THINK BIOSPHERE

A CLIMATE-WISE WILDLIFE CORRIDOR PLANNING TOOLKIT FOR THE GOLDEN GATE BIOSPHERE

Report prepared by:

Marina Stern
Landscape Architecture & Environmental Planning
University of California, Berkeley

In collaboration with EcoAdapt.

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Committee members:
Laura Hilberg, Lead Scientist EcoAdapt
Kristina Hill, Director of IURD & Associate Professor LAEP UC Berkeley
Iryna Dronova, Associate Professor LAEP UC Berkeley

Special Thanks to:
Alison Forrestel, Supervisory Vegetation Ecologist GGNRA NPS
Darren Fong, Aquatic Ecologist NPS
Eric Rubenstahl, MALT
Jennifer Wolch, Professor Emeritus City & Regional Planning UC Berkeley
Nancy Scolari, Marin RCD
Patrick Kleeman, Supervisory Ecologist USGS
Sharon Farrell, The Stewardship Network

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PROJECT GOALS

This report is intended to provide a model process for wildlife corridor planning and design in the Golden Gate Biosphere. These climate-wise strategies support selected GGB target species' movement and contribute toward regional coordinated climate adaptation. This report is focused on two target species with related habitat needs to exemplify how assembling multi-species needs could produce new, coordinated land-use plans that conserve and enhance biodiversity.

This wildlife corridor report:

1. Provides categories of wildlife corridors to develop a resource list for decision makers.
2. Discusses various methods of spatial analysis, with a sample methodology for mapping connectivity using the Linkage Pathways tool from Linkage Mapper.
3. Develops a process for planning and designing a wildlife corridor based on the goals and two of the target species of the Golden Gate Biosphere.
4. Suggests a mutually beneficial steppingstone corridor in the form of stock ponds, as a strategy for climate adaptation that contributes toward wildlife habitat and water sources for livestock and to support rancher livelihoods.
5. Recommends opportunities for expanded partnerships, monitoring, and policy, particularly related to agricultural land that sits between and adjacent to protected areas managed by partners of the Golden Gate Biosphere.

This document serves as a summary of a professional report prepared for EcoAdapt and the Golden Gate Biosphere and submitted in partial satisfaction of the requirements for the degree of Master of Landscape Architecture and Environmental Planning at UC Berkeley.

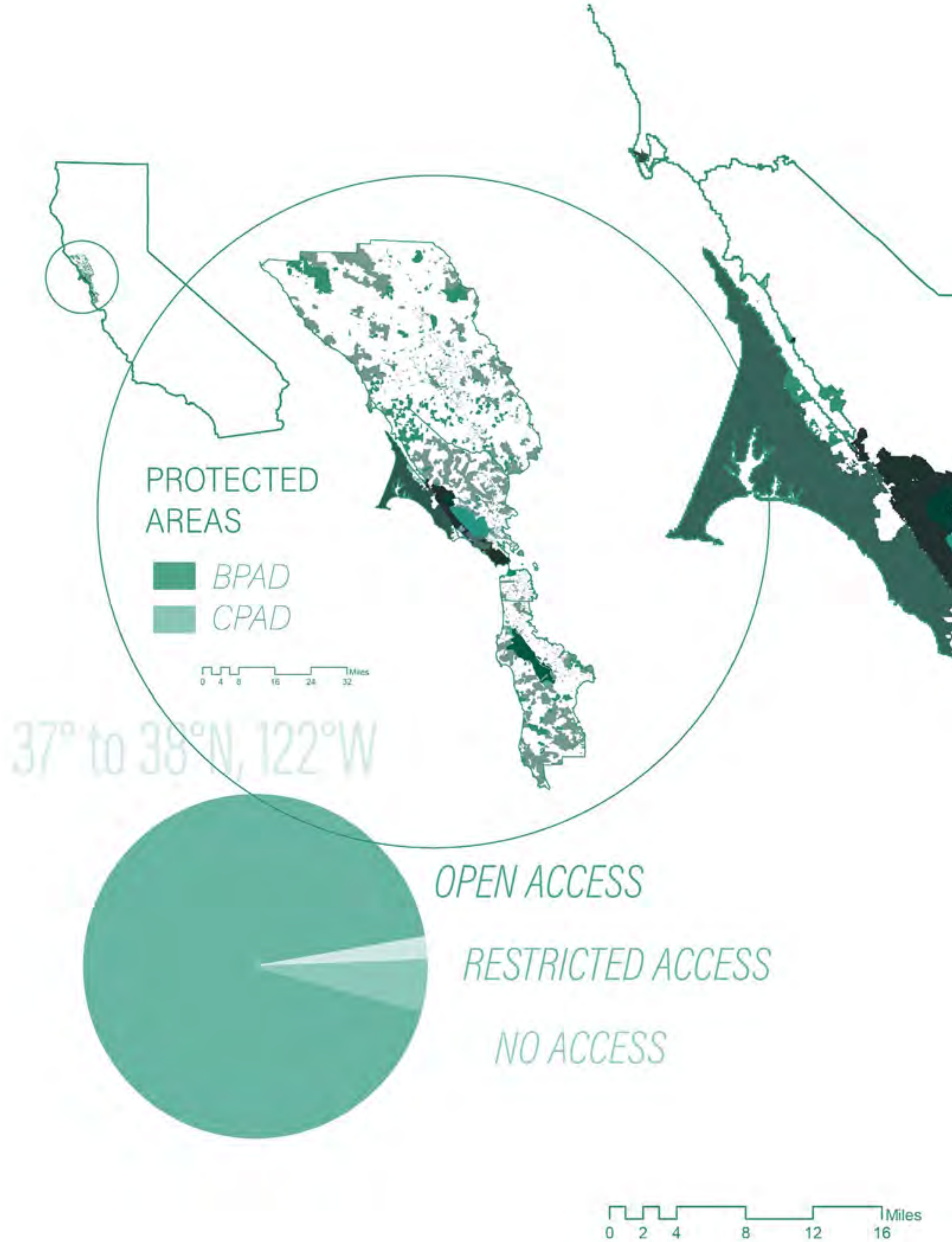
The full thesis document can be found online at the following link:

Think Biosphere: A Climate-Wise Wildlife Corridor Planning Toolkit for The Golden Gate Biosphere (https://acrobat.adobe.com/link/track?uri=urn:aaid:scds:US:f49117bc-f01b-3cb6-b06f-77f3ad671c65)

