Edwards to Gulf

Landscape Conservation Design Pilot Project

Conservation Blueprint

Table of Contents

Acknowledgements

We would like to thank the many people who participated throughout this process, who are too numerous to list here in their entirety. Special thanks are in order to the representatives of the partner agencies and organizations that comprised the core team: Scott Alford, Preston Bean, Michael Brasher, James Giocomo, Charlotte Reemts, Mitch Sternberg, Amie Treuer-Kuehn, and Blair Tirpak. Many stakeholders went out of their way to provide detailed and constructive feedback, for which we are especially grateful: Tim Anderson, Chuck Ardizzone, Bill Balboa, Trey Barron, Lisa Benton, Russell Castro, Jill Csekitz, Nikki Davis, Beau Hardegree, Kirk Feuerbacher, Chris Harper, Wade Harrell, John Huffman, Rich Kostecke, Cindy Loeffler, Steve Magnelia, Kelly McDowell, Steven Raabe, Tim Siegmund, Elizabeth Smith, Garry Stephens, Charrish Stevens, Matt Wagner, Barry Wilson, and Woody Woodrow. We also appreciate the critical technical and biological input from the following people: Emma Clarkson, Steve DeMaso, Tim Grabowski, George Guillen, Toby Hibbitts, Norman Johns, Mark Parr, Charles Randklev, Clint Robertson, Nate Smith, Ryan Smith, Alan Stahnke, and Bill Vermillion. Special thanks also go out to Ian Kelly, our GIS assistant. We were lucky enough to have the assistance of a fantastic group of facilitators during the stakeholder workshop, whom we are particularly thankful for: Marcia Brown, David Kramer, Adrienne Marvin and Lisa Williams. This project would not have been possible without the funding provided by the United States Fish and Wildlife Service, through grant GCPLCC 2017-3. We are also grateful for the guidance provided by James Broska and Adam Zerrenner during the subsequent outreach phase of the project, which was funded by the United State Fish and Wildlife Service CFDA program, through grant F19AC00059. Last, but certainly not least, we are grateful for the guidance and vision provided by Bill Bartush and Benjamin Kahler, without which this project would not have succeeded.

Executive Summary

The Edwards to Gulf Conservation Blueprint represents a participatory effort to develop a suite of decision support tools that facilitate cooperation between conservation partners in the region. The blueprint was created in a transparent and iterative process, building upon a previously existing coarse filter blueprint to generate a fine filter by increasing the spatial resolution, and number and variety of indicators used. This iteration of the blueprint focused on a subset of habitats within the region (floodplain forests, freshwater wetlands, major rivers, rice agriculture, tallgrass prairie, and tidal wetlands), with an emphasis on promoting conservation of focal species identified by the Gulf Coast Prairie Landscape Conservation Cooperative. A core team of partner representatives, led by a team of researchers at Texas State University, followed the Open Standards for the Practice of Conservation to coordinate the participatory process of developing the blueprint with these habitats as conservation targets. This process included outreach to subject matter experts, numerous in-person meetings with individual stakeholders, a multi-day stakeholder workshop, release of draft spatial products for stakeholder review, and a series of stakeholder webinars and questionnaires. The first major output of this process was a viability assessment, where the ecological condition of each conservation target was evaluated based on a suite of key ecological attributes. The next step consisted of identifying, modeling and rating direct threats to the conservation targets, as well as their contributing factors. Then, a list of relevant conservation strategies was generated, and stakeholders worked together to articulate the activities needed to achieve highlighted strategies (i.e., strategies that were both important and underdeveloped in the region). The core team synthesized the preceding outputs with stakeholder feedback to develop spatially-explicit decision support tools that rate ecological integrity, prioritize habitat management (e.g., maintenance and restoration), and prioritize habitat protection. After completion of the blueprint, the spatial products were uploaded to DataBasin, where they are now publicly available, and all supporting documentation and materials were made available on the Edwards to Gulf Conservation Blueprint website. In the end, the process and tools will serve as a blueprint for conservation in the Lower Colorado, Guadalupe, and San Antonio River watersheds that will shape a future for conservation across the many working lands and ranches that the landscape supports.

Recommended Citation

Tarbox, B., J. Jensen, T. Hardy, and M. C. Green. 2019. Edwards to Gulf Landscape Conservation Design Pilot Project – Conservation Blueprint. Texas State University, San Marcos, TX. http://edwardstogulflcd.wp.txstate.edu/documents/

Background

A conservation blueprint is a living spatial plan that prioritizes conservation delivery in order to maximize the complementarity of the work conducted by various conservation entities. Developing a conservation blueprint through a participatory and transparent process ensures that the end product will effectively facilitate cooperative achievement of a shared vision of an ecologically healthy and sustainably managed region (Groves 2003). This blueprint consists of a series of maps and models that use the highest quality data available to assess ecological integrity of targeted broadly defined habitats, and prioritize habitat protection, management, or restoration based on a variety of socio-ecological inputs. The structure of these spatial products reflects a participatory conceptualization of the conservation targets, human well-being targets, direct threats, contributing factors, conservation strategies, and conservation goals that interact to determine conservation outcomes in our project region.

The Gulf Coast Prairie Landscape Conservation Cooperative (LCC) spans four ecoregions, including the Edwards Plateau, Gulf Coastal Prairie, Oaks and Prairies, and Tamaulipan Brushlands. These ecoregions include territory within six states (Kansas, Louisiana, Mississippi, Oklahoma, Tamaulipas, and Texas) and two countries (Mexico and the United States). The Gulf Coast Prairie LCC identified 28 focal species and 17 associated 'broadly defined habitats' (Gulf Coast Prairie LCC 2014) to guide research and planning efforts towards realizing their vision of, "a sustainable landscape of natural and cultural resources in the Gulf Coast Prairie geography that is resilient to the threats and stressors associated with climate and land uses changes." The first iteration of a conservation blueprint for this region assessed the amount of each broadly defined habitat within each subwatershed (12-digit Hydrologic Unit Code, or HUC). This 'coarse filter' approach assessed only habitat amount, and excluded any input on habitat condition or configuration.

Figure 1-1. Boundaries of the landscape conservation design geography. The region spans from the Edwards Plateau to the Gulf of Mexico and includes the watersheds of the Lower Colorado River, Guadalupe River, and San Antonio River.

This document describes a pilot project aimed at developing the 'fine filter' stage of the conservation blueprint, within a subset of the broader Gulf Coast Prairie LCC geography, spanning from the Edwards Plateau to the Gulf of Mexico in Texas (Figure 1-1). The 'fine filter' includes input on habitat condition and configuration, at a finer resolution than subwatersheds (specifically, 200-m x 200-m reporting units).

Prior to the initiation of this project, the Gulf Coast Prairie LCC identified a subset of broadly defined habitats (rivers, grasslands, and coastal wetlands) to help focus efforts on priority conservation and associated science needs, including the development of landscape conservation design (LCD) products that aid decision-making for conservation delivery actions. A core team of state, federal, non-governmental, and academic biologists (Table 1-1) then collaborated with a broad community of resource agencies to create (1) a common vision for conservation across state, federal, and non-governmental conservation agencies, and (2) spatially-explicit decision-support tools that can be used to identify and prioritize where to protect, manage, and restore habitats in this landscape. The first step in this process was to expand and refine the list of target habitats, and pare down the list of focal species to reflect the geographic and ecological bounds of the pilot project (Table 1-2; Tarbox et al. 2018a).

Table 1-1. Members of the Edwards to Gulf Landscape Conservation Design core team.

Name	Affiliation
Principal and Co-Investigators	
Clay Green, Ph.D.	Texas State University
Jennifer Jensen, Ph.D.	Texas State University
Thom Hardy, Ph.D.	Texas State University
Project Manager	
Bryan Tarbox, Ph.D.	Texas State University
Other Members	
Ben Kahler	U.S. Fish and Wildlife Service
Scott Alford	Natural Resources Conservation Services
Preston Bean, Ph.D.	Texas Parks and Wildlife Department
Michael Brasher, Ph.D.	Gulf Coast Joint Venture
Jesús Franco	Rio Grande Joint Venture
James Giocomo, Ph.D.	Oaks and Prairies Joint Venture
Charlotte Reemts	The Nature Conservancy
Mitch Sternberg	U.S. Fish and Wildlife Service
Amie Treuer-Kuehn	Texas Parks and Wildlife Department
Blair Tirpak	U.S. Geological Survey

Table 1-2. Conservation targets and related focal species. Higher tiers indicate greater conservation concern. Lower tiers indicate less concern, or critical knowledge gaps (Gulf Coast Prairie LCC 2014).

	Focal Species		
Habitat Types	**Tier 1**	**Tier 2**	**Tier 3**
Floodplain forests, swamps, and riparian systems	Alligator gar (*Atractosteus spatula*)	Little blue heron (*Egretta caerulea*)	
Freshwater wetlands	Mottled duck (*Anas fulvigula*)	Little blue heron	Northern pintail (*Anas acuta*)
Major rivers	Alligator gar Guadalupe bass (*Micropterus treculii*) Freshwater mussels (*Quadrula* spp.)	Broadcast-spawning prairie minnows (*Notropis*, *Macrhybopsis*, and *Hybognathus* spp.)	River prawn (*Machrobrachium* spp.)
Rice agriculture	Mottled duck	Little blue heron	Northern pintail
Tallgrass prairie	Mottled duck Northern bobwhite (*Colinus virginianus*)	Eastern meadowlark (*Sturnella magna*)	Crawfish frog (*Lithobates areolatus*)
Tidal wetlands	Alligator gar American oyster (*Crassostrea virginica*) Mottled duck	Blue crab (*Callinectes sapidus*) Penaeid shrimp	Diamondback terrapin (*Malaclemys terrapin*) Gulf menhaden (*Brevoortia patronus*) River prawn

To develop the LCD, the core team employed the Conservation Measures Partnership's Open Standards for the Practice of Conservation. The planning stage of this project consisted of extensive technical webinars and meetings with members of the core team, as well as a variety of stakeholders and species experts, followed by a multi-day stakeholder workshop (Tarbox et al. 2018a). The project manager and PIs then developed draft spatial products and product documentation. These products aimed to assess ecological integrity of target habitats, and prioritize areas for protection, management, and restoration. The draft products then were released to a broad group of stakeholders across numerous organizations and agencies who provided feedback through a questionnaire and multiple webinars (Tarbox et al. 2018b). Stakeholder feedback informed a comprehensive revision process that resulted in the final products that now comprise the conservation blueprint.

After the release of the Edwards to Gulf Conservation Blueprint, stakeholder outreach was conducted to ensure continued engagement with the products into the future. A subsequent report will be released detailing the accomplishments of that phase of the project.

Introduction

We used the Conservation Measures Partnership's Open Standards for the Practice of Conservation to guide the development of the Edwards to Gulf Landscape Conservation Design (LCD). We used the Open Standards to ensure a systematic approach that facilitates an iterative and transparent planning and design process (Salafsky et al. 2002). Here we describe how we determined the foundational aspects of the project: scope, vision, conservation targets, nested targets, and human well-being targets. In subsequent chapters, we describe the process of building upon this foundation to conduct a viability assessment, identify and rate direct threats and their contributing factors, outline conservation strategies, and develop the spatial products that bring the conservation blueprint to life.

Scope

This LCD applies to the watersheds of the Lower Colorado, Guadalupe, and San Antonio Rivers. The geographic extent spans from the base of the Edwards Plateau to the Gulf of Mexico, with the cities of San Antonio, Austin, Lake Jackson and Corpus Christi approximating the western, northern, eastern, and southern corners, respectively (Figure 1-1).

Ecologically, this LCD includes a specific subset of broadly defined habitats: tallgrass prairie (or shrub- and grasslands with the potential to be tallgrass prairie), tidal wetlands, major rivers, floodplain forests, freshwater wetlands, and rice agriculture (Table 1-2; Gulf Coast Prairie LCC 2014). The absence of other habitats, such as oak hardwood and pine forests, or semi-desert shrub and grasslands, does not discount their importance, but only reflects the limited scope of this iteration of the Edwards to Gulf LCD. As such, this document and its associated spatial products should only be used to prioritize conservation actions within the target habitats.

