biological activities or processes	
Disease	Disease
Eating	Eating
Foraging	Foraging
Molting (*renamed*)	Molt
Nest Attendance	Nest Attendance
Nest Predation (*new*)	
Nest Site Selection	Nest Site Selection
Predation (*renamed*)	Predation and Competition
Thermal Stress (*renamed*)	Temperature Regulation
Habitat elements	
Anthropogenic Disturbance	Anthropogenic Disturbance
Brood/Litter Size (*renamed)*	Brood Size
Density of Conspecifics	Density of Conspecifics
Emergent Vegetation Assemblage	Emergent Vegetation Assemblage
Food Availability	Food Availability
Infectious Agents	Infectious Agents
Marsh Size	Marsh Size
Nest Predators (*new*)	
Parental Care (*new*)	Parental Feeding Behavior
	Parental Nest Attendance
Predators (*renamed*)	Predator/Competitor Density
Temperature	Temperature
Water Depth	Water Depth
Water Chemistry	Water Quality
Turbidity	Water Turbidity
Woody Vegetation Management	Woody Vegetation Management
Controlling factors	
Fire Management	Fire Management
Fishing Activity and Fisheries Management (*renamed*)	Fisheries Management
Habitat Management and Restoration	Marsh Management and Restoration
Nuisance Species Introduction and Management	Nuisance Species Introduction and Management
Off-Site Land Management and Use (*renamed*)	Off-Marsh Land Use
On-Site Water Management	
Recreational Activities	Recreational Activities
Wastewater and Other Contaminant Inflows (*renamed*)	Wastewater and Other Contaminant Inputs
Water Storage-Delivery System Design and Operation	Water Storage-Delivery System Design and Operation

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ATTACHMENT 1

Least Bittern (*Ixobrychus exilis*) Habitat Data

Table 1-1.—Least bittern habitat data
(*Note*: This is an update of table 2.1 found in attachment 2 of the original LEBI model document.
* 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.)

Habitat element	Value or range	Location	Reference
Anthropogenic disturbance	No quantifiable values found in literature.		
Density of conspecifics	Least bittern solitary nesters, with nest density < 1 per hectare (ha).	Lower Colorado River; rangewide	Rosenberg et al. 1991; Poole et al. 2020
	If large marsh with good food resources, then nests can be 10 meters (m) apart (15 nests per ha) or less.	Iowa, Florida	Weller 1961; Kushlan 1973; Poole et al. 2020
Emergent vegetation assemblage	Cattail (*Typha* spp.), *Scirpus* spp., and *Carex* spp. are dominant vegetation, also *Sagittaria* spp. or *Myriscus* (= *Cladium*) spp.; nests in clumps of vegetation at least 2 m high.	Rangewide	Palmer 1962 *in* Poole 2020; Poole et al. 2020
	Nest sites predominantly cattail or bulrush (Cyperaceae).	Lower Colorado River	Rosenberg et al. 1991; BIO-WEST, Inc. 2005; Corman 2005
	Nests in giant cutgrass.	Missouri, Tennessee	Arnold 2005; Winstead and King 2006
	Marsh structural type 1, 2, 3, and 5.	Lower Colorado River	Anderson and Ohmart 1976 *in* BIO-WEST, Inc. 2005
	Avoid sites with non-robust vegetation not strong enough to support nests, perching.	Louisiana	Valente et al. 2011
	Hemi-marsh configuration—half open water, half dense vegetation, 1:1 ratio.	Iowa; New York	Weller and Spatcher 1965 *in* Bogner and Baldassarre 2002; Lor and Malecki 2006
	Amount open water: 15–35%.	New York	Osborne et al. 2011
	Distance between nest and open water < 10 m.	Rangewide	Poole et al. 2020
	Distance between nest and open water 15 centimeters (cm) to 6 m, mean of 2.4 m.	Iowa	Weller 1961
	Mean distance between nest and open water 3.5 ± 0.8 m.	New York	Bogner and Baldassarre 2002
	No values provided on vegetation height or density.		

Table 1-1.—Least bittern habitat data
(*Note*: This is an update of table 2.1 found in attachment 2 of the original LEBI model document.
* 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.)

Habitat element	Value or range	Location	Reference
Food availability	Species lists available.	Rangewide	Poole et al. 2020
Infectious agents	No quantifiable values found in literature.		
Marsh size	> 5 acres.	Iowa	Brown and Dinsmore 1986
	> 10 ha optimal.	Rangewide	Poole et al. 2020
	≥ 6.8 ha.	Canada	Tozer et al. 2010
	0.4 ha.	Maine	Gibbs and Melvin 1990 *in* Poole et al. 2020
	Rarely use small marshes or narrow strips of cattails at water's edge.	Ohio	Peterjohn and Rice 1991
	Nested in patches of cattail 37 x 4 m wide; 76 x 15 m wide.	California	Sterling 2008
	Mean home range of adult nesting LEBI is 9.7 ha.	Western New York	Bogner and Baldassarre 2002
	Mean home range is 223.2 ± 47.9 ha, and mean core range is 37.6 ± 9.4 ha.	Missouri	Griffin et al. 2009
Predators	Species list available.	Rangewide	
Temperature	No quantifiable values in the literature.		
Turbidity	No quantifiable values found in literature.		
Water depth at nest	25–60 cm deep.	Rangewide	Poole et al. 2020 and references therein
	≥ 25.2 cm deep.	Canada	Tozer et al. 2010
	20.2–75.5 cm deep (average 42.2 ± 1.2 cm).	Western New York	Lor and Malecki 2006
	Maintain water depth > 30 cm.		Arnold 2005
	Average water depth at nest approximately 80 cm.	Missouri Mingo National Wildlife Refuge	Arnold 2005
	Average water depth at nest between 40–60 cm across 4 years.	Minnesota Agassiz National Wildlife Refuge	Arnold 2005
	8–96 cm deep.	Iowa	Weller 1961
	Mean water depth under nest: 34.4 ± 2.1 cm.	Western New York	Bogner and Baldassarre 2002

Table 1-1.—Least bittern habitat data
(*Note*: This is an update of table 2.1 found in attachment 2 of the original LEBI model document.
* 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.)

Habitat element	Value or range	Location	Reference
Water chemistry	High salinity levels may affect vegetation composition (e.g., cattails cannot survive > 30 parts per thousand).	Lower Colorado River	Garnett 2012
	High selenium levels were found in prey at sites along the lower Colorado River. > 0.3% parts per million present in 95% samples; Baseline selenium levels in water of 2 parts per billion biomagnifies 600 and 1,800x for sediment and invertebrates, respectively.	Lower Colorado River	Rusk 1991; Martinez 1994; King 2000
Woody vegetation assemblage	Only scattered shrubs or woody vegetation in marshes used for breeding; no values for shrub density found in literature.	Rangewide	Poole et al. 2020
	Scrub/shrub coverage minimal to moderate at 5–15%.	New York	Osborne et al. 2011

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