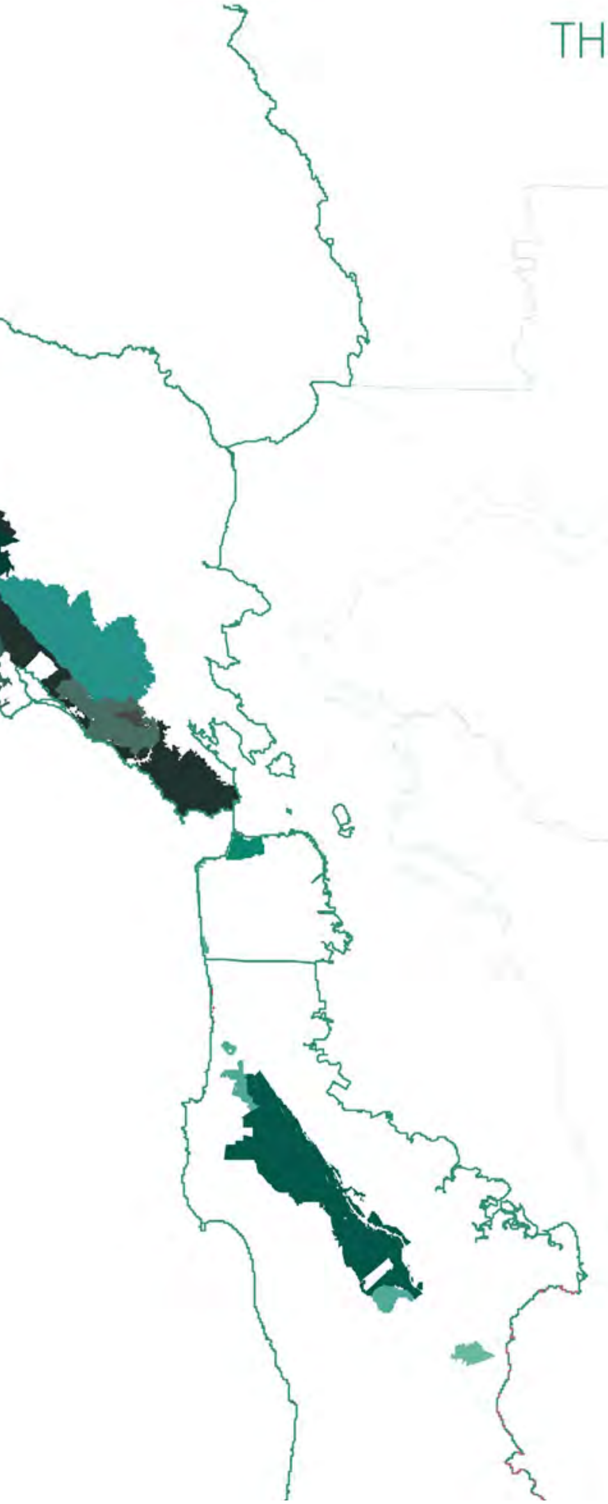
CONTEXT

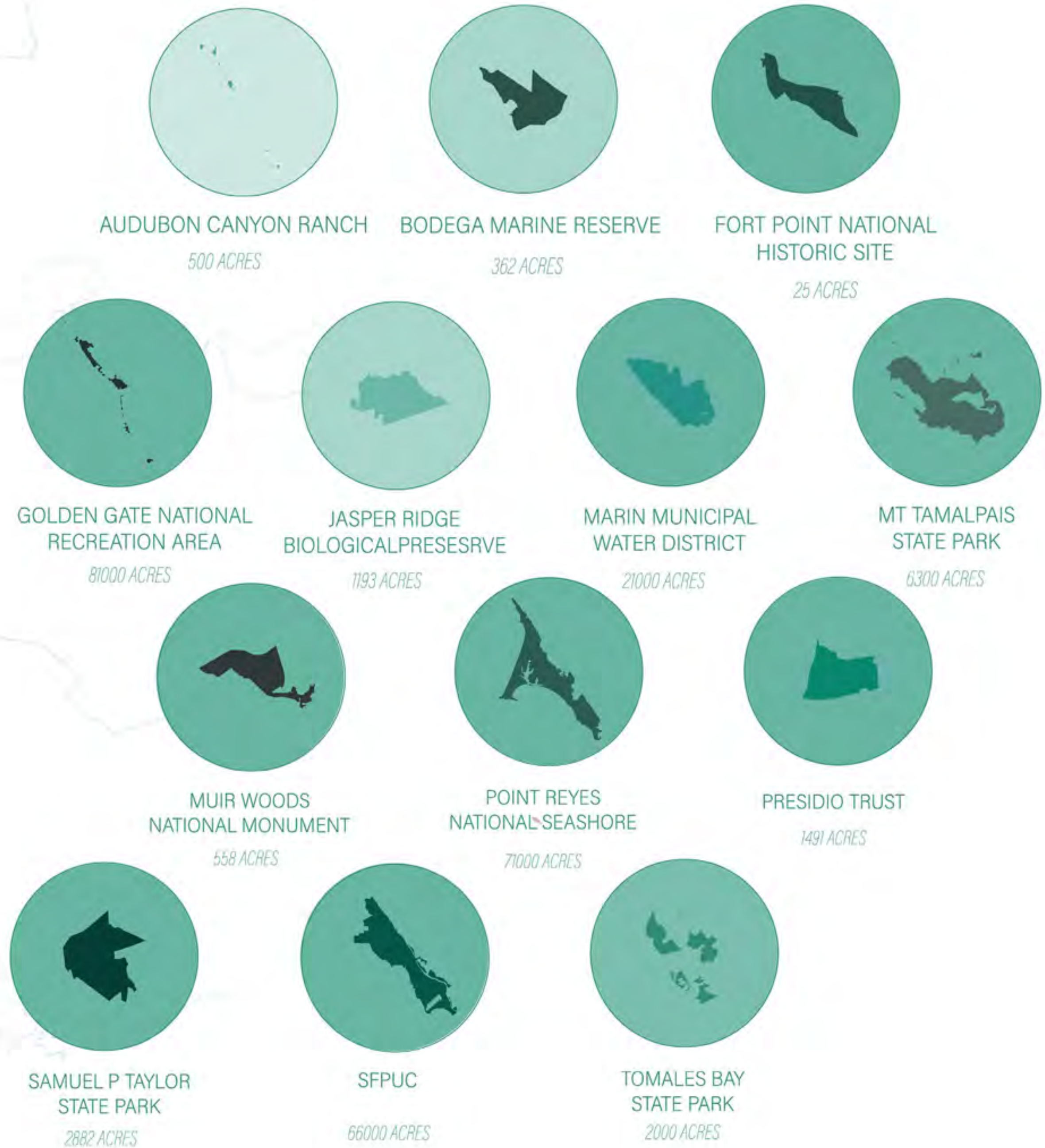
The location of this project is the highly biodiverse region designated as the Golden Gate Biosphere (GGB) under the UNESCO Man and the Biosphere Programme (MAB). The main goals of this program involve garnering enhanced human and environmental connection. This includes contributions toward increased scientific understanding of biodiversity and ecosystem processes, especially related to human activities and livelihoods (UNESCO, 2022). The GGB consists of a team of 13 partner organizations within protected areas with varying levels of public access (NOAA, 2016). My research, as part of the climate adaptation project led by EcoAdapt, is oriented around the collective vision for responsible management of the GGB through increasing awareness and promotion of environmental, cultural, and social activity.

Tectonic shifts, hydrologic cycles, and wildlife movement, along with human activities including subsistence ways of life, mining, and urban development, have contributed to the present identity of the Biosphere. These unique habitats contain a high diversity of flora and fauna, making them especially vulnerable. With climate change projections, alternating wet seasons and drought years may increase in extremity, and thus necessitate a regional approach to conservation that provides corridors for species' movement and adaptation.



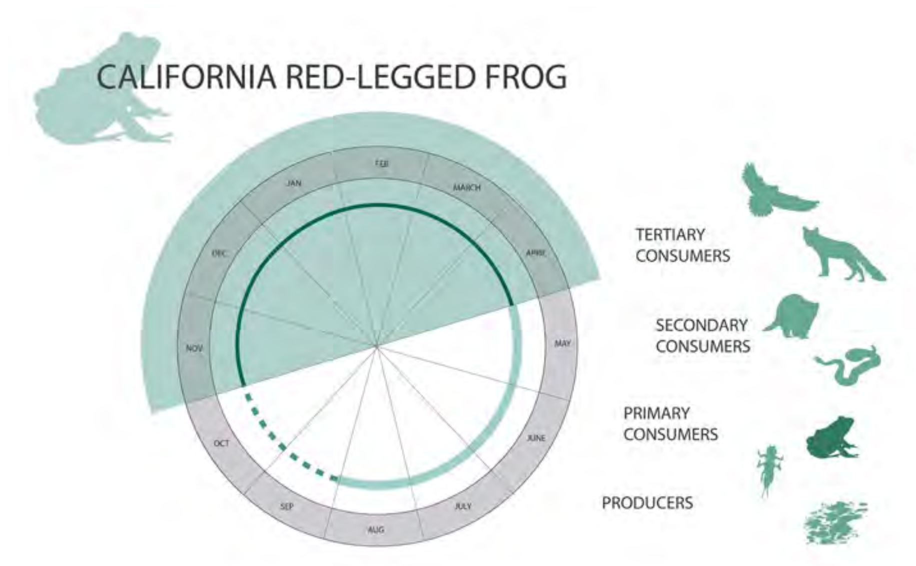
THE 13 PARTNERED SITES OF THE GOLDEN GATE BIOSPHERE





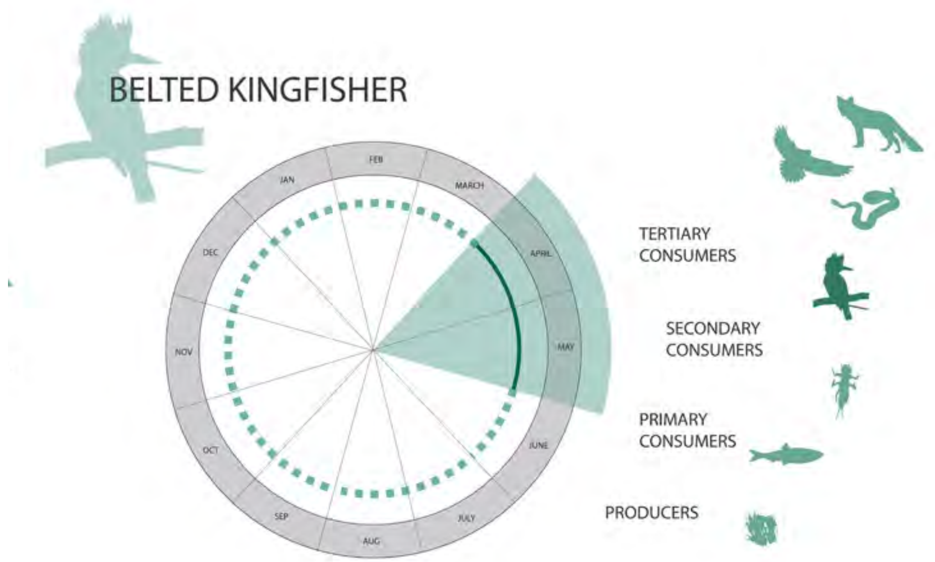
TARGET RESOURCES & SPECIES

For the purposes of this project, a set of 10 ecosystems and 11 species were chosen by stakeholders (UNESCO, 2016), as targets for climate adaptation planning. Listed below, these ecosystems and species were chosen because they act as umbrella species and/or because they represent the unique character of the site including rare systems or endangered species. Therefore, I have taken a multispecies approach, setting a framework for developing corridors which account for the needs of many. This may allow for increased potential for overlapping resources, such as management programs and funding sources, as well as opportunities for enhanced ecological productivity.