The temporal scope of this LCD is generally limited to the next 10 years (2020 to 2029). Assessment of most threats was conducted with that time frame in mind. However, there were some exceptions. The threats of inadequate allocation of freshwater resources, residential / urban development, and land loss due to erosion, subsidence and sea level rise were assessed over the next 50 years, to account for the importance of these processes unfolding over long time periods, and the high degree of severity and irreversibility associated with them.

Vision

The vision for this LCD is a modified version of the vision for the Gulf Coast Prairie LCC:

A sustainable landscape of natural and cultural resources from the Edwards Plateau to the Gulf of Mexico that is resilient to the threats and stressors associated with climate and land use changes.

Conservation Targets

The primary targets of this LCD consist of six broadly defined habitats: tallgrass prairie, tidal wetlands, major rivers, floodplain forests, freshwater wetlands, and rice agriculture (Table 1-2). These targets are based on classifications developed by the Gulf Coast Prairie LCC (Gulf Coast Prairie LCC 2014). Each habitat includes a suite of vegetation classes from the Texas Ecological Mapping Systems classification (Appendix Table A-1). The broad nature of their conceptualization facilitates regional scale assessment of ecological integrity and conservation planning. While this approach may appear to over represent some habitats, it ensures that all potential pathways for achieving conservation objectives are included in our spatial analyses.

Tallgrass prairie is the dominant (potential) habitat within this geography. While true tallgrass prairie plant communities are now extremely rare, there is an abundance of former prairie that has been transformed by intentional conversion to and unintentional invasion by nonnative pasture grasses (Smeins et al. 1991; Samson et al. 2004). Additionally, there are extensive former grasslands that are now shrub- or woodlands due to alterations of various ecological process (Van Auken 2000; D'Odorico et al. 2012). These former prairies are included under tallgrass prairie for their potential to 1) be restored to tallgrass prairie, or 2) serve similar ecological functions as tallgrass prairie, despite differences in vegetation composition.

Tidal wetlands include tidally influenced riverine systems, fresh to saline tidal marshes, saline coastal prairie and salt flats. Saline coastal prairies are included in tallgrass prairie spatial products because they represent a transitional zone between each of these broadly defined habitats, that could meet conservation objectives relevant to either of these two broadly defined habitats.

Major rivers refer to rivers that fall under TNC Classifications 4 and 5 (cumulative drainage area of 3,000-10,000 km^2 and more than 10,000 km^2, respectively; Gulf Coast Prairie LCC 2014). Seven rivers within this geography meet those requirements: the Medina, San Antonio, Guadalupe, San Marcos, Lavaca, Navidad, and Colorado Rivers. The Blanco and San Bernard are two significant rivers within the geography that did not meet these requirements and thus were not included. The Gulf Coast Prairie LCC also includes natural lakes within this designation, but not manmade reservoirs. Within our geography, the only large bodies of fresh water are manmade reservoirs (e.g., Lake Texana, Coleto Creek Reservoir).

Floodplain forests include all riparian forests and forested wetlands within the pilot geography, reflected in the full title used by the Gulf Coast Prairie LCC (floodplain forests, swamps and riparian systems). They are distinct from non-forested (i.e., herbaceous) freshwater wetlands, however they do include some herbaceous habitats that are considered part of the floodplain forest complex (e.g., riparian grasslands within the Columbia bottomlands). Floodplain forests are predominantly located along the major rivers (and their tributaries) described above, as well as the Columbia bottomlands associated with the Colorado, San Bernard and Brazos Rivers.

Freshwater wetlands are dominated by herbaceous vegetation and are evenly split between riverine (e.g., riparian herbaceous wetland) and palustrine (e.g., coastal prairie pondshore) wetlands.

Rice agriculture was included because it can serve an ecological role similar to that of freshwater wetlands if managed appropriately (Elphick et al. 2010), and because it is threatened by some of the same processes that degrade and destroy natural wetlands. Furthermore, rice production is an economically and culturally important livelihood in the region that highlights the links between ecological integrity and human well-being.

Nested Targets (Focal Species)

Each broadly defined habitat is associated with a group of focal species that were originally identified by the Gulf Coast Prairie LCC (Table 1-2; Gulf Coast Prairie LCC 2014). This LCD does not consider these focal species as conservation targets themselves. Instead, we used the ecological needs of focal species to guide selection of the indicators used to assess the ecological integrity of each broadly defined habitat, including some indices specifically designed to assess a given species' habitat needs.

Human Well-being Targets

Each conservation target provides ecosystem services that benefit local and regional human communities (Table 2-1). Ecosystem services fall under four different categories: provisioning (e.g., provision of food, fuelwood), regulating (e.g., crop pollination, carbon sequestration), supporting (e.g., nutrient cycling, soil formation), and cultural services (e.g., spiritual values, aesthetic values). Human well-being targets themselves are loosely based on the Millennium Ecosystem Assessment's five dimensions of human well-being: necessary material for a good life, health, good social relations, security, and freedom and choice (CMP 2012).

Table 2-1. Links between conservation targets, ecosystem services, and human well-being targets.

Human Well-being Targets	Ecosystem Services	Conservation Targets
Fisheries-based livelihoods	Provision of fish and wildlife habitat	All habitats
Human health	Water quality	All natural habitats
Hunting and fishing traditions	Provision of fish and wildlife habitat	All habitats
Livelihoods from working landscapes	Provision of pasture for livestock, provision of resources for agriculture	Rice agriculture, tallgrass prairie
Security from natural disasters	Coastal protection, flood and erosion control	All natural habitats
Tourism-based livelihoods	Opportunities for tourism and recreation	All habitats

Viability Assessment

Viability assessment is a structured approach to evaluating the ecological health or integrity of conservation targets based on their key ecological attributes. This process also facilitates setting goals and developing monitoring plans (FOS 2013). We later use the viability assessment to inform the development of ecological integrity models (Tarbox et al. 2019b).

Key Ecological Attributes

Key ecological attributes (KEAs) are the characteristics that collectively indicate whether conservation targets are healthy, or in danger of extirpation or degradation. KEAs should be measurable and related to the conservation target's capacity to sustain itself. Under the Open Standards framework, KEAs are separated into three categories: size, condition, and landscape context. Size attributes refer to the amount of the target that exists (e.g., population for species targets, land area for habitat targets). Condition attributes refer to local scale structural, compositional, or functional aspects of the target (e.g., canopy cover, species richness, water quality). Landscape context attributes refer to landscape scale aspects (e.g., connectivity; FOS 2013).

To conduct the viability assessment, indicators for each KEA are identified, and thresholds are set to determine the ecological status of each attribute. The status of each KEA is defined by the categories of Poor, Fair, Good, or Very Good. These categories reflect the need for human intervention to avoid extirpation or degradation, with Poor and Fair ratings falling outside an 'acceptable range of variation', and Good and Very Good ratings indicating that an attribute is within the acceptable range of variation (Table 3-1; FOS 2013).

The core team (Table 1-1) developed a list of potential key ecological attributes for each conservation target through a literature review and series of webinars. We selected attributes that reflected the capacity of conservation targets (i.e., broadly defined habitats) to sustain relevant focal species (Table 1-2). In some cases, we also included critical aspects of a conservation target that were not captured by the focal species' needs (e.g., forest structure for floodplain forests). We then selected indicators for each attribute that could be quantified at a resolution and extent appropriate for the scale of this project. Next, we refined the list of key ecological attributes and indicators via outreach to relevant species and habitat experts, and identified the thresholds between Poor, Fair, Good, and Very Good ratings. The final list of key ecological attributes and their indicators was completed after being reviewed at the stakeholder workshop in November 2017 (Tarbox et al. 2018a).

Table 3-1. Range of ratings for ecological integrity indicators, and their definitions (FOS 2013).

Poor	Fair	Good	Very Good
Restoration increasingly difficult; may result in extirpation	Outside acceptable range of variation; requires human intervention	Indicator within acceptable range of variation; some intervention required for maintenance	Ecologically desirable status; requires little intervention for maintenance

Habitat Assessments

We used key ecological attributes and their indicators to develop models for ecological integrity used as the basis of the conservation blueprint (Tarbox et al. 2019b). We then calculated the mean values of indicators across the pilot geography for each KEA to complete the viability assessment. Most habitats included a KEA for focal species' habitat suitability. We used an OR operator to combine the indicators for each species' because some species have conflicting habitat requirements. As a result, the rating for the focal species' KEA was calculated as the mean of the highest value for any given species within each unit of habitat. The results of the viability assessment are described separately for each conservation target below.

Floodplain Forests, Swamps, and Riparian Systems

The ecological integrity of floodplain forests was rated Good. Most KEAs were rated Good, except for forest structure (Fair) and landscape matrix (Very Good; Table 3-2). For more information, refer to the Ecological Integrity Ratings manual (Tarbox et al. 2019b).

Table 3-2. Viability assessment for floodplain forests, swamps, and riparian systems.

Key Ecological Attribute (KEA)	Category	Indicator(s)	Status
Amount of habitat	Size	Percent cover (within 200-m units) Percent landscape (PLAND; within 1-km)	Good
Focal species' habitat suitability (includes floodplain connectivity)	Condition	Alligator gar distribution index Flood frequency Little blue heron GAP distribution LBH foraging habitat cover (10-km) LBH nesting colony density (10-km) Suitable gar spawning vegetation	Good
Heterogeneous forest structure	Condition	Basal area Canopy cover	Fair
Landscape matrix in natural vegetation cover	Landscape context	Energy infrastructure density Land use land cover change Transportation infrastructure density	Very Good
Large blocks of habitat	Landscape context	Mean patch area	Good

Freshwater Wetlands and Rice Agriculture

The ecological integrity of freshwater wetlands was rated Fair. Most KEAs were rated Fair, except for landscape matrix (Good) and native wetland vegetation (Very Good; Table 3-3). Thresholds for amount of habitat and large blocks of habitat indicators are lower for freshwater wetlands and rice agriculture, to account for their naturally limited size and distribution compared to other target habitats. Native wetland vegetation was probably overestimated due to the inability to account for invasive wetland species beyond *Phragmites* at an appropriate spatial scale and resolution. The ecological integrity of rice agriculture was rated Good. Most KEAs were rated Good, except for focal species' habitat suitability (Fair; Table 3-4). We originally intended to distinguish between flooded fallow and post-harvest rice land, but instead used wintering waterfowl assessment data as an indicator of hydrologic condition, which did not separate the two (Tarbox et al. 2019b).

Table 3-3. Viability assessment for freshwater wetlands.

Key Ecological Attribute (KEA)	Category	Indicator(s)	Status
Amount of habitat	Size	Percent cover (within 200-m units) Percent landscape (PLAND; within 1-km)	Fair
Focal species' habitat suitability	Condition	Little blue heron GAP distribution LBH nesting colony density (10-km) LBH nesting habitat cover (10-km) Mottled duck brood-rearing habitat index Mottled duck GAP distribution Northern pintail GAP distribution Wintering waterfowl surface water assessment	Fair
Landscape matrix in natural vegetation cover	Landscape context	Energy infrastructure density Land use land cover change Transportation infrastructure density	Good
Large blocks of habitat	Landscape context	Mean patch area	Fair
Native wetland vegetation	Condition	*Phragmites* cover (%)	Very Good

Table 3-4. Viability assessment for rice agriculture.

Key Ecological Attribute (KEA)	Category	Indicator(s)	Status
Amount of habitat	Size	Percent cover (within 200-m units) Percent landscape (PLAND; within 1-km)	Good
Focal species' habitat suitability	Condition	Little blue heron GAP distribution LBH nesting colony density (10-km) LBH nesting habitat cover (10-km) Mottled duck brood-rearing habitat index Mottled duck GAP distribution Northern pintail GAP distribution Wintering waterfowl surface water assessment	Fair
Landscape matrix in natural vegetation cover	Landscape context	Energy infrastructure density Land use land cover change Transportation infrastructure density	Good
Large blocks of habitat	Landscape context	Mean patch area	Good

Major Rivers

The ecological integrity of major rivers was rated Good. Most KEAs were rated Good, except for floodplain connectivity and sinuosity (Fair), and riparian buffer health and water quality (Very Good; Table 3-5). Water quality was likely overestimated because we used water bodies listed as impaired by the EPA as an indicator, which only identifies severely impaired water bodies (Tarbox et al. 2019b). Future efforts should incorporate more direct and specific indicators of water quality. We also excluded attributes directly associated with Guadalupe bass recruitment and genetic integrity, which are important, but not currently feasible to include in the models. More direct indicators of substrate and in-stream habitat diversity could also improve future models.