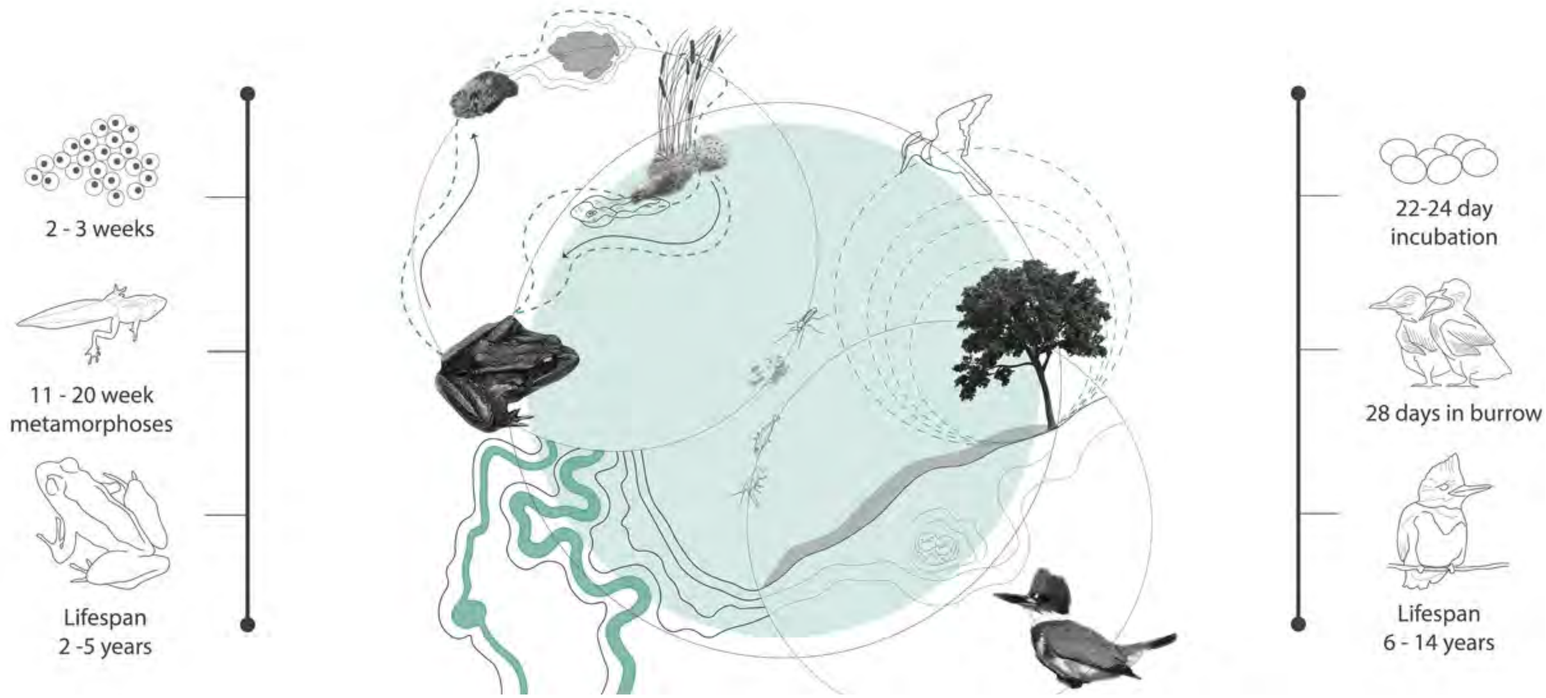
ECOSYSTEM
Coast redwood forests
Coastal dunes
Coastal prarie
Coastal scrub
Freshwater marshes
Maritime chaparral
Mixed evergreen forests
Open oak woodlands/savannahs
Riparian forests/woodlands
Tidal marshes

SPECIES
Belted kingfisher
California black oak
California red-legged frog
Coho and steelhead
Mission blue butterfly
Moss' elfin butterfly
Mountain lion
Sanderlings
Serpentine endemic rare plants
SF common yellowthroat
Western Leatherwood



Overlapping Species Needs

To analyze the core habitat and movement opportunities for two of the eleven target species, I studied the overlapping ecological and biological requirements that may sustain them. This process involves analyzing each species' life cycle, along with the key resources which support their feeding, shelter, and reproductive needs. Along with this, broadening the taxonomic scope and looking at each species' trophic level, and where they sit within the food web, is necessary to mitigate unwanted outcomes as well as bolster the target species within the ecosystem.



California Red-Legged Frog

The California Red-Legged Frog is a federally threatened species under the Endangered Species Act (National Wildlife Federation, 2023). They breed during the winter and spring, laying their eggs in aquatic vegetation, then hide out in upland vegetation under the cover of grassland and shrubs in the dry season. These frogs often remain near water bodies, feeding mainly on algae and insects (Stebbins, 1985). Though, they can travel up to a mile away in sparsely vegetated areas and along ridgelines (Fellers & Kleeman, 2007).

The Belted Kingfisher

The Belted Kingfisher is the only Kingfisher found in California. These birds are non-migratory and are thus active year-round in this area, with their breeding season in spring. They are secondary to tertiary consumers feeding on aquatic insects, small fish, and amphibians (Cornwell, 1963). They require higher water quality and clarity, and perches for hunting, and need vertical cliffs and streambanks for nesting and reproduction (Brooks & Davis, 1987). Belted Kingfishers generally maintain a territory of 0.6 miles along the edge of waterbodies.

PRINCIPLES OF WILDLIFE CORRIDORS

This section discusses socio-cultural perceptions of wildlife as well as varied ecological definitions of wildlife corridors. These topics act as guidelines for the purposes of developing, analyzing, and supporting the planning and visualization strategies of wildlife corridors discussed in this report.

Landscape Ecology provides concepts and tools to analyze features that comprise the physical composition of the environment. These landscape parameters develop a "matrix" of patterns and processes (Wu, 2008).

Island Biogeography is primarily an ecology and population dynamics theory. Islands create isolated populations, decrease gene flow, and lower genetic diversity, eventually contributing toward speciation or extinction (McArthur & Wilson, 1967). In thinking about the landscape as a network of terrestrial islands, corridors become vital features in the landscape.

Ecological Urbanism emphasizes how the natural world can and should be woven into the urban and peri-urban fabric rather than designed separately (Spirn, 2014). Ecotones, or in-between spaces should be prioritized for connectivity studies, and other biodiversity-oriented protection measures (Weller, 2019).

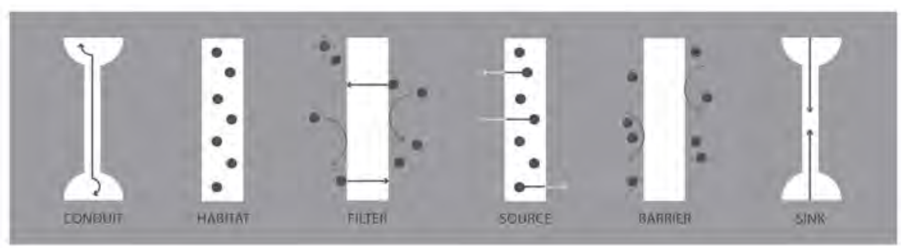
Human Attitudes Toward Animals & Rewilding

Associations and perceptions of wildness and "wilderness" vary widely. Human attitudes toward animals fall under many categories, tied to broad biogeographical and cultural backgrounds, as well as our personal emotional and aesthetic associations. Opening these conversations can broaden collective understandings allowing for multispecies relationships to include multiple experiences (Arcari, 2020).

Paired with this, the concept of rewilding is focused on the "re-creation of borderland spaces through relational configurations of the human and more than human world" (Ward, 2019). This directly relates to ecological urbanism in rethinking what "human" and "wild" spaces are, and where there may be occasions for overlaps. Together, the conceptual approaches delineated in this section serve as prospective points of departure from my research, design, and planning analyses in this report.

Defining Wildlife Corridors

This study develops design strategies for wildlife corridors, with particular focus on steppingstone opportunities which span a mix of wildland, agricultural land, and peri-urban settings within the GGB. Corridor definitions vary across the fields of conservation biology, landscape architecture, urban planning, and more (Hess & Fischer, 2000). These varied definitions emphasize the reality that corridors are a complex mix of features and are multi-functional. As such, they need to be managed with consideration of both planned and unintended outcomes. This section outlines foundational definitions and key considerations for wildlife corridor planning, as well as examples of wildlife corridors as a jumping off point for future initiatives in the GGB.



TERM	DEFINITION
CORRIDOR	Expansive internally varied stretch of land which allows for and/or guides the movement of organisms from one region or location to another (may or may not include all resources necessary to be considered habitat). Allows for movement between "islands" within a hostile landscape.
HABITAT	Includes an area with the necessary resource combination for survival (food and shelter) and reproduction.
LINKAGES	An area where connectivity is at risk, often locations between wildlands. May allow varied movement ability of plants and animals, but all should have the potential to restore or enhance connectivity.
CONDUIT	A corridor which provides movement between one place to another, from one habitat to another habitat. Does not include provisions for reproduction (not considered habitat).
FILTER	Having to do with permeability. May impact entrance into or movement within corridors. Includes animal and plant species movement as well as movement of land and water.
BARRIER	Complete or nearly complete blockage. Species are unable to move between habitats.
SOURCE	An area where local reproduction exceeds mortality, often allowing a given species to expand or spread.
SINK	A feature or area that traps populations. This may be due to edge-exposure with higher predation from corridor dwellers, along with competition particularly from generalist species.
CORRIDOR DWELLER	Species with smaller scales of movement, leading to slow movement through a corridor and in some cases necessitating multiple generations to pass through a corridor.

Key Considerations

Below is a list of guiding questions which outline key considerations when planning for a wildlife corridor. In this way, variations in wildlife corridor and crossing types can be differentiated by their intended outcomes, with the goal of implementing the most effective option. Taking into account these preliminary considerations may allow for an integrated approach to planning and designing wildlife corridors. *Adapted from (Beier, 1992).*

- What are the intended functions and outcome(s) of the wildlife corridor?
- What is the ecological context of the wildlife corridor?
- How many (core) habitat areas will be connected?
- What are the target species?
- Are the target species "passage species" or "corridor dwellers"?
- Is the target species currently present throughout or is it being reintroduced?
- What are the movement patterns and territories of the target species?
- How long will it take for the species to pass through?
- What are current barriers or sinks?
- Will the corridor lead to the harmful spread of introduced or invasive species?
- Will the implementation displace native species? And/or lead to homogenization?
- What will be the cascading impacts on higher or lower trophic levels?
- Will there be impacts to human health or livelihoods?

Categories of Wildlife Corridors

Projects which contribute toward regional corridors or linkages may include a wide range of features. Some are as literal as crossings or passageways, while others may provide shelter or habitat as a secondary benefit. Analyzing case studies enhances the potential for application of useful practices from prior projects in the coordination of biosphere-scale corridor efforts. This section details a sample of the categories synthesized from case study analysis. *Refer to full thesis report for case study details (Stern, 2023).*

Landform Overpass - *Conduit, Habitat*

These types of overpasses often cross larger highways and roads. They generally target larger mammals (who may be the most vulnerable to automobile collisions). These crossings usually connect raised hillsides or other topography that sits on either side of a less elevated road. Design considerations include creating the proper width and length to influence entrance and movement along the crossing. Some more species-specific choices include planting plans and proper vegetation cover to allow the most successful usage of the crossing by target and ancillary species.