Table 3-5. Viability assessment for major rivers.

Key Ecological Attribute (KEA)	Category	Indicator(s)	Status
Floodplain connectivity	Landscape context	Flood frequency Suitable alligator gar spawning vegetation	Fair
Focal species' presence	Size	Alligator gar distribution index Broadcast-spawning prairie minnow distribution index Guadalupe bass distribution index Important freshwater mussel habitat	Good
In-stream connectivity	Landscape context	Distance to downstream dam Stream network patch length	Good
Landscape matrix in natural vegetation cover (includes permeability)	Landscape context	Energy infrastructure density Land use land cover change Transportation infrastructure density	Good
Riparian buffer health	Condition	Riparian cover	Very Good
Sinuosity	Condition	Sinuosity	Fair
Water quality	Condition	Water impairment	Very Good
Water quantity	Size	Percent time natural flows unaltered	Good

Tallgrass Prairie

The ecological integrity of tallgrass prairie was rated Good. Most KEAs were rated Good, except for fire return interval (Poor), and herbaceous species composition and large blocks of habitat (Good; Table 3-6). Control of woody encroachment was probably overestimated because LANDFIRE underestimates woody cover in this region, and EMS cover only identifies 10-m units with >50% woody cover, as such. Fire return interval possibly was underestimated due to the coarse spatial and temporal resolution of MODIS data. However, fire is known to be relatively rare in the region, so this may not be the case (Tarbox et al. 2019b). The indicators we used to assess herbaceous composition were rough proxies; their replacement by more direct assessments of herbaceous composition would certainly improve model results (Tarbox et al. 2019b). Texas Parks and Wildlife is currently developing such a project, which may be included in models when available. Grazing intensity and timing of mowing were important factors that were not currently possible to include as indicators in our models.

Table 3-6. Viability assessment for tallgrass prairie.

Key Ecological Attribute (KEA)	Category	Indicator(s)	Status
Adequate control of woody encroachment	Condition	EMS woody cover LANDFIRE woody cover	Good
Amount of habitat	Size	Percent cover (within 200-m units) Percent landscape (PLAND; within 1-km)	Good
Appropriate fire return interval	Condition	Burn frequency	Poor
Appropriate herbaceous species composition	Condition	EMS category index Prairie remnant cover	Fair
Focal species' habitat suitability	Condition	Crawfish frog GAP distribution Mottled duck GAP distribution Mottled duck nesting habitat index Northern bobwhite BBS density Northern Bobwhite Conservation Initiative biologists' ranking index Northern bobwhite GAP distribution Prairie pondshore cover	Good
Landscape matrix in natural vegetation cover	Landscape context	Energy infrastructure density Land use land cover change Transportation infrastructure density	Good
Large blocks of habitat	Landscape context	Mean patch area	Fair

Tidal Wetlands

The ecological integrity of tidal wetlands was rated Good. Most KEAs were rated Good, except for landscape matrix and unimpaired hydrology (Very Good; Table 3-7). Water quality possibly was overestimated because we used water bodies listed as impaired by the EPA as an indicator, which only identifies severely impaired water bodies. We also included the coastal condition index for water and sediment quality, which should help offset inadequacies of using impaired water bodies as an indicator. However, this indicator was interpolated from a spatially coarse dataset, and therefore may mask localized variations in water and sediment quality (Tarbox et al. 2019b). Future efforts could incorporate more direct and specific indicators of water and sediment quality. Freshwater inflows were a key ecological attribute we identified that were not feasible to include in this pilot project.

Table 3-7. Viability assessment for tidal wetlands.

Key Ecological Attribute (KEA)	Category	Indicator(s)	Status
Amount of habitat	Size	Percent cover (within 200-m units) Percent landscape (PLAND; within 1-km)	Good
Focal species' habitat suitability	Condition	Diamondback terrapin GAP distribution Mottled duck GAP distribution Mottled duck nesting habitat index Percent cover of oyster reefs within 500m Tidal wetland : open water edge density	Good
Landscape matrix in natural vegetation cover	Landscape context	Energy infrastructure density Land use land cover change Transportation infrastructure density	Very Good
Large blocks of habitat	Landscape context	Mean patch area	Good
Unimpaired hydrology	Condition	Ditch density Shipping lane proximity	Very Good
Water and sediment quality	Condition	Coastal condition index Water impairment	Good

Direct Threats and Contributing Factors

After identifying conservation targets and their key ecological attributes, we built a conceptual model of our system to identify all threats to the persistence of the conservation targets, as well as the various factors that may contribute to or counteract those threats (Figure 4-1). Direct threats consist of human actions, or natural events exacerbated by humans, that directly degrade conservation target(s). Contributing factors comprise the economic, cultural, societal, and institutional factors responsible for the existence or severity of direct threats (FOS 2012). We then rated the scope, severity and irreversibility of each threat for each conservation target to devise overall threat ratings (Table 4-1). Scope indicates the proportion of each conservation target that a given threat impacts. Severity refers to the amount of damage or degradation a given threat causes. Irreversibility indicates the degree to which the damage caused by a given threat can be restored (FOS 2012). Each threat was assessed with the next 10 years in mind. However, for some threats (urban development, inadequate allocation of freshwater resources, and sea-level rise) we used a period of 50 years to better account for the long-term impacts associated with them. This process fed into the development of conservation strategies in the following chapter by allowing us to set objectives related to addressing specific threats or contributing factors. We later used these threat ratings to inform the development of threat rankings in the conservation prioritization models (Tarbox et al. 2019a).

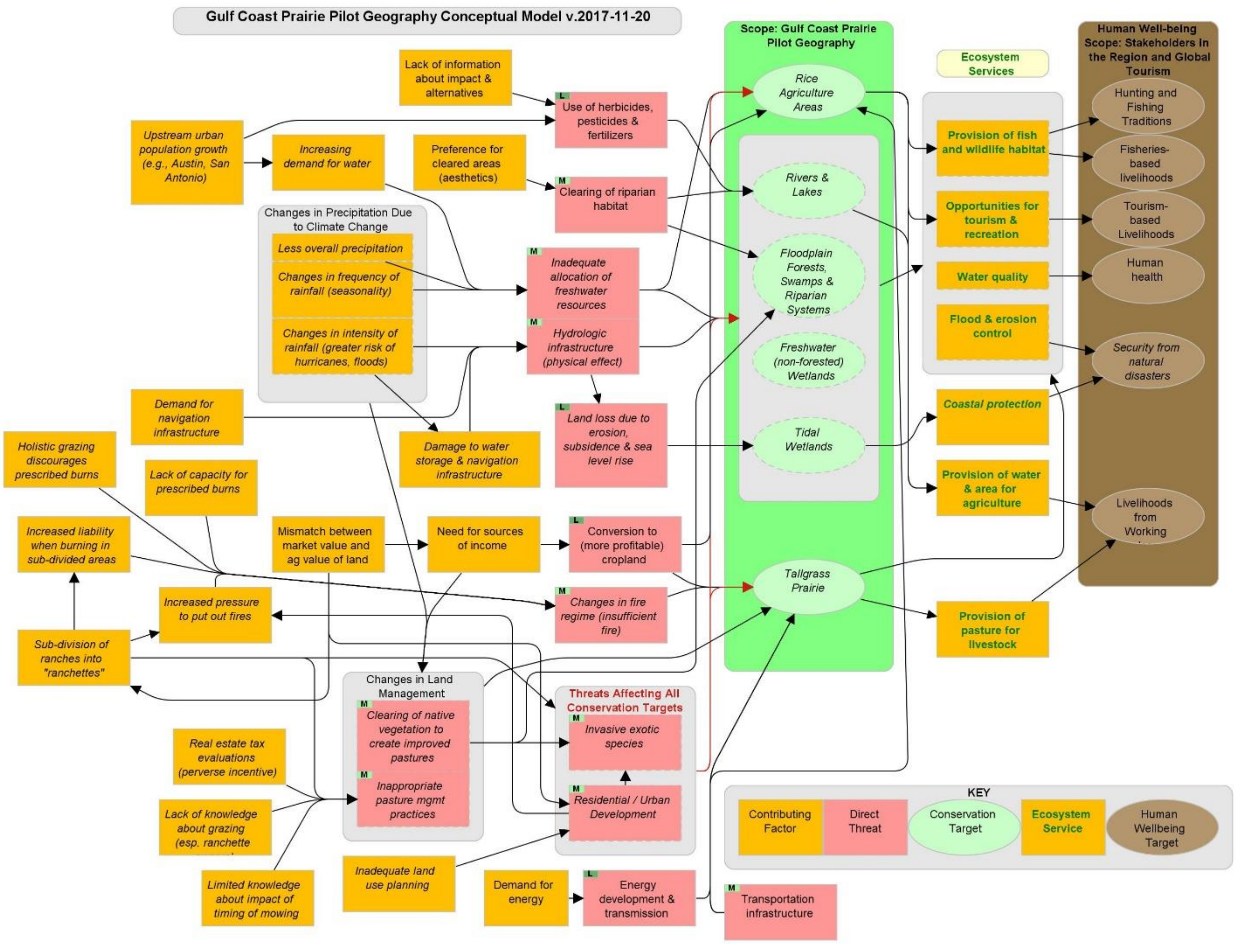

Figure 4-1. Conceptual model illustrating the links between conservation targets, ecosystem services, human well-being targets, direct threats, and contributing factors.

Table 4-1. Rating of direct threats (L=low, M=medium, H=high, V=very high) to conservation targets (FF=floodplain forests, FW=freshwater wetlands, MR=major rivers, RA=rice agriculture, TP=tallgrass prairie, TW=tidal wetlands). Threats were rated in Miradi (FOS 2016). Scope, severity, and irreversibility subcomponents to threat ratings are in subscript (FOS 2012).

Direct Threat	FF	FW	MR	RA	TP	TW	Summary Threat Rating
Transportation infrastructure				M_{LVV}	M_{LVV}		M
Hydrologic infrastructure	H_{HHH}	M_{MHH}	M_{HMH}			M_{MHH}	M
Inadequate allocation of freshwater resources	L_{HML}	L_{HML}	M_{HHL}	H_{VHM}		L_{VML}	M
Clearing of riparian habitat	H_{HHM}		M_{HMM}				M
Inappropriate pasture mgmt.					H_{HMM}		M
Changes in fire regime					H_{MHM}		M
Invasive exotic species	M_{HMM}	L_{MLM}	M_{MMM}	M_{MMM}	H_{HHM}	L_{LMM}	M
Clearing of native vegetation to create improved pasture	L_{LVM}	M_{LVV}	L_{LHH}	M_{MHM}	L_{LHH}	L_{LHH}	M
Residential / urban development	M_{LVV}	M_{LVV}	M_{LVV}	M_{LVV}	M_{LVV}	M_{LVV}	M
Energy dev. & transmission					L_{LHH}		L
Use of agrochemicals			M_{HMM}				L
Land loss due to erosion, subsidence & sea level rise						M_{VMH}	L
Conversion to (other) cropland				M_{HLL}	L_{LVM}		L
Summary Target Rating	H	M	M	H	H	M	H

Conservation Strategies

Conservation strategies consist of a series of actions that collectively work to achieve conservation goals by reducing direct threats, mitigating or taking advantage of contributing factors, or improving the viability of conservation targets (FOS 2009). The core team conducted a review of existing conservation plans in the region to create a list of potential conservation strategies and assess the extent to which each strategy had been successfully implemented to date. The core team then drafted conservation goals based on the preliminary viability assessment conducted before the stakeholder workshop. The draft goals and strategies were presented to workshop participants so that they could prioritize strategies (Table 5-1) and develop results chains for a subset of key strategies (Figures 5-1 through 5-4; Tarbox et al. 2018a). Due to post-workshop revisions of the viability assessment, many of the draft goals are no longer appropriate and therefore not included here.