Bridge - *Conduit*

These structures have the same intended purpose of allowing passage over a road. These are often smaller than landform overpasses though and consist of mostly inorganic material. Target species may be smaller mammals, crustaceans, amphibians and/or insects. Key design considerations include accounting for the slope of each roadside, as well as the height over the road.

Tunnel or Grate Underpass - *Conduit, Filter*

Crossings that sit below the road instead of above. These may be used by small or large wildlife. In some cases, stormwater, or culvert infrastructure such as large metal pipes and short tunnels may also allow passage of both aquatic and terrestrial species. Design considerations include depth, width, and height of the underpass, to allow proper passageway and to maintain the integrity of the road.

Pond Network - *Habitat, Source, Filter*

Coordinated pond installation and/or restoration involves taking into account the movement patterns and buffer distances of target species. With proper vegetation and monitored access to the water, along with management of water levels, target species may be prioritized over competitors or predators.

Fish Ladder - *Conduit*

A ladder is used in waterways which contain dams, drop structures, or other barriers to aquatic movement. Fish and other aquatic species are unable to jump or pass normally. These take many forms, depending on the topographical, hydrological, and geological features as well as precipitation and runoff patterns at the site. Some include pool and weir fishways or ladders which form steps, rock ramps, and/or baffle structures.

Shelterbelts - *Filters, Habitat, Conduits*

These act as separation between agricultural fields and are usually implemented for reducing wind speeds. Shelterbelts provide potential for multi-benefit spaces, as they protect crops from winds and runoff, while also providing habitat space for wildlife.

Strip disking - *Habitat*

Often used as an agricultural management practice, strip disking replenishes soils while also preventing overgrowth of woody plants. In this way, plants which provide nutrition and shelter may continue to service wildlife, while also creating healthy growing spaces.

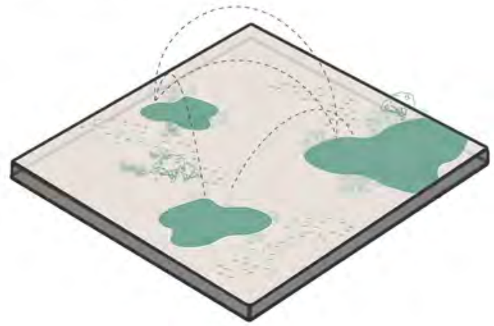
Reusing dredged material - *Habitat*

A relatively new practice, reuse of dredged material presents a sustainable option for creating spaces for wildlife and supporting existing habitat. Targeting sediment movement from tides and currents, dredged material is an opportunity to create islands and sandbars, balancing sediment deposits while enhancing wetland and shoreline connectivity.

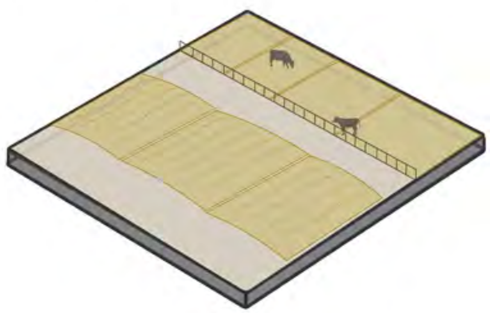
Tree planting and management - *Filter, Habitat, Conduits*

Managing tree growth is often related to fire risk with primary focus on the wildland urban interface (WUI). If properly coordinated, tree planting and management can target beneficial growth for wildlife while also providing proper protection from wildfires.

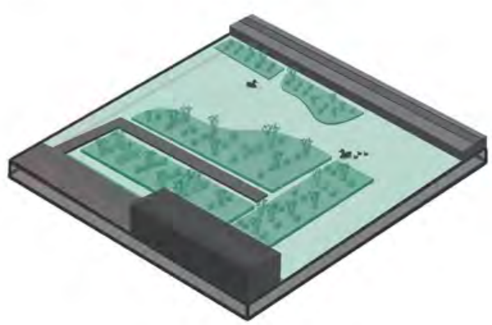
OPEN SPACE
ecosystem conservation

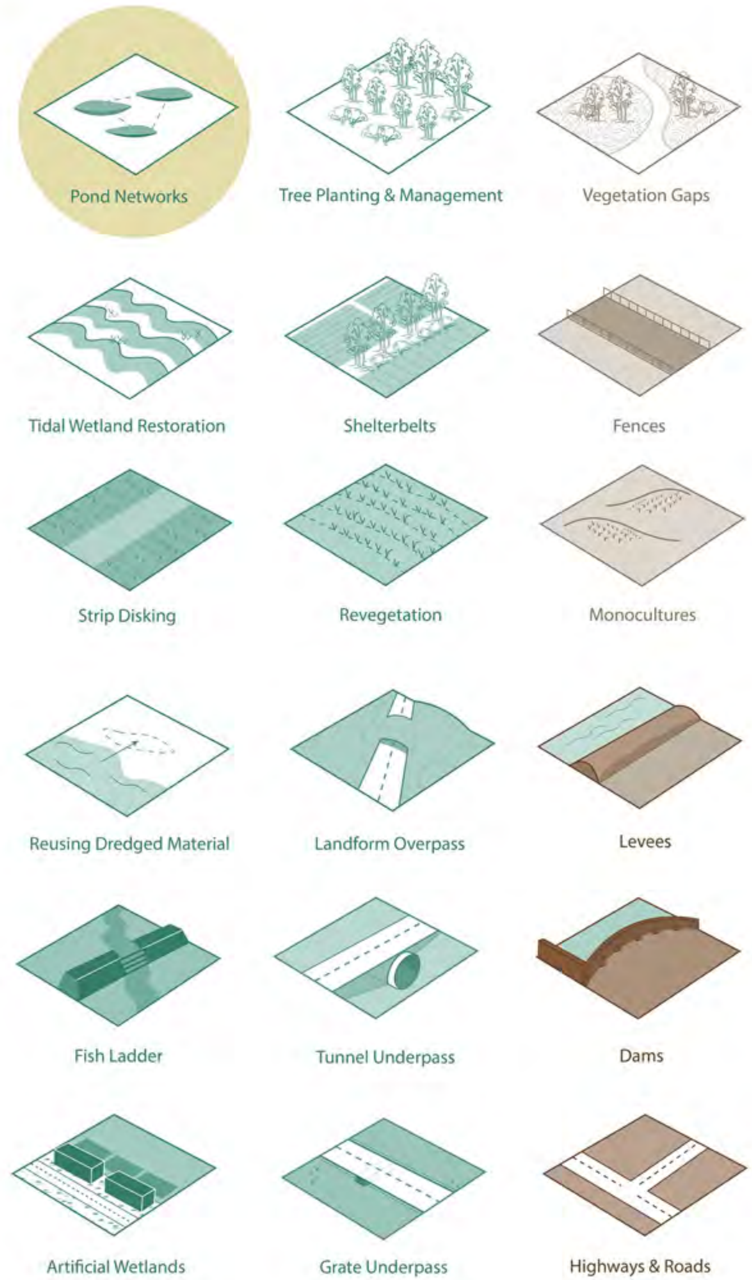


CULTIVATED
working landscapes



URBAN
blue & green infrastructure





SPATIAL ANALYSIS

This research analyzes potential locations of corridors and linkages for two target species across various ecosystems in the Golden Gate Biosphere. I intend to supplement EcoAdapt's vulnerability assessments and spatial analysis of climate change impacts in the Golden Gate Biosphere by directly relating these factors to species habitat and movement. First, I present a collection of existing spatial analysis tools for corridor modeling with discussion of the benefits and drawbacks of each. This includes comparison to existing wildlife corridor models to contextualize this project as it fits into broader wildlife corridor studies.

Next, after reflecting on the various corridor modeling software options, I discuss a test run of LinkageMapper. As part of this analysis, a suitability analysis and resistance raster dataset were developed, outlined in the following sections. When paired with core habitat, these spatial analysis tools compare features in the landscape that block movement, with areas that species are known to inhabit. This culminates in an output that displays varying opportunities for wildlife corridors in the Golden Gate Biosphere.

Choosing a Tool for Corridor Analysis

Currently, there are a wide range of existing tools for conducting corridor analyses. Each method varies in its methods of calculation, but all involve developing quantitative measurements and criteria for comparison of each input (Beier, 1992). In most cases, this leads to the definition of representative weights for each variable. *Refer to full thesis report for discussion of alternative corridor modeling tools (Stern, 2023).*

Any modeling technique, and its associated tools, requires a complex combination of inputs and extensive knowledge of species' needs, human land use, and projected climatic changes and physical patterns. With the GGB criteria of including a large regional scale, considering multiple species' needs, and representing a wide variety of land uses and land covers, some tools function more effectively than others.

Previous studies have used multiple species to test Circuitscape and Linkage Mapper. Circuitscape was found to be better for modeling general species dispersal patterns while Linkage Mapper is effective for showing connectivity among habitats. Moreover, Circuitscape has been used at global, as well as state-wide scales, while Linkage Mapper may be better applied at smaller regional scales (Araujo and New, 2006). LinkageMapper provides an opportunity to differentiate between more significant and less significant parts of corridors. This differs from other tools which produce evenly distributed corridors (Zhao, 2021). Lastly, Linkage Mapper also sits in between the functionality of multiple tools; this tool uses network theory to perform a combination of spatial and statistical analyses at moderate complexity with the output of several paths (Norden, 2016). This tool also contains foundational analysis methods that overlap with that of existing and well-established modeling techniques. Prior research has been performed by The Nature Conservancy utilizing Circuitscape and Omniscape (the parent tools of LinkageMapper) to model corridors and broader connectivity in the Bay Area, the state of California, and beyond. Thus, through a comparative process I have chosen to analyze the GGB by testing LinkageMapper as a tool that has multiple benefits and sits in between the analysis techniques of many established studies. I consider the needs of two of the GGB target species, specifically the Belted Kingfisher and California Red Legged Frog.

METHODOLOGY

Suitability for Movement

It is first necessary to create a suitability analysis, as this suitability layer is part of a resistance raster required as an input in the LinkageMapper tool, Linkage Pathways. This suitability analysis considers some of the key habitat and movement needs of the Belted Kingfisher and California Red Legged Frog. These variables include opportunities and constraints related to the two species' movement. These were weighted on a scale of one to nine, one being harmful, and nine being most beneficial. *Refer to full thesis report for variable weights (Stern, 2023).* As suggested by prior multi-scale habitat modeling approaches, weights were chosen through literature review and expert interviews, as there is a gap in field observations of these two species (Store, 2003).

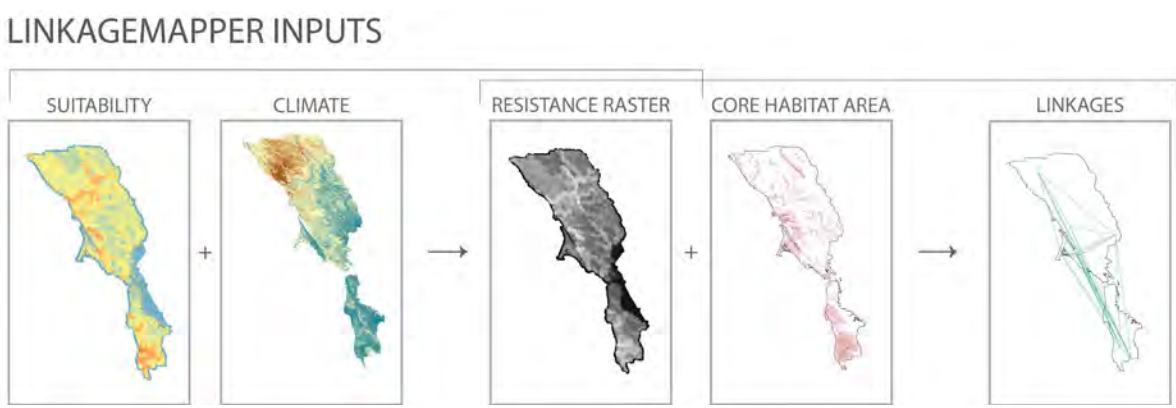
By overlapping the critical inputs for each of these species the weights of each variable can be compiled to add up to a suitability surface which encompasses the whole Biosphere region. The physical and environmental variables to be incorporated in this study include slope (steepness), ecosystem type (particular focus on water bodies including wetlands, rivers, and streams), vegetation cover (particular focus on aquatic and nearby upland vegetation in Marin, Sonoma, and San Mateo), as well as hydric soils and permeable geomorphology and bedrock (related to the occurrence of wetlands and water related habitats). Jurisdictional policies were also incorporated in this suitability analysis as this impacts the feasibility of implementing restoration or connectivity measures. These include land use, protection status (BPAD), and location of highways. Climate change scenario-informed variables will be used as inputs as well. The variable used in this step was pulled from a Basin Model prepared by Pepperwood (Pepperwood Preserve, 2023), involving water movement and/or yield through runoff.

Results of Suitability Analysis

This suitability analysis highlights opportunities as well as barriers for movement of the Belted Kingfisher and California Red Legged Frog within the GGB. Adding the variable weights together creates a continuous surface. However, this does not show linkages, or areas where pathways of opportunity may be connected to one another. Some areas in this analysis may appear to have higher suitability, however they may not actually connect to a larger corridor. On the other hand, some areas may appear isolated and/or lower in suitability, but when analyzed using corridor modeling software, may correspond with greater accessibility and potentially allow for enhanced opportunities for wildlife movement.

Running Linkage Mapper

Using the suitability analysis, combined with climatic variables from the IPCC Report's GFDL Climate Scenario (including precipitation or PPT Average, PPT Maximum and PPT Minimum, Runoff, Recharge, and Climatic Water Deficit) I created a resistance raster to use with Linkage Mapper. Next, this resistance raster layer is paired with core habitat (represented by a core habitat value field). As seen in the workflow outlined below, together these inputs allow the algorithms in LinkageMapper to represent potential linkages.



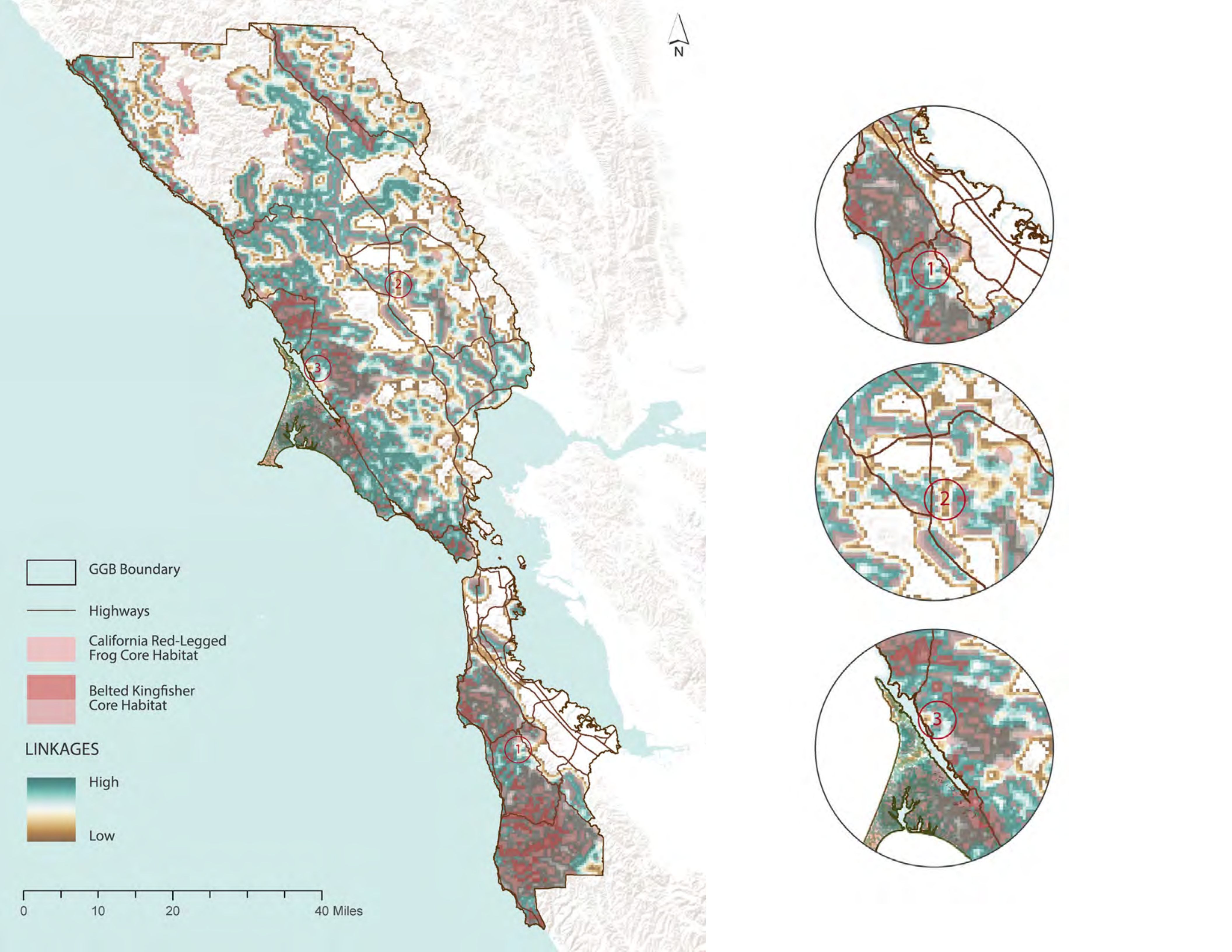
Discussion

The output from LinkageMapper (found on the following pages) can differentiate a range of higher and lower opportunities for linkages within the larger corridor zone. This output eliminates areas where there are complete barriers or no direct links to the main corridor. While Linkage Mapper's analysis clearly follows water bodies and core habitat boundaries most directly, it provides more opportunity for identifying barriers within this regional corridor zone. Zooming in, Linkage Mapper presents greater potential for analyzing open space areas and might be used to identify vegetation gaps between areas of greater connectivity (teal) and lower connectivity (brown).

Some areas where this study might be improved include utilizing additional species-specific variables. Honing in on vegetation cover can more precisely allow differentiation between plants used as cover and shelter, and plants used primarily as food sources. Another opportunity for improvement may be the additional variable of impermeable surfaces, particularly for analysis in urban and residential settings. When providing weights for the variables, the collection of a greater number of interviews and/or surveys would enhance the accuracy of this analysis through synthesizing expert input. Other methods of evaluation of input criteria may include pairwise comparison (i.e. the Analytical Hierarchy Process or AHP) in order to more accurately reflect expert opinion on the level of benefit or harm for each variable (Store, 2003). In this way, the weights will reflect the perspectives and goals of a greater number of land managers within the GGB. This may also be an opportunity to broaden social connectivity in the Biosphere, as organizations and community members can give firsthand input.