Highlighted Strategies

To prioritize conservation strategies and develop results chains, the core team separated participants in the stakeholder workshop into groups based on four key themes: 1) management and restoration of tallgrass prairie, 2) allocation and hydrology of freshwater resources, 3) land loss mitigation and adaptation for tidal wetlands, and 4) addressing the threat of residential development and subdivision of large ranches. Each group separately rated their list of relevant conservation strategies based on potential conservation impact, technical feasibility (including social and political feasibility), and financial feasibility (Table 5-1; Tarbox et al. 2018a).

Based on these prioritizations and the review of existing conservation plans, each stakeholder group selected two conservation strategies for which to develop results chains. Development of results chains was intended to identify important strategies that were not yet being successfully implemented in the region, and generate insight for the development of spatial products that would facilitate the implementation of these strategies by partner agencies and organizations.

Results chains are a method for clarifying assumptions and necessary steps involved in realizing the achievement of conservation strategies (FOS 2009). Stakeholders identified intermediate results (blue boxes) needed to meet thread reduction results (pink boxes) and viability results (purple boxes). Stakeholders then identified activities (yellow boxes) necessary for achieving each result, and set objectives for each activity (Figures 5-1 through 5-4; Tarbox et al. 2018a).

Table 5-1a. Prioritization of conservation strategies for the groups working on 1) management and restoration of tallgrass prairie, and 2) allocation and hydrology of freshwater resources. Strategies selected for action plan development are in green.

	Strategy	Criteria: Potential Impact	Criteria: Technical Feasibility	Criteria: Financial Feasibility	Total	Rank
Group 1	Promote good wildlife management	4	8	8	20	#1
Group 1	Promote good grazing management	8	6	5	19	#2
Group 1	Establish best practices for prescribed fire through partnerships	7	5	7	19	#3
Group 1	Promote native grasses in landowner incentive programs and prohibit use of nonnative invasive grasses	6	7	5	18	#4
Group 1	Establish prescribed fire coops or teams throughout the pilot geography	7	3	3	13	#5
Group 1	Promote appropriate use of agrochemicals (IPM)	3	4	6	13	#5
Group 1	Promote market-driven incentives for tallgrass prairie restoration	5	2	2	9	#6
Group 1	Educate tax appraisers about appropriate stocking rates	2	1	4	7	#7
Group 2	Provide technical assistance / science support on water management	3	5	5	13	#1
Group 2	Build public support for water conservation and management	5	3	4	12	#2
Group 2	Increase transparency related to existing regulations for water management	1	4	3	8	#3
Group 2	Implement voluntary strategies for environmental flows	4	2	1	7	#4
Group 2	Protect and improve water quality	2	1	2	5	#5

Table 5-1b. Prioritization of conservation strategies for the groups working on 3) land loss mitigation and adaptation for tidal wetlands, and 4) addressing the threat of residential development and subdivision of large ranches. Strategies selected for action plan development are in green.

	Strategy	Criteria			Total	Rank
		Potential Impact	Technical Feasibility	Financial Feasibility		
Group 3	Acquire land or rights in priority areas to conserve or restore existing wetlands	5	8	8	21	#1
Group 3	Acquire land or rights in priority upland areas for migration of tidal wetlands	7	7	4	18	#2
Group 3	Restore and create wetlands using various approaches	6	6	6	18	#2
Group 3	Use breakwaters and vegetation for erosion control	3	5	7	15	#3
Group 3	Restore landscape-scale hydrology (e.g., reverse channelization)	4	4	5	13	#4
Group 3	Implement zoning restrictions near tidal wetlands to provide buffer (e.g., rolling easements)	8	1	1	10	#5
Group 3	Promote voluntary wetland conservation for non-jurisdictional wetlands	1	3	3	7	#6
Group 3	Strengthen enforcement of shipping traffic laws	2	2	2	6	#7
Group 4	Acquire land to abate development	8	8	1	17	#1
Group 4	Provide outreach to landowners about incentive programs and other tools for preventing development or subdivision	3	7	7	17	#1
Group 4	Inform landowners about expected changes in sea level and areas of marsh expansion	2	6	8	16	#3
Group 4	Work with rice producers to maintain land in rice cultivation	5	5	6	16	#3
Group 4	Encourage county-level planning (and information exchange about risks)	6	3	5	14	#5
Group 4	Protect land through zoning, PDRs and non-permanent easements	7	4	2	13	#6
Group 4	Advocate to allow voters to make resource decisions	4	1	3	8	#7
Group 4	Lobby for green infrastructure during planning	1	2	4	7	#8

Management and Restoration of Tallgrass Prairie

Tallgrass prairie (or grasslands with the potential to become tallgrass prairie) is by far the most dominant broadly defined habitat in the region. Furthermore, grassland conservation will likely depend more on managing and restoring grasslands on private land, rather than acquiring land through federal/state agencies or NGOs. Workshop participants in this group developed results chains for their fourth and sixth ranked conservation strategies because these are key strategies that were not receiving enough attention at the time of the workshop. The first of these two strategies (promote native grasses in landowner incentive programs) focused on conducting outreach to landowners and non-traditional organizations to increase use of native grasses among landowners benefiting from incentive programs (e.g., Environmental Quality Incentives Program [EQIP]; Figure 5-1a). The next strategy (promote market-driven incentives for tallgrass prairie restoration) focused on marketing land uses that utilize native grass species and pressuring pipeline and transportation agencies to plant native grass species to increase market demand for native grass species and increase availability of native seed (Figure 5-1b).

To facilitate conservation partner efforts to implement these strategies, we included data on landowner participation in incentive programs (e.g., EQIP, Pastures for Upland Birds program) as an opportunity ranking indicator for relevant conservation targets. These indicators feed into overall maintenance and restoration rankings in the Tallgrass Prairie Management Prioritization tool, and can be viewed directly as separate layers on DataBasin (Tarbox et al. 2019a).

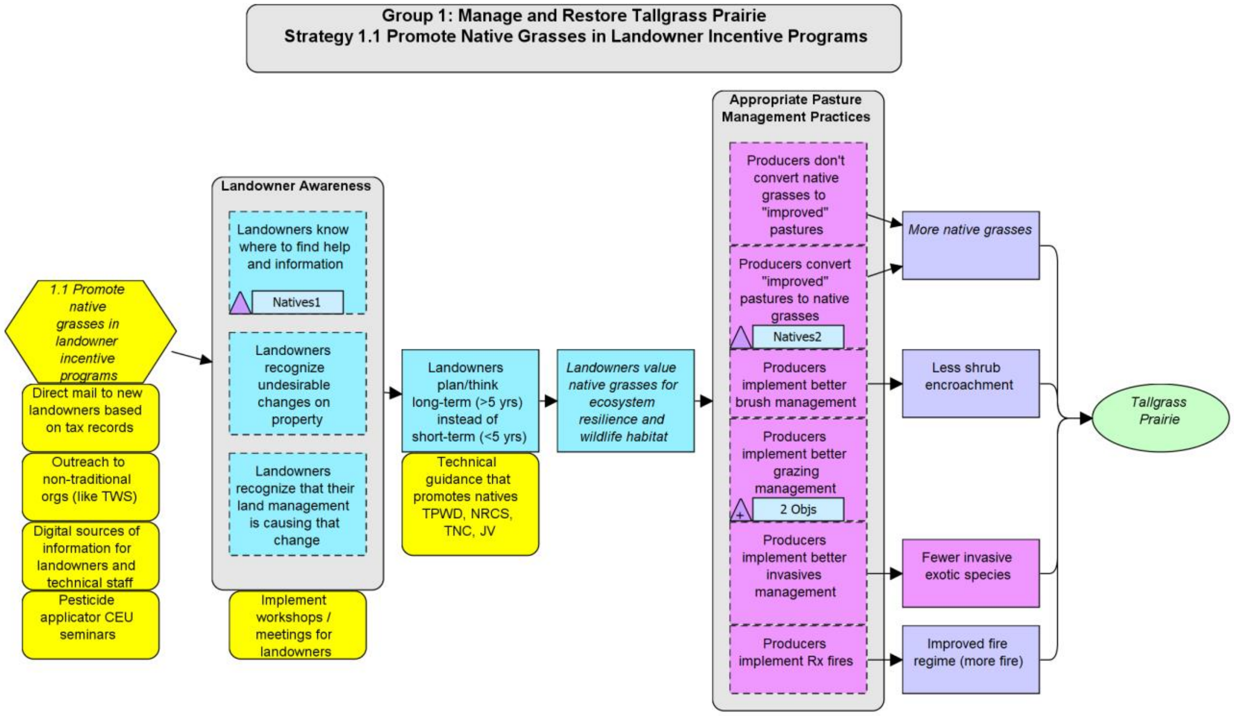

Figure 5-1a. Results chain for the conservation strategy: promote native grasses in landowner incentive programs. This strategy was the fourth ranked strategy for the group working on management and restoration of tallgrass prairie. It was selected primarily because it was deemed a seriously underappreciated aspect of improving grassland habitat quality in the region.

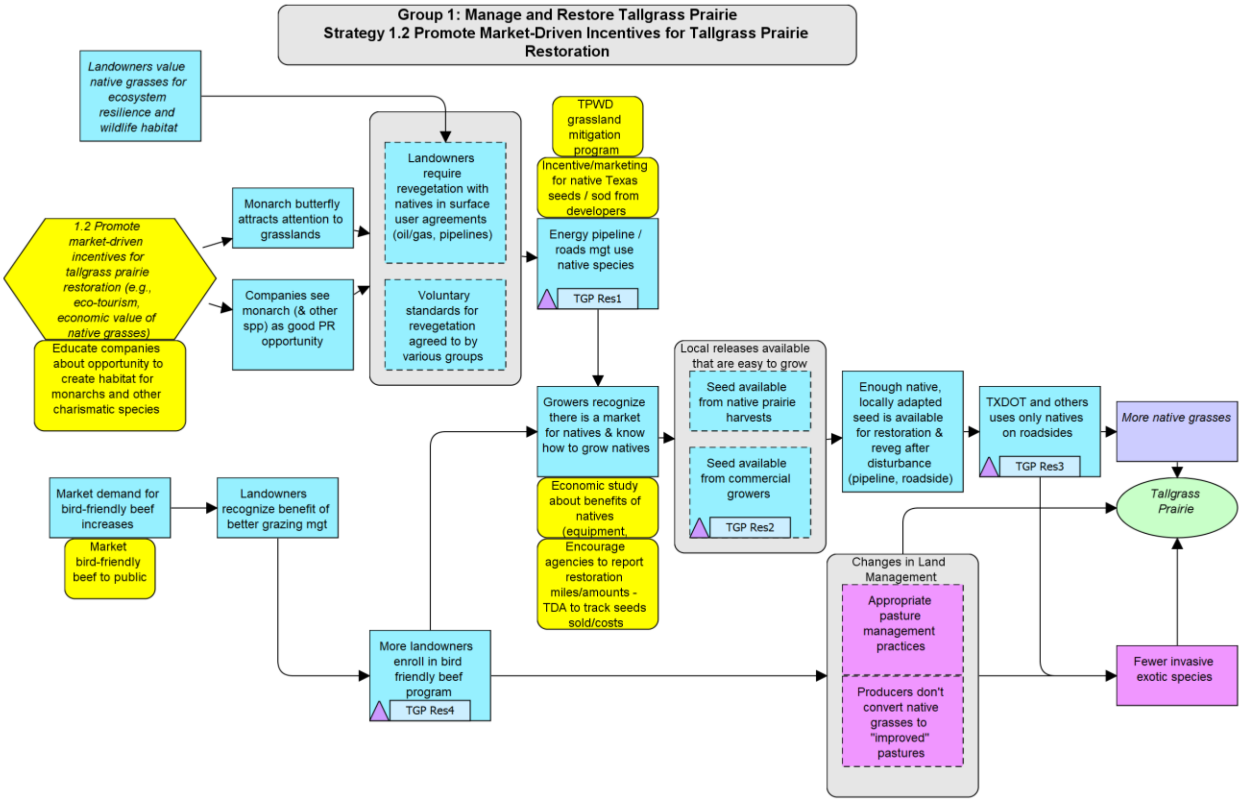

Figure 5-1b. Results chain for the conservation strategy: promote market-driven incentives for tallgrass prairie restoration. This strategy was the seventh ranked strategy for the group working on management and restoration of tallgrass prairie. It was selected because it was deemed critical to the success of the prior strategy (Figure 5-1a), due to the need to increase availability of native plant stock.