Along with the improvements to the weighting system, some alternative analysis workflows and techniques may improve the accuracy of this LinkageMapper output. At its current output, in urban and developed areas with more densely situated infrastructure and landscape features, the resolution of this analysis lacks the level of detail required for suggesting site-specific strategies. Thus, considering the nested scales of this analysis, this output has potential vulnerabilities when zooming in and transitioning between regional to site-specific connectivity. It may be possible for a higher resolution output to inform corridor strategies more directly across scales, especially smaller site-specific scales. As data continues to be collected, and wildlife more directly monitored, one main data gap that could be filled is the addition of species distribution data (at the group or individual level). The current polygons for core habitat in Linkage Mapper contain large areas which lack detail. Through conversation with aquatic and avian ecologists and literature review, I found that detailed species counts are currently missing for many core habitat areas. Particularly when studying the California Red Legged Frog, there are numerous private lands where monitoring and recording of this kind of information is not an active part of operations. This may be partially due to restrictions and regulatory burdens that may arise related to the presence of an endangered species on site, as well as lack of funding and personnel with proper surveying knowledge (Huntsinger, 2012).

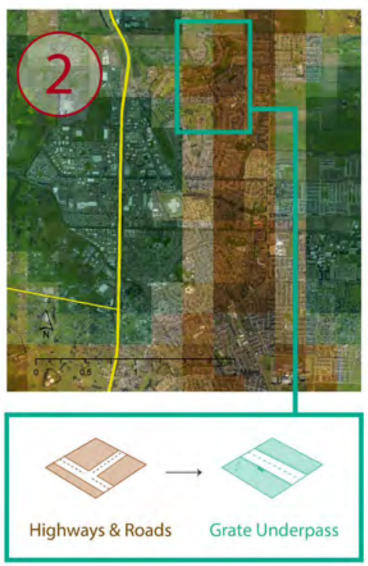
Taking these opportunities for improvement into account, one potential strategy for GGB stakeholders to investigate further lies in grazing and cultivated lands as a resource for corridor enhancement. Wet sites on grazing and cultivated land may have greater vulnerability in the face of climate change, as water availability and vegetation cover are likely to see relatively rapid shifts. There is a clear need and a number of opportunities for increasing water storage, and thus enhancing accessibility for livestock as well as wildlife.


N
1
2
3
GGB Boundary
Highways
California Red-Legged
Frog Core Habitat
Belted Kingfisher
Core Habitat
LINKAGES
High
Low
0
10
20
40 Miles

OPEN SPACE & URBAN

TWO MILE SCALE

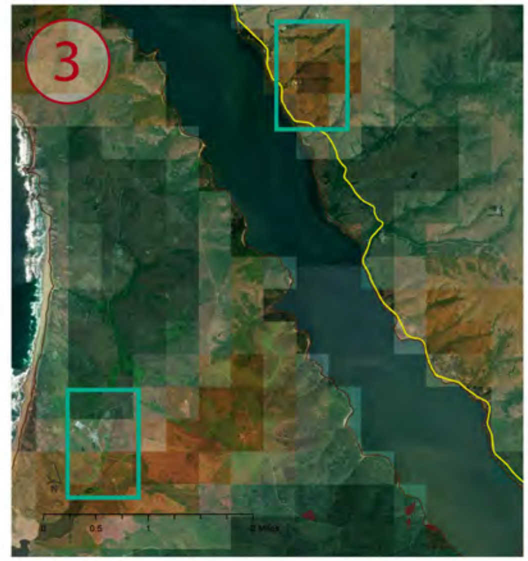
HALF-MILE SCALE

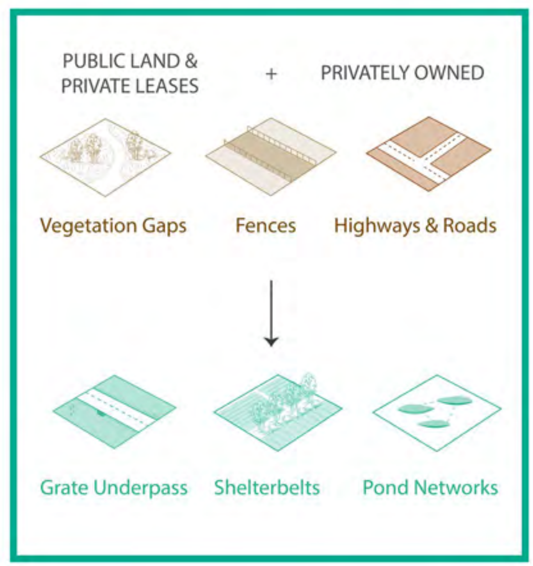


GRAZING & CULTIVATED

TWO MILE SCALE

HALF-MILE SCALE





A STOCK POND STEPPINGSTONE CORRIDOR

In this chapter, I will outline how stock ponds are one opportunity for a climate adaptive steppingstone corridor. First, I define stock ponds in order to relate this steppingstone strategy to working lands conservation principles. Second, I articulate the climate adaptation opportunities that this strategy offers. Finally, I highlight ponds as an untapped resource for new partnerships within the Golden Gate Biosphere. In this way, an interdisciplinary approach can show how climate corridors might account for both anthropocentric and biocentric landscape ecologies.

What are Stock Ponds?

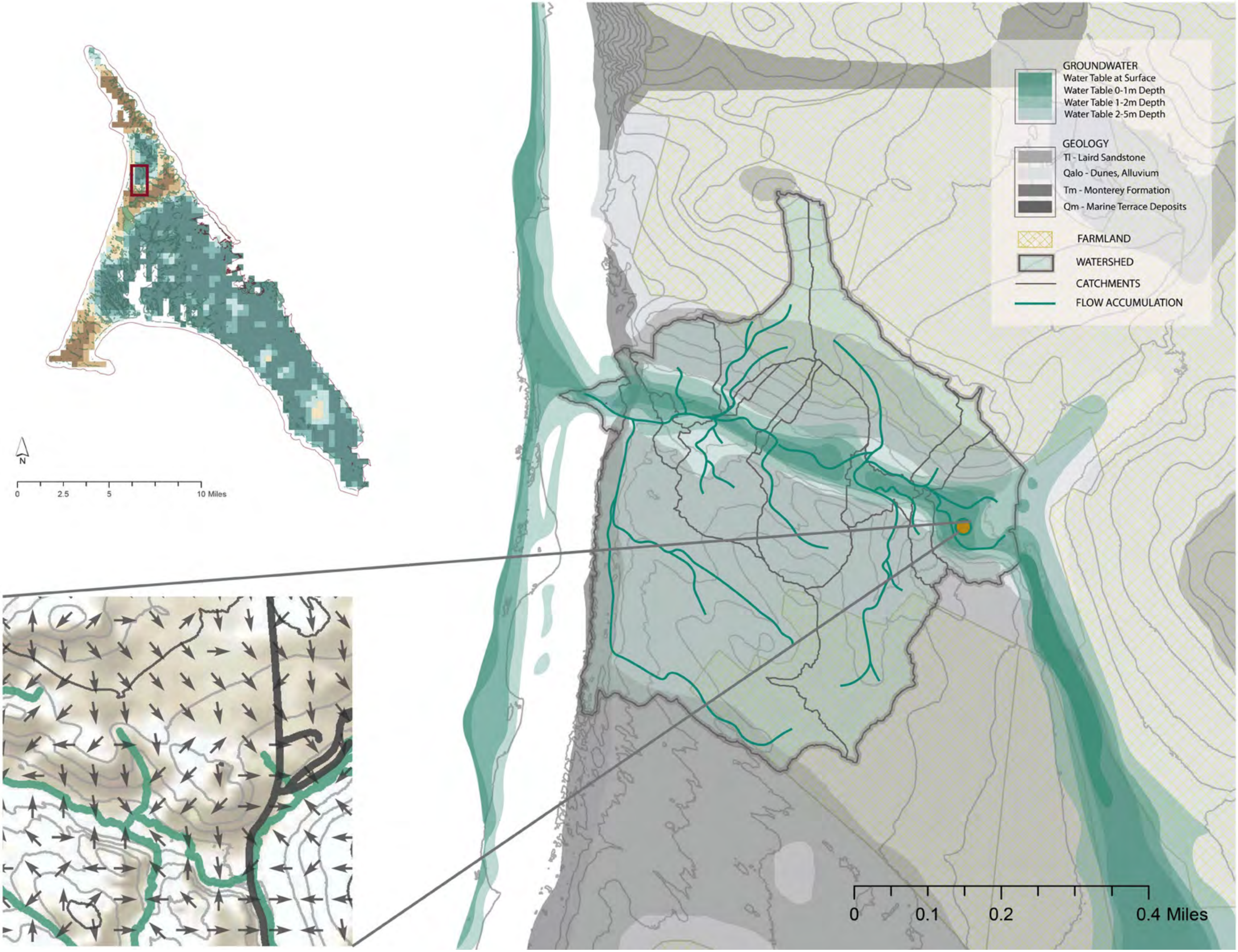
Stock ponds are small, permanent, or mostly permanent bodies of standing water (USDA, 2021). These ponds may be created for various reasons, including usage for irrigation, fish production, fire protection, recreation, and in the case of this study, for the drinking water needs of livestock. Each of these uses has a coupled, and seemingly hidden impact of creating wildlife habitat. In California, and particularly in the GGB region, these ponds are known habitat for California Red Legged Frogs, with waterbirds often frequenting these areas as stopover habitat as well (EPA, 2023).