Allocation and Hydrology of Freshwater Resources

Inadequate allocation of freshwater resources and hydrologic infrastructure threaten all conservation targets, except for tallgrass prairie (Figure 4-1). These threats will likely become more important over time, because regional projections predict more frequent and intense precipitation extremes (e.g., droughts, floods) due to anthropogenic climate change (Emanuel 2017; Venkataraman et al. 2016; Wang & Wang 2019).

Workshop participants in this group developed results chains for their third and fourth ranked conservation strategies because regional stakeholders were more successfully implementing the highest ranked strategies at the time of the workshop. The first of these two strategies (implement voluntary strategies to support environmental flows) focused on identifying pain points (i.e., locations where environmental flow standards were not being met; TWDB 2019) and working with key water rights holders to meet environmental flow standards (Figure 5-2a). The next strategy (increase transparency related to existing regulations for water management) focused on increasing stakeholder participation in the regulatory process, as well as stakeholder understanding about the benefits of well-regulated water management (Figure 5-2b).

To facilitate conservation partner efforts to implement these strategies, we used projections of future water demand to calculate predicted changes in water use over time as a threat ranking indicator for relevant conservation targets (Tarbox et al. 2019a). As part of the Major River Management Prioritization tool, we also calculated management rankings for each subwatershed to guide outreach to stakeholders and water rights holders at a landscape scale (Tarbox et al. 2019a).

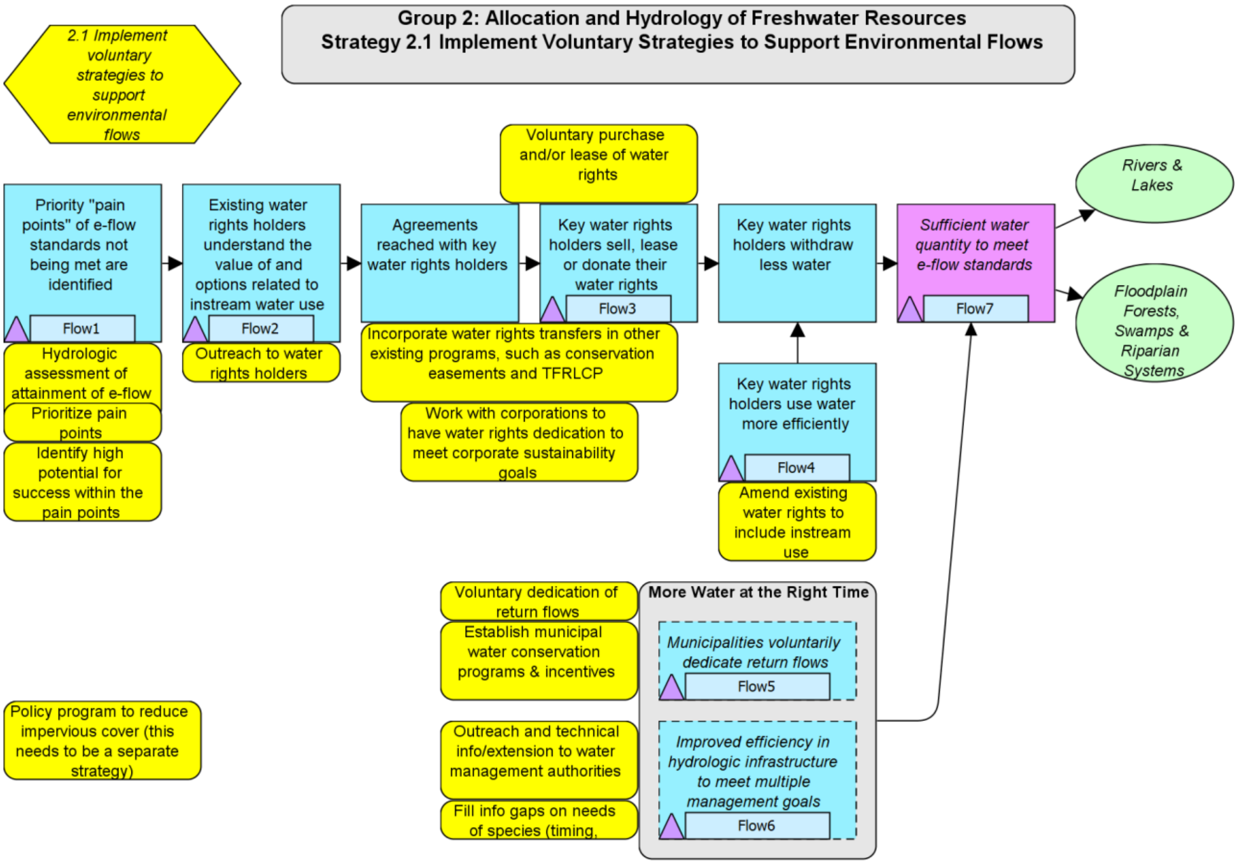

Figure 5-2a. Results chain for the conservation strategy: increase transparency related to existing regulations for water management. This strategy was the third ranked strategy for the group working on allocation and hydrology of freshwater resources. It was selected in part to facilitate the success of the accompanying strategy (Figure 5-2b).

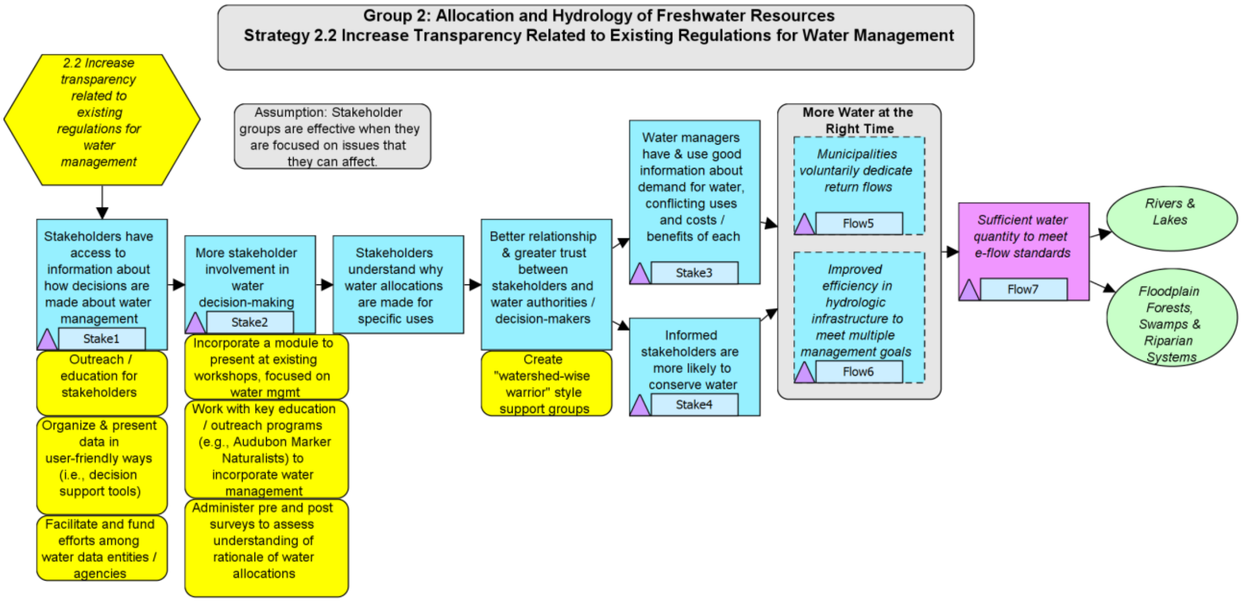

Figure 5-2b. Results chain for the conservation strategy: promote native grasses in landowner incentive programs. This strategy was the fourth ranked strategy for the group working on allocation and hydrology of freshwater resources. It was selected because it is perceived to be an especially challenging strategy to implement successfully.

Land Loss Mitigation and Adaptation for Tidal Wetlands

Besides the threat of diminished freshwater inflows addressed previously, land loss due to erosion, subsidence and sea level rise is probably the most critical threat that tidal wetlands face in the region (Anderson et al. 2014; Reece et al. 2018; White et al. 2002). Workshop participants in this group developed results chains for the three strategies that were most closely linked to addressing this threat. They developed results chains for the first two strategies (acquire land or rights in priority upland areas for migration of tidal wetlands, and restore landscape-scale hydrology) concurrently because restored landscape-scale hydrology would facilitate upland migration of tidal wetlands. Their results chains focused on increasing funding opportunities for protection of potential wetland migration sites, and identifying and removing structures that impede landscape-scale hydrology (Figure 5-3a). The next strategy (strengthen enforcement of shipping traffic laws) focused on determining whether shipping traffic laws themselves, or their enforcement, needed to be strengthened, and then conducting outreach to legislators, shipping operators, recreational boaters, and Coast Guard officials as needed (Figure 5-3b).

To facilitate conservation partner efforts to implement these strategies, we included shipping disturbance and ditch density as indicators of Tidal Wetland Ecological Integrity (Tarbox et al. 2019b). We also included sea level rise risk as a threat ranking indicator, and wetland migration potential as a landscape ranking indicator, for Tidal Wetland Management and Protection Prioritization tools (Tarbox et al. 2019a).

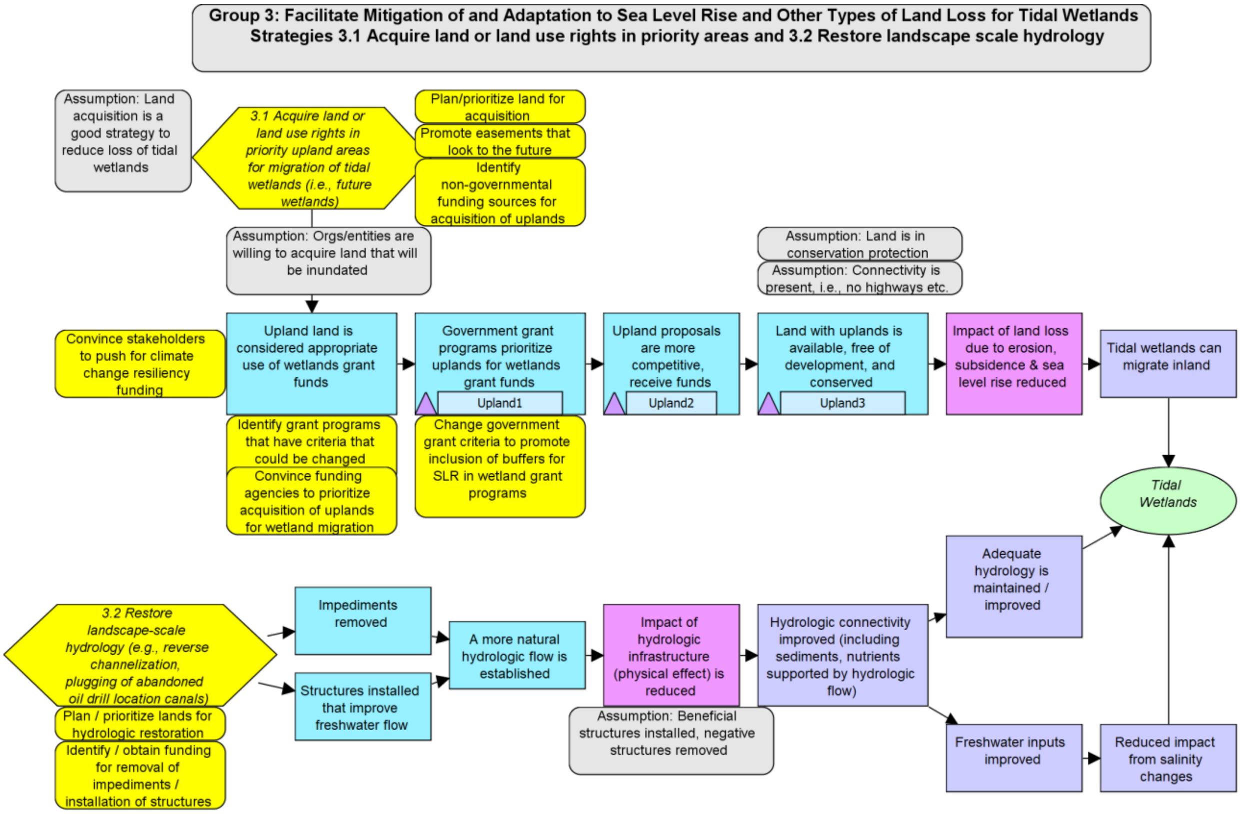

Figure 5-3a. Results chain for the conservation strategies: acquire land or rights in priority upland areas for migration of tidal wetlands, and restore landscape-scale hydrology (e.g., reverse channelization). These strategies were the second and fourth ranked strategies for the group working on land loss mitigation and adaptation for tidal wetlands. They were developed together because their implementation is critically linked.

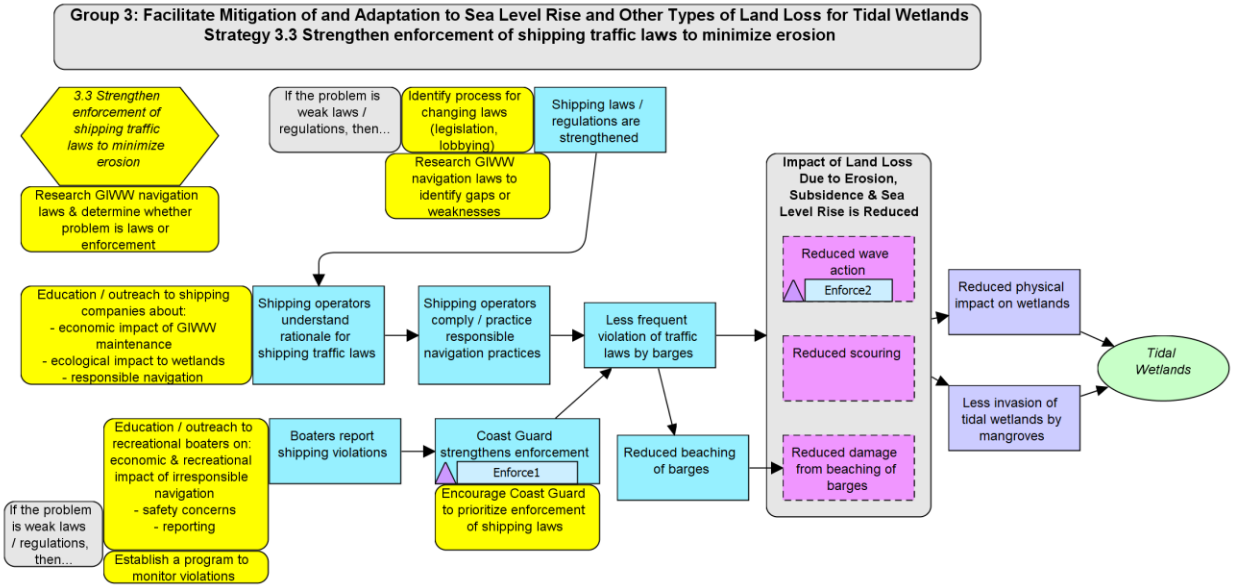

Figure 5-3b. Results chain for the conservation strategy: Strengthen enforcement of shipping traffic laws. This strategy was the seventh ranked strategy for the group working on land loss mitigation and adaptation for tidal wetlands. It was selected because it was determined to be a strategy in the region that was not yet being successfully implemented.

Addressing the Threat of Residential Development and Subdivision of Large Ranches

Residential and urban development is a serious threat to all conservation targets, while subdivision of ranches into 'ranchettes' is a less critical, though important and closely linked contributing factor to many conservation targets (Figure 4-1). Workshop participants in this group developed results chains for their fifth and sixth ranked conservation strategies because these are particularly challenging strategies to implement in the region. The first of these two strategies (encourage county-level planning) focused on identifying market forces that drive development and subdivision of properties, and conducting community outreach to encourage citizens to pressure local governments to implement policies that guide development away from ecologically important areas (Figure 5-4a). The next strategy (protect land through zoning, PDRs, and non-permanent easements) focused on assessing attitudes and values of local communities, and conducting outreach and fundraising to protect land through voluntary incentives such as purchase of development rights (PDRs), transfer of development rights (TDRs), easements, and certifications (Figure 5-4b).

To facilitate conservation partner efforts to implement these strategies, we used data on changing land values and farm sizes, as well as projections of urban development risk, as threat ranking indicators for relevant conservation targets (Tarbox et al. 2019a). As part of the protection prioritization tools for each habitat, we also calculated protection rankings for each subwatershed to guide the activities (e.g., outreach, research) necessary to achieve the objectives of both of these strategies at a landscape scale (Tarbox et al. 2019a).

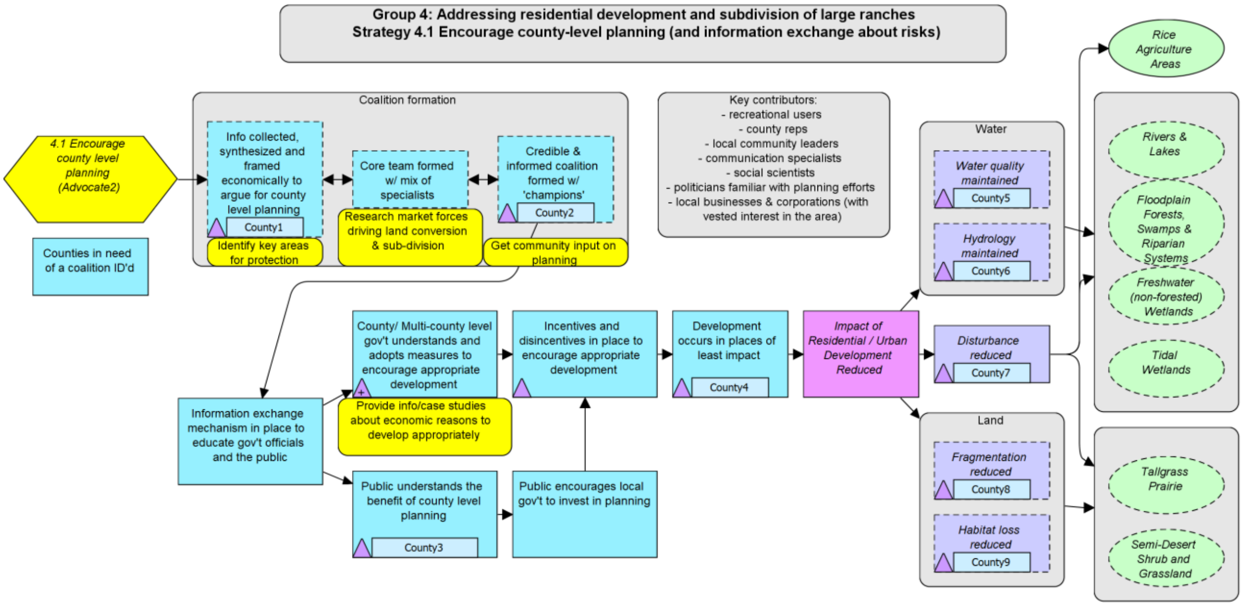

Figure 5-4a. Results chain for the conservation strategy: encourage county-level planning (and information exchange about risks). This strategy was the fifth ranked strategy for the group working on addressing the threat of residential development and subdivision of large ranches. Both this strategy and the subsequent strategy (Figure 5-4b) were selected because the higher ranked strategies under this working group theme were considered to be well-developed strategies that partner organizations and agencies already understood how to implement successfully.

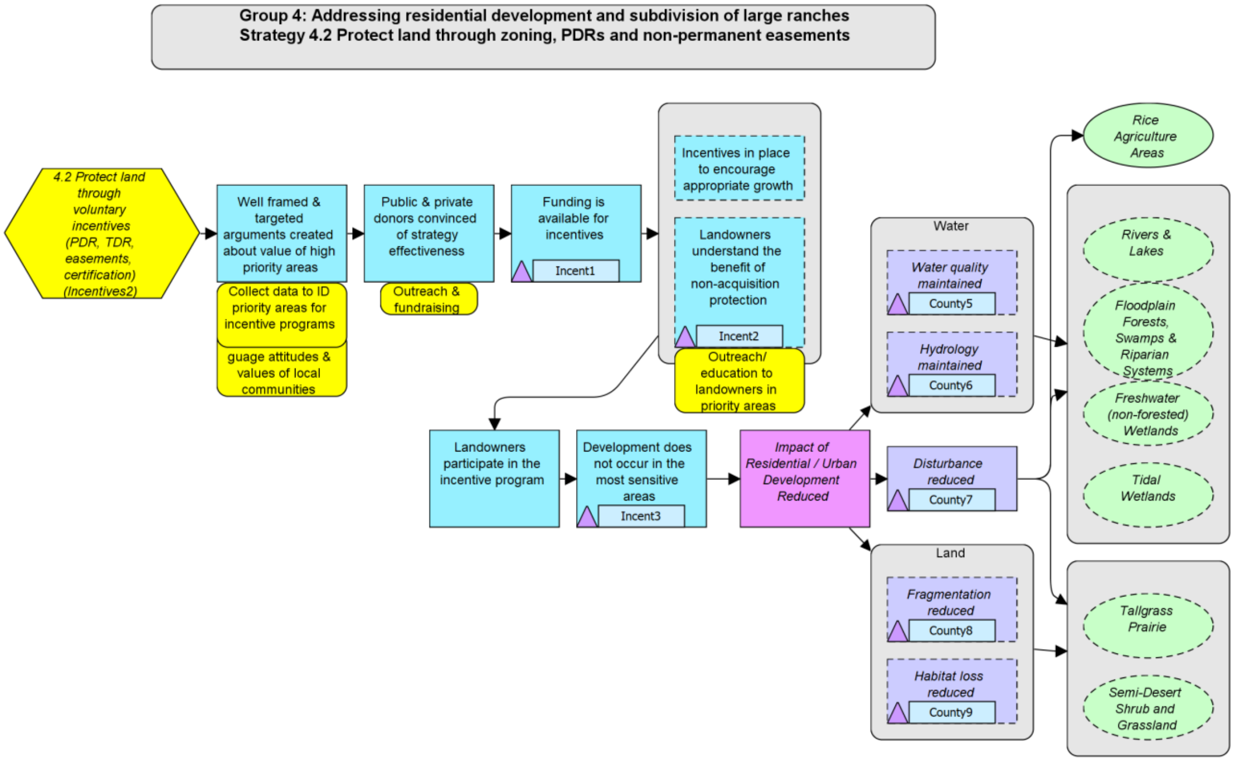

Figure 5-4b. Results chain for the conservation strategy: protect land through zoning, PDRs and non-permanent easements. This strategy was the sixth ranked strategy for the group working on addressing the threat of residential development and subdivision of large ranches. Both this strategy and the preceding strategy (Figure 5-4a) were selected because the higher ranked strategies under this working group theme were considered to be well-developed strategies that partner organizations and agencies already understood how to implement successfully.

Spatial Products

We developed a suite of spatially explicit decision support tools to assist partner agencies and organizations in prioritizing where to target conservation delivery. These products consist of three major outputs: ecological integrity ratings, habitat protection rankings, and habitat management rankings. Ecological integrity ratings were generated for each conservation target (e.g., tidal wetlands) based on the key ecological attributes identified during the viability assessment. Habitat protection and management rankings combine the results of the ecological integrity products with broader indicators of landscape integrity (e.g., connectivity), threats (e.g., urban development), and conservation opportunities (e.g., incentive program participation). These inputs reflect the various steps of the participatory process outlined in preceding sections of this document, and were intended to ensure that these tools prioritize conservation delivery in ways that align with the goals and capacities of partner agencies and organizations.