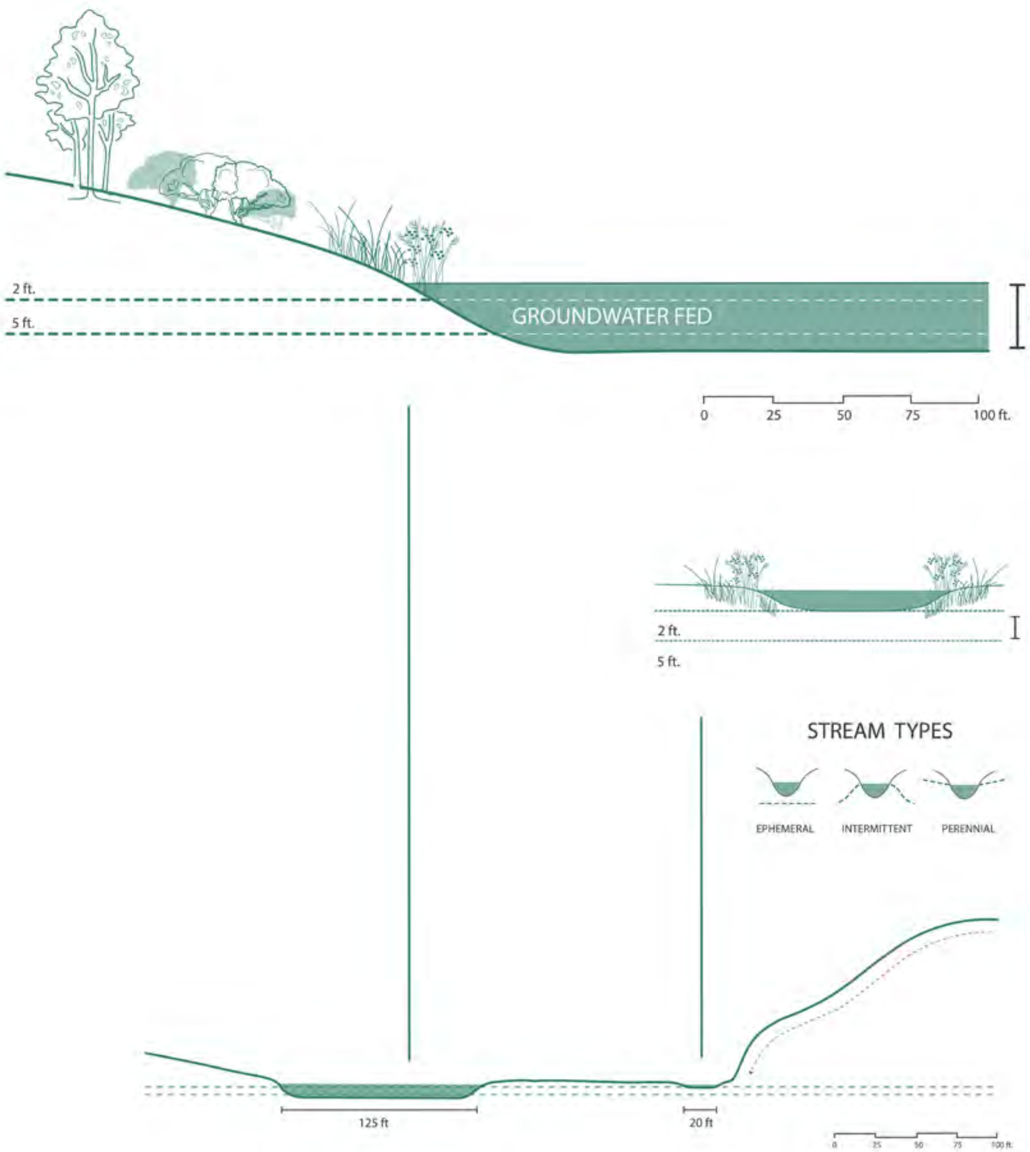
Why Stock Ponds?

Stock ponds are currently an underutilized resource for wildlife connectivity. Many of these ponds have existed in the GGB for decades, with farms dotting the region since the mid-1800s (Larson & Barry, 2015). Though, prior to recent restoration projects, these spaces have often served the sole purpose of providing water for livestock. This translates toward sparsely vegetated, relatively low activity, low biodiversity spaces. With present inactivity in these spaces, the pressing threat of climate change reveals stock ponds to be a potentially innovative strategy for future wildlife and livestock needs. Warmer climate projections translate to reduced water availability as natural wetlands and streams (particularly waterbodies with intermittent persistence) are increasingly likely to dry out and remain dry for longer periods of time. This is even more likely with projected frequency and severity of extended periods of drought.

Since stock ponds are needed for livestock and agricultural use, they are more likely to be prioritized and maintained by ranchers as the region moves toward drier conditions. This can also maintain the necessary conditions for wildlife refugia even as other water sources dry up. Thus, these ponds are an opportunity to build on "working lands conservation" within the GGB. This involves supporting biodiversity while also contributing to production of goods and services for people (Kremen & Merenlender, 2019). Livestock and crop health can be boosted by greater access to water and improved water quality, supporting human livelihoods, while also aiding sustainability and resilience measures. These working lands may also create buffers and protection from environmental threats for GGB target species while providing space for species' movement toward protected areas.

Along with this, these biodiversity-based working lands management practices are relatively accessible options for people as well as wildlife, as individual ranchers may be empowered to have a direct hand in managing the region's natural resources (Kremen & Merlender, 2019). Incentivizing these projects as part of a larger connectivity strategy may draw new funding and supportive government policies toward conservation of working lands. *Refer to full thesis report for stock pond corridor case study details (Stern, 2023).*


GROUNDWATER
Water Table at Surface
Water Table 0-1m Depth
Water Table 1-2m Depth
Water Table 2-5m Depth
GEOLOGY
Tl - Laird Sandstone
Qalo - Dunes, Alluvium
Tm - Monterey Formation
Qm - Marine Terrace Deposits
FARMLAND
WATERSHED
CATCHMENTS
FLOW ACCUMULATION
0
0.1
0.2
0.4 Miles
N
0
2.5
5
10 Miles



Planning & Design

Ecological and social contexts have informed the choice of Point Reyes National Seashore as a sample for planning and designing a stock pond steppingstone corridor. Though, ranches throughout the GGB will likely face similar challenges to those in Point Reyes with longer drought seasons and variability in water access. Along with this, access to funding and support for farm and ranch practices is relatively limited. Given this context, each ranch or farm will have its own social and physical context and so, rather than a site-specific placement or restoration project, my study is intended to be a model process for planning a steppingstone corridor in grazing and agricultural areas.

General Considerations

To communicate the needs of ranchers along with the needs of GGB land managers, a set of key considerations are outlined in the following sections. In this way, proper design, planning, and monitoring can take place accounting for both livestock and wildlife.

Groundwater, Flow Direction, Watershed & Catchments

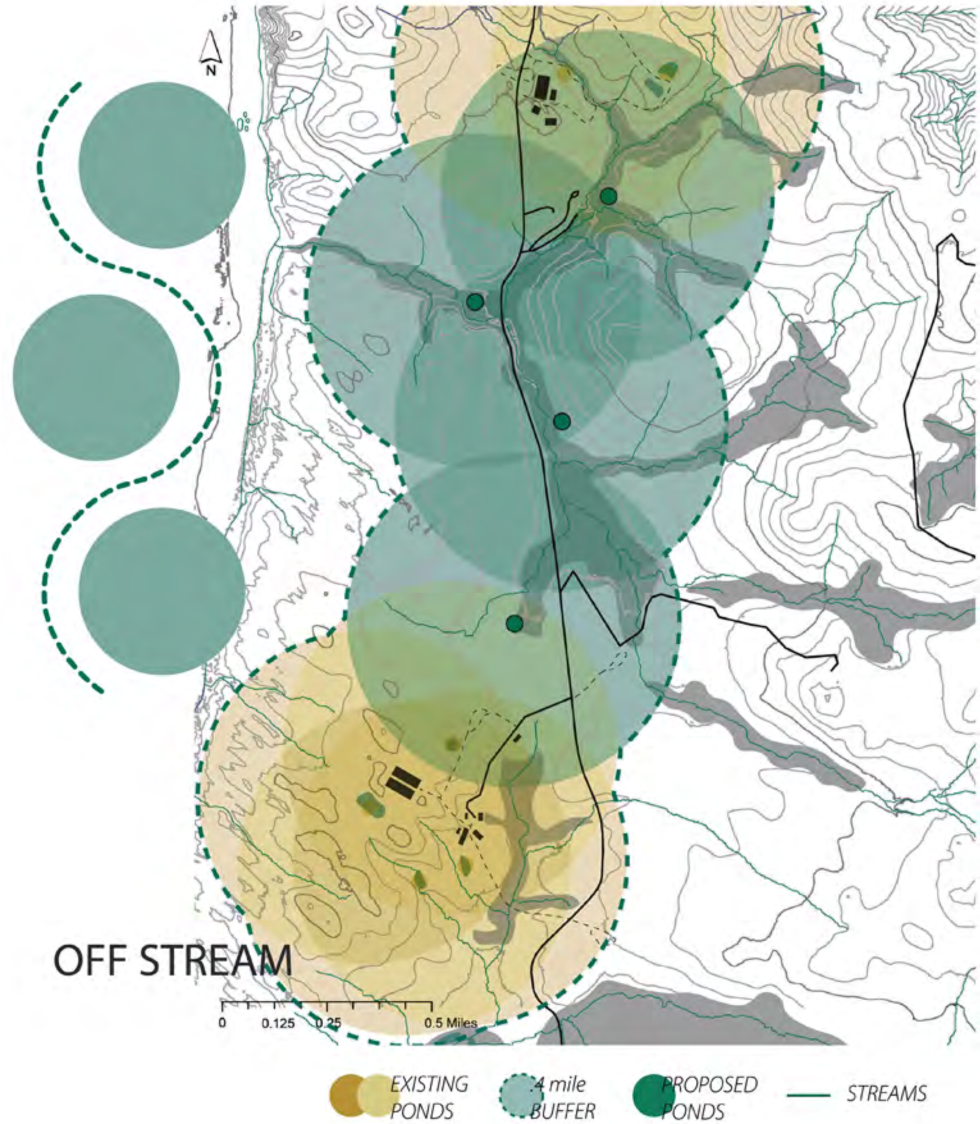
Of highest priority for placing a stock pond or a series of stock ponds is considering the drainage area which feeds the water bodies. This should provide sufficient water to fulfill the intended volume that is to be stored. Along with this, the least disturbance of soil is ideal (USDA, 1997). Adequate drainage is especially important for ponds which mostly rely on runoff. With this, the ratio to follow for proper pond requirements should be 10 to 15 acres of land to 1 surface acre of water (Provin, 2013). Flow direction and runoff should also be studied to determine a location which is most conducive to water movement and drainage directed toward the pond (Almeida, 2021). Pictured on the previous page, flow direction analysis can be used for developing a basis for properly feeding water toward a stock pond. Using the Hydrology tools in the Spatial Analyst toolbox on ArcMap 10.8.2, I have combined the fill, flow accumulation, and pour point outputs to create a Flow Direction map, which indicates where movement of water is directed down ridges toward valleys and streams. Flow direction in this demonstration highlights a pocket of lower elevation between two ridges.