All spatial products were created using the Environmental Evaluation Modeling System (EEMS; Sheehan 2016). EEMS is a tree-based, fuzzy logic modeling system that enables the combination of disparate datasets (i.e., quantitative and qualitative, continuous and discrete) under a transparent framework to generate intuitive results. The fuzzy math used by EEMS translates all inputs to a -1 to +1 scale, where -1 indicates that a condition is entirely false and +1 indicates that a condition is entirely true. We set thresholds for translating each input to this scale based on the viability assessment. For example, to model the key ecological attribute of water quantity for major rivers, we used the percent of time that natural flows were unaltered as an indicator. We set the thresholds for translating this input into a fuzzy variable at 25% (false or -1: the threshold between a Poor and Fair rating) and 85% (true or +1: the threshold between a Good and Very Good rating). When viewing the ecological integrity ratings for major rivers on DataBasin, the user can turn on the Low Alteration of Natural Flows layer to see where this indicator is rated Poor (<25%), Fair (25-54%), Good (55-84%), or Very Good (≥85%). These various inputs were then combined in EEMS using Boolean operators (e.g., OR, AND, UNION) to generate intermediate outputs (e.g., habitat quality) and final outputs (e.g., ecological integrity).

Inputs were summarized in 200-m x 200-m reporting units, meaning that outputs are provided at the resolution of 200-m x 200-m (4-hectare or ~10-acre) pixels. We also calculated mean values of each output (e.g., ecological integrity ratings) for every subwatershed (12-digit HUC) to facilitate landscape-oriented planning and delivery of conservation.

Ecological Integrity Ratings

For each habitat, we assembled a group of indicators for three components of ecological integrity: habitat amount and local-scale connectivity, human development, and site-scale habitat quality. Habitat amount and connectivity included key ecological attributes (KEAs) reflecting a combination of size and landscape context (e.g., patch size), while human development mostly reflected landscape context KEAs (e.g., road density), and habitat quality consisted primarily of condition KEAs (e.g., woody vegetation cover; FOS 2013).

For each terrestrial habitat, habitat amount and local-scale connectivity was evaluated by combining assessments of patch size, percent cover within a 1-km radius, and percent cover within each 200-m reporting unit. For rivers, we used alteration of natural flows, length of intact stream network patches, and distance to next downstream dam. Human development included land use land cover change (LULCC), road density (e.g., highways, railroads, etc.), and energy development (e.g., oil wells, wind turbines). For terrestrial habitats, indicators of human development were assessed within a 1-km radius of each reporting unit, whereas for major rivers they were assessed across each subwatershed. The indicators used to assess habitat quality varied considerably among habitats, reflecting their differing vegetation structure and focal species' needs.

For a detailed explanation of the development of ecological integrity models and the selection and processing of indicators, please refer to the Ecological Integrity Ratings manual (Tarbox et al. 2019b).

Protection Rankings

Protection rankings are intended to prioritize land for acquisition or easement establishment for each habitat of interest. For major rivers, we prioritized protection of terrestrial habitat within subwatersheds that drain directly into major rivers. Protection rankings combined ecological integrity ratings with threat rankings, opportunity rankings and landscape rankings to derive an overall protection ranking. Threat rankings were based on the identification and rating of direct threats described previously. However, it was not possible to include all relevant threats for each habitat due to lack of spatially explicit future projections (e.g., probability of increase in an invasive exotic species' range or abundance). Opportunity rankings were based on land value, parcel density and partner interest. Landscape rankings were based on mean ecological integrity across each subwatershed, mean ecological integrity of major rivers across subwatersheds, and current values derived from connectivity analyses conducted for each habitat using Circuitscape (McRae et al. 2008; McRae et al. 2013). Because many of the indicators used to generate protection rankings were subjective, we frequently set thresholds based on quantiles of the range of values within the target geography. As such, protection rankings are relative.

For a detailed explanation of the development of habitat protection ranking models and the selection and processing of indicators, please refer to the

Conservation Prioritization Rankings manual (Tarbox et al. 2019a).

Management Rankings

For most habitats, we split management rankings into two categories: restoration and maintenance. Restoration models were run for all reporting units where habitat quality was rated Poor or Fair, while maintenance models were run where habitat quality was rated Good or Very Good. This reflects the definitions of each rating used by Open Standards, where Poor and Fair indicate habitat or indicators that are outside the acceptable range of variation (and thus necessitate restoration), and Good and Very Good indicate habitat or indicators within the acceptable range of variation (and thus necessitate maintenance; FOS 2013). We divided habitats for restoration or maintenance based on habitat quality instead of overall ecological integrity because restoration or maintenance efforts are likely to focus on site-level management rather than the broader factors that determine habitat amount and local-scale connectivity or human development.

For rice agriculture, we did not separate management rankings into maintenance and restoration rankings because rice production is an agro-ecosystem that provides beneficial habitat and ecosystem services without the need to restore it to a natural state. For major rivers, we created an additional product that prioritizes management of uplands within subwatersheds that drain directly into major rivers. Because this product included multiple terrestrial habitats, we did not separate these management rankings into maintenance and restoration rankings either.

Management ranking models were structured similarly to protection ranking models, using a combination of ecological integrity ratings, threat rankings, opportunity rankings, and landscape rankings. However, there were some key differences. Management models did not include land values within opportunity rankings, but instead included an indicator of the degree of landowner participation in various conservation-oriented incentive programs (e.g., Landowner Incentive Program, EQIP) at the county or subwatershed-scale. Additionally, because restoration rankings target already degraded habitat, we did not include threat rankings in restoration ranking models.

For a detailed explanation of the development of habitat management ranking models and the selection and processing of indicators, please refer to the Conservation Prioritization Rankings manual (Tarbox et al. 2019a).

Conclusions and Recommendations

The intent of this work is to add value to current planning efforts and to define, design, and deliver a common landscape vision within the target geography that will facilitate cooperation between various organizations and agencies to achieve conservation objectives. This project will help set the stage for further LCD efforts and implementation strategies to aid decision-making for conservation delivery actions (e.g. restoring grasslands) by a variety of organizations and agencies in the region and surrounding areas.

The most serious concern voiced by numerous stakeholders throughout the development of the Edwards to Gulf LCD was that the Gulf Coast Prairie LCC was in the process of dissolving, leaving stakeholders uncertain about the future relevance of the conservation blueprint. To this end, the project manager and PIs applied for additional funding to conduct stakeholder outreach to ensure that potential end users were aware of the products, and their proper use. This phase is ongoing, and currently focused on conducting demonstration projects with partner organizations to provide concrete examples of how end users can incorporate the Edwards to Gulf Conservation Blueprint into their existing decision-making processes. Furthermore, outreach efforts are intended to generate continued cooperation between conservation partners in the wake of the LCC's dissolution. The results of this effort will be disseminated in a separate report.

Indicator Data Recommendations

Most of our recommendations focus on improving the quality of indicator data or adding new indicators.

For tallgrass prairie, existing datasets poorly assess woody cover and herbaceous composition. Woody cover in our models appears to be substantially underestimated. We used a combination of Texas Ecological Mapping Systems vegetation categories and a Texas Parks and Wildlife Department inventory of prairie remnants as a proxy for herbaceous composition (Tarbox et al. 2019b). The Texas Parks and Wildlife Department is currently developing a more direct assessment of herbaceous composition that could be incorporated into an update of the Edwards to Gulf LCD or its next iteration, when available. Accurate assessments of herbaceous composition and woody cover are critical to evaluating habitat quality for grassland species, making improvements to these indicators a high priority.

For major rivers, wetlands and floodplain forests, our models would benefit from improved hydrological and water quality data. Advanced models for assessing alligator gar habitat exist for the Guadalupe River (Meitzen et al. 2018), and should be expanded for other major rivers within the region as soon as feasible. We used EPA listings of impaired waters and Coastal Condition Assessment data as indicators of water quality (Tarbox et al. 2019b), but future LCD efforts would likely benefit from incorporating direct measures of specific water quality components (e.g., turbidity, DO, nutrient and pesticide loads, etc.).

Additional indicators that could be added to ecological integrity models include freshwater inflows for tidal wetlands, in-stream habitat for major rivers, pipeline density for the human development index, and habitat suitability indices for focal species as they become available.

Threat rankings were limited by data availability, as few spatially explicit projections of future conditions exist. Including indicators related to future road, pipeline, dam, wind and solar development would all increase capacity for prioritizing conservation delivery. Climate change and invasive species are two threats that we only partially accounted for in our models. Tidal wetland models included sea level rise, but changes in temperature and precipitation are key factors that threaten regional conservation goals, as well. Future iterations of the LCD should include estimated change in potential evapotranspiration and annual rainfall, if possible. The only invasive species we included was *Phragmites*. Many additional invasive species within the region (e.g., fire ants, Chinese tallow, deep-rooted sedge, feral hogs, zebra mussels) threaten the LCD's conservation targets and should be included in future products when feasible.

Opportunity ranking indicators could also be improved. We used the Original Texas Land Survey to calculate parcel density for each subwatershed (Tarbox et al. 2019a). Most counties in the region make parcel data publicly available, but there are some exceptions, which prevented us from using up to date parcel data because it would bias opportunity rankings across the entire geography. If these gaps are filled, the updated parcel data from each county should be used instead of the Original Texas Land Survey. We used partner priority areas to indicate potential partner interest in collaborating on conservation delivery. This indicator could be improved by assessing partner capacity to collaborate on conservation delivery by adding data on conservation personnel in any given subwatershed, county, or priority area. Opportunity rankings could also benefit from including additional socio-economic indicators that influence local attitudes and behaviors related to conservation.

Ecological Scope Recommendations

Future iterations of regional landscape conservation design efforts will likely expand the regional and ecological scope of the products developed here. If a full accounting of the 17 broadly defined habitats identified by the Gulf Coast Prairie LCC is not feasible, during this process we identified habitats that appear to be regional priorities beyond those included in these products.

Semi-desert shrub and grassland was excluded because within this geography, most of the habitat was considered shrubland, rather than grassland (the latter of which was identified as a priority habitat). However, conservation partners still prioritize management of this habitat within the Edwards to Gulf geography. Furthermore, if the geographic scope is expanded, its importance would likely increase, as well.

Oak hardwood and pine forest was also excluded from this iteration of the Edwards to Gulf blueprint. This decision resulted in the majority of Aransas National Wildlife Refuge not being included in the spatial products because deep sand live oak shrublands are the dominant vegetation cover of the refuge. This is another case where the broad habitat definitions necessary to categorize geographies that span multiple ecoregions generate issues for localized habitat prioritization. Future LCD efforts in the region should either include the broader oak hardwood and pine forest habitat type altogether, or at least deep sand live oak shrublands and other savannah habitats that require similar management to grasslands.

Another broadly defined habitat that should be prioritized in the near future is headwaters and streams. There was noted interest in expanding the products developed for major rivers to include their tributaries.

Spatial Product Recommendations

The spatial products we developed consist of a suite of static maps of each indicator and their syntheses. For many end users, the conservation delivery questions they want answered will likely necessitate downloading the geodatabases from ScienceBase and analyzing them in a GIS. While many conservation partners have their own GIS staff, creating a more user-friendly web-based interface that allows end users to analyze the outputs generated by decision support tools online without the use of their own GIS would be beneficial. Furthermore, when viewing these products on DataBasin, users can turn layers on and off, but they cannot modify how indicators were combined to generate prioritization rankings. While the goal of this project was to create a shared vision for landscape scale conservation in the region, increased customizability of decision support tools would likely benefit end users by allowing them to adjust particular indicators as needed. To these ends, future LCD efforts may benefit from hiring a programmer or using a different modeling system (e.g., Marxan).

Hiring a programmer could also facilitate the capacity of partner organizations and agencies to update spatial products more easily in the future. As it stands, updating the spatial products would entail processing new or updated datasets in a GIS, then combining them with the existing reporting unit files, running them through EEMS, converting outputs to raster packages, and uploading them to DataBasin. A programmer could potentially develop a user-friendly web-based interface for updating these products, instead.

Institutional Recommendations

Ultimately, the longevity of the Edwards to Gulf Conservation Blueprint and the continuity of regional planning efforts depend on continued communication and cooperation between conservation partners. The demise of the Gulf Coast Prairie LCC represents a considerable challenge to these efforts, but partner agencies and organizations are unlikely to abandon cooperative conservation efforts as a result. The creation of a new network or partnership to replace the role of the LCC would be beneficial, particularly with regard to obtaining and coordinating funding for cooperative regional conservation efforts. In lieu of such a network, we found it useful to work with the existing regional Migratory Bird Joint Ventures and state river authorities to develop spatial product demonstrations as part of the subsequent outreach phase of this project. This approach allowed us to address both terrestrial and aquatic habitats, though clearly a more integrated and comprehensive network or partnership would be ideal.

References

Anderson JB, Wallace DJ, Simms AR, Rodriguez AB, and KT Milliken (2014). Variable response of coastal environments of the northwestern Gulf of Mexico to sea-level rise and climate change: Implications for future change. *Marine Geology*, 352: 348-366.

Conservation Measures Partnership (2012). Addressing Social Results and Human Wellbeing Targets in Conservation Projects. Guidance. June 27. http://fosonline.org/wp-content/uploads/2014/05/Guidance-on-HWT-and-Social-Results-in-Conservation-Projects-v2012-06-27.pdf

D'Odorico P, Okin GS, and BT Bestelmeyer (2012). A synthetic review of feedbacks and drivers of shrub encroachment in arid grasslands. *Ecohydrology*, 5: 520-530.

Elphick CS, Taft O, and PM Lourenco (2010). Management of Rice Fields for Birds during the Non-Growing Season. *Waterbirds*, 33: 181-192.

Emanuel K (2017). Assessing the present and future probability of Hurricane Harvey's rainfall. *PNAS*, 114: 12681-12684.

Foundations of Success (2013). Step 1B Viability Assessment and Goals. Foundations of Success. Bethesda Maryland, USA.

Foundations of Success (2012). Step 1C Critical Threat Ranking. Foundations of Success. Bethesda Maryland, USA.

Foundations of Success (2009). Step 2A Develop a Formal Action Plan: Goals, Strategies, Assumptions, & Objectives. Foundations of Success. Bethesda Maryland, USA.

Groves C (2003). Drafting a Conservation Blueprint: A Practitioners Guide to Planning for Biodiversity. Contributing authors: MW Beck, JV Higgins, and EC Saxon. Island Press. Washington DC, USA.

Gulf Coast Prairie Landscape Conservation Cooperative (2014). Gulf Coast Prairie LCC: Focal Species & Associated Habitats. Gulf Coast Prairie Landscape Conservation Cooperative. Lafayette Louisiana, USA. https://gulfcoastprairielcc.org/media/16924/gcplcc_fs_habitats_summary_august2014.pdf

McRae BH, Dickson BG, Keitt TH, and VB Shah (2008). Using circuit theory to model connectivity in ecology and conservation. *Ecology*, 10: 2712-2724.

McRae BH, Shah VB, and TK Mohapatra (2013). Circuitscape 4 User Guide. The Nature Conservancy. http://www.circuitscape.org

Meitzen K, Jensen J, and T Hardy (2018). Floodplain inundation analysis of the lower Guadalupe River: linking hydrology and floodplain-dependent resources. Final Report to Texas Parks and Wildlife Department: Contract No. 474120. Texas State University. San Marcos TX, USA. http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1448311791b.pdf

Reece JS, Watson A, Dalyander PS, Edwards CK, Geselbracht L, LaPeyre MK, Tirpak BE, Tirpak JM, and M Woodrey (2018). A multiscale natural community and species-level vulnerability assessment of the Gulf Coast, USA. *PLOS ONE*, 13. https://doi.org/10.1371/journal.pone.0199844

Salafsky N, Margoluis R, Redford KH, and JG Robinson (2002). Improving the practice of conservation: a conceptual framework and research agenda for conservation science. *Conservation Biology*, 16: 1469-1479. https://doi.org/10.1046/j.1523-1739.2002.01232.x

Samson FB, Knopf FL, and WR Ostlie (2004). Great Plains Ecosystems: Past, Present, and Future. *Wildlife Society Bulletin*, 32: 6-15.

Sheehan T (2016). A platform-independent fuzzy logic modeling framework for environmental decision support (submitted for publication). https://consbio.org/products/tools/environmental-evaluation-modeling-system-eems

Smeins FE, Diamond DD, and CW Hanselka (1991). Coastal Prairie. *In* Coupland RT (ed.) 1991. Natural Grasslands: Ecosystems of the World, Volume 8. Elsevier Press. New York NY, USA.

Tarbox B, Jensen J, Hardy T, and MC Green (2018a). Edwards to Gulf Landscape Conservation Design Pilot Project – Conceptualization and Action Planning Workshop Report, November 28th-30th, 2017. Texas State University. San Marcos TX, USA. http://edwardstogulflcd.wp.txstate.edu/documents/

Tarbox B, Jensen J, Hardy T, and MC Green (2018b). Edwards to Gulf Landscape Conservation Design Pilot Project – Stakeholder Review Summary, October 5th, 2018. Texas State University. San Marcos TX, USA. http://edwardstogulflcd.wp.txstate.edu/documents/

Tarbox B, Jensen J, Hardy T, and MC Green (2019a). Edwards to Gulf Landscape Conservation Design Pilot Project – Conservation Prioritization Rankings. Texas State University. San Marcos TX, USA.

http://edwardstogulflcd.wp.txstate.edu/documents/

Tarbox B, Jensen J, Hardy T, and MC Green (2019b). Edwards to Gulf Landscape Conservation Design Pilot Project – Ecological Integrity Ratings. Texas State University. San Marcos TX, USA. http://edwardstogulflcd.wp.txstate.edu/documents/

Texas Water Development Board (2019). Environmental Flows. Austin Texas, USA. Accessed from: http://www.twdb.texas.gov/surfacewater/flows/index.asp

Van Auken OW (2000). Shrub invasions of North American semiarid grasslands. *Annual Review of Ecology and Systematics*, 31: 197–215.

Venkataraman K, Tummuri S, Medina A, and J Perry (2016). 21st century drought outlook for major climate divisions of Texas based on CMIP5 multimodel ensemble: Implications for water resource management. *Journal of Hydrology*, 534: 300-316.

Wang S, and Y Wang (2019). Improving probabilistic hydroclimatic projections through high-resolution convection-permitting climate modeling and Markov chain Monte Carlo simulations. *Climate Dynamics*, 53: 1613-1636.

White WA, Morton RA, and CW Holmes (2002). A comparison of factors controlling sedimentation rates and wetland loss in fluvial-deltaic systems, Texas Gulf coast. *Geomorphology*, 44: 47-66.

Appendix

Table A-1. Crosswalk used to convert Texas Ecological Mapping Systems categories to broadly defined habitats.

Gulf Coast Prairie LCC Broadly Defined Habitats	Texas Ecological Mapping Systems Categories
Agriculture	Row Crops Grass Farm
Developed	Urban High Intensity Urban Low Intensity
Floodplain Forests, Swamps & Riparian Systems	Edwards Plateau: Floodplain Live Oak Forest Edwards Plateau: Floodplain Hardwood - Ashe Juniper Forest Edwards Plateau: Floodplain Hardwood Forest Edwards Plateau: Floodplain Ashe Juniper Shrubland Edwards Plateau: Floodplain Deciduous Shrubland Edwards Plateau: Floodplain Herbaceous Vegetation Edwards Plateau: Riparian Ashe Juniper Forest Edwards Plateau: Riparian Live Oak Forest Edwards Plateau: Riparian Hardwood - Ashe Juniper Forest Edwards Plateau: Riparian Hardwood Forest Edwards Plateau: Riparian Ashe Juniper Shrubland Edwards Plateau: Riparian Deciduous Shrubland Edwards Plateau: Riparian Herbaceous Vegetation Central Texas: Floodplain Evergreen Forest Central Texas: Floodplain Live Oak Forest Central Texas: Floodplain Hardwood - Evergreen Forest Central Texas: Floodplain Hardwood Forest Central Texas: Floodplain Evergreen Shrubland Central Texas: Floodplain Deciduous Shrubland Central Texas: Floodplain Herbaceous Vegetation Central Texas: Floodplain Seasonally Flooded Hardwood Forest Central Texas: Floodplain Baldcypress Swamp Central Texas: Riparian Evergreen Forest Central Texas: Riparian Live Oak Forest Central Texas: Riparian Hardwood - Evergreen Forest

	Central Texas: Riparian Hardwood Forest Central Texas: Riparian Evergreen Shrubland Central Texas: Riparian Deciduous Shrubland Central Texas: Riparian Herbaceous Vegetation Coastal Bend: Floodplain Live Oak Forest Coastal Bend: Floodplain Live Oak - Hardwood Forest Coastal Bend: Floodplain Hardwood Forest Coastal Bend: Floodplain Evergreen Shrubland Coastal Bend: Floodplain Deciduous Shrubland Coastal Bend: Floodplain Grassland Coastal Bend: Riparian Live Oak Forest Coastal Bend: Riparian Live Oak - Hardwood Forest Coastal Bend: Riparian Hardwood Forest Coastal Bend: Riparian Evergreen Shrubland Coastal Bend: Riparian Deciduous Shrubland Columbia Bottomlands: Live Oak Forest and Woodland Columbia Bottomlands: Mixed Evergreen - Hardwood Forest and Woodland Columbia Bottomlands: Hardwood Forest and Woodland Columbia Bottomlands: Evergreen Shrubland Columbia Bottomlands: Deciduous Shrubland Columbia Bottomlands: Grassland Columbia Bottomlands: Riparian Live Oak Forest and Woodland Columbia Bottomlands: Riparian Mixed Evergreen - Hardwood Forest and Woodland Columbia Bottomlands: Riparian Hardwood Forest and Woodland Columbia Bottomlands: Riparian Evergreen Shrubland Columbia Bottomlands: Riparian Deciduous Shrubland Columbia Bottomlands: Baldcypress Swamp Columbia Bottomlands: Riparian Grassland South Texas: Floodplain Deciduous Shrubland South Texas: Floodplain Grassland South Texas: Ramadero Dense Shrubland South Texas: Ramadero Shrubland Swamp
Freshwater (non-forested) Wetlands	Edwards Plateau: Floodplain Herbaceous Wetland Edwards Plateau: Riparian Herbaceous Wetland Central Texas: Floodplain Herbaceous Wetland

	Central Texas: Riparian Herbaceous Wetland Coastal Bend: Floodplain Herbaceous Wetland Coastal Bend: Riparian Grassland Coastal Bend: Riparian Herbaceous Wetland Columbia Bottomlands: Herbaceous Wetland Columbia Bottomlands: Riparian Herbaceous Wetland Gulf Coast: Coastal Prairie Pondshore Coastal and Sandsheet: Deep Sand Grassland Swale Marsh Marsh
Open Water	Open Water
Tallgrass Prairie	Blackland Prairie: Disturbance or Tame Grassland Crosstimbers: Savanna Grassland Post Oak Savanna: Savanna Grassland Pineywoods: Disturbance or Tame Grassland Post Oak Savanna: Sandyland Grassland Edwards Plateau: Savanna Grassland Gulf Coast: Coastal Prairie Gulf Coast: Salty Prairie Coastal and Sandsheet: Active Sand Dune Coastal and Sandsheet: Deep Sand Shrubland Coastal and Sandsheet: Deep Sand Grassland Coastal Plain: Terrace Sandyland Grassland
Tidal Wetlands	Gulf Coast: Salty Prairie Shrubland Gulf Coast: Salty Prairie Coastal: Tidal Flat Coastal: Sea Ox-eye Daisy Flats Coastal: Mangrove Shrubland Coastal: Salt and Brackish Low Tidal Marsh Coastal: Salt and Brackish High Tidal Shrub Wetland Coastal: Salt and Brackish High Tidal Marsh South Texas: Wind Tidal Flats South Texas: Algal Flats