Another significant consideration is groundwater depth. Depth to groundwater is related to precipitation storage and the permeability of surface water beneath bedrock (Lamontagne, 2021). These are linked to the geology and soil type found on site, which impact infiltration. A shallow groundwater depth is desirable for a pond location. In addition, if a pond is located near an intermittent or perennial stream that may not store water consistently, the pond may provide an opportunity for prolonged water storage. Land managers should consider historical and current vegetation and hydrological patterns (of runoff and streamflow) as well as projected climate change patterns. In this way, planners and managers can ensure that restored and newly placed ponds will remain effective sites several decades into the future.

<u>Stock Pond Forms & Steppingstone Topologies</u>

Along with siting, there are considerations regarding the pond's form. These include the individual size and shape, as well as distance of ponds from one other. These factors may largely depend on the needs of the rancher and livestock. Generally, a pond should be able to provide 12-15 gallons per cow with 20-30 gallons or more for including management of ranch facilities and other operations (Kersbergen, 2023). To calculate desired pond area, an average of the length, width, and depth of the pond should be measured, along with the maximum length, width, and depth (Swistock, 2022). Varying calculations exist for ponds depending on whether they are circular, rectangular, trapezoidal, or irregular. In terms of distance between ponds, livestock proximity to grazing pastures and wildlife movement should inform the steppingstone patterns. This means about ¼ mile between ponds in rougher terrain, and 1 mile across more level areas for livestock. For wildlife, the Belted Kingfisher generally creates territories of approximately 0.6 miles in length, while the California Red Legged Frog travels up to a mile from water bodies (though they often remain in closer proximity outside of their breeding seasons).

It is important to note that each of these recommendations are based on previously established practices in present conditions. Ponds will need to respond to changing climatic patterns. The current recommended pond depth for the region, is about 8 feet. However, this will likely change over the coming decades as shifts in water availability or evapotranspiration rates may lead to an increase in the recommended depth of ponds. This may also impact the overall size and shape requirements as well. Hotter temperatures and vegetation shifts could contribute toward greater demand for water by livestock and wildlife. Lastly, distance between ponds may need to be shortened over several decades, depending on the vegetation cover and temperature ranges between ponds.



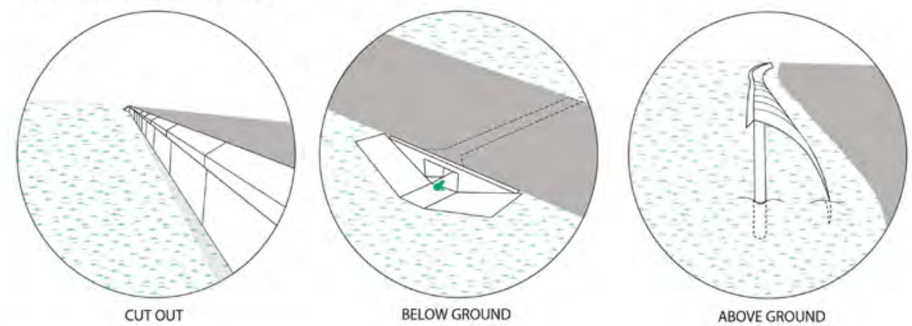
Design & Management Strategies

Management opportunities may be paired with this steppingstone corridor strategy to support wildlife habitat and climate adaptation outcomes. These include amphibian walls, modified culverts, and grate crossings for safe terrestrial passageway, along with artificial burrows, and perches, as well as revegetation and streamside buffers for silt management and erosion control of pondside grounds and nearby riparian corridors.

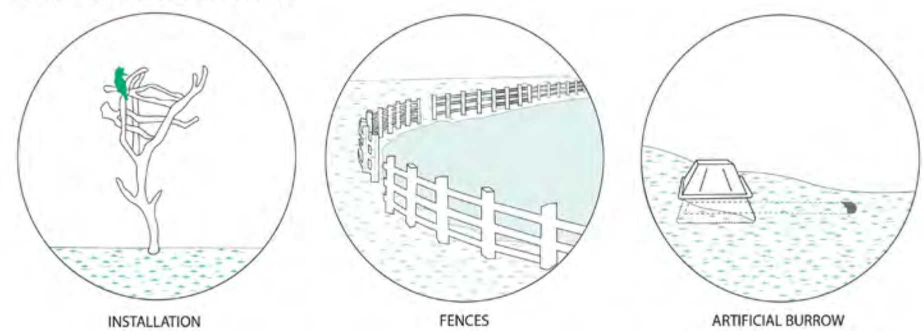
Paired with smaller scale co-management strategies, stock ponds can be managed in more permanent technological and structural forms as well. For example, waterbirds benefit from irregular shorelines with contoured slopes for feeding. Moreover, management of livestock access through mutually beneficial fencing will protect water quality for both livestock and wildlife. As a general guideline, “For a small herd, you want at least 20 feet of access; double that width to 40 feet for herds up to 200 cows” (Angus Media, 2017). This will prevent trampling of aquatic vegetation growing immediately along pond banks and will prevent entrance into the ponds by livestock. Paired with this, dams, pumps, and spillways may contribute toward water quality and flood management for stock ponds. Dams contribute toward creating pools of water on-stream, and with proper structural modifications can develop whole ponds, while pumps can be used to funnel water toward troughs and may also contribute to preventing livestock from negatively impacting water quality by entering the ponds. Spillways can be used to move water out of the pond and away from sensitive habitat during flood events (USDA, 1997).

Lastly, management of stock pond water levels is significant, as relates to target species’ competitors and predators. The invasive bull frog inhabits the same spaces as the California Red Legged Frog, often outcompeting or predating on said target species. Interviews with aquatic ecologists and amphibian biologists reveal one difficulty that arises with management and consideration toward seasonal draining of stock ponds. This strategy may alleviate issues of predation and competition by bull frogs as California Red Legged frogs do not require standing water year-round, while bull frog tadpoles cannot survive without permanent water levels. In this case, differences arise between dry-season water needs of livestock during seasons where drainage may benefit California Red Legged frogs by mitigating bull frog populations. Thus, communication and enhanced partnership between ranchers and GGB partners may lead to more intensive management strategies and solutions.

AMPHIBIAN PASSAGEWAY



BIRD PERCHES & BURROWS




N
0
50
100
150
200 ft.
MIXED GRASSLAND
FENCED POND
AQUATIC VEGETATION
RIPARIAN VEGETATION
UPLAND VEGETATION
EXISTING VEGETATION
AMPHIBIAN CROSSING
ARTIFICIAL BURROW
PERCHES

Policy, Funding & Partnerships

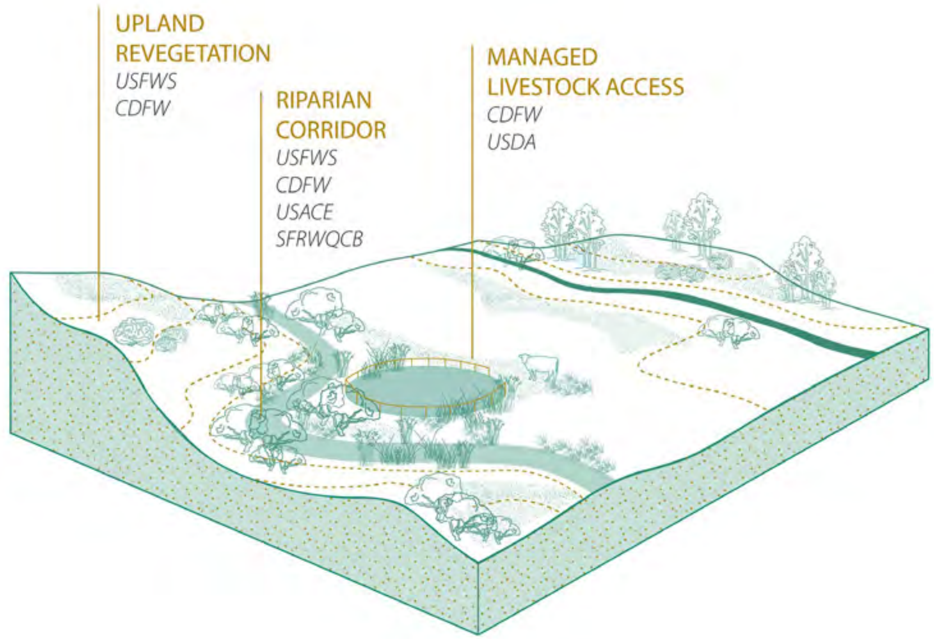
With these environmental considerations and species needs in mind, in order to plan for cross-jurisdictional GGB-scale steppingstone ponds, there are many jurisdictional blocks which need to be navigated for this kind of corridor to be implemented. Policies and programs as well as funding sources already exist for restoration of ponds, and many of these show promise for inclusion of wildlife corridors and climate change connectivity goals.

The first permitting requirements to begin the process of restoring and/or placing stock ponds involve federal and state regulations on Water Rights, the Endangered Species Act, and the Clean Water Act. This entails a complicated mix of permitting processes. Along with this, the pathways for funding vary greatly depending on whether the land is privately or publicly owned. But, there are resources at the local, county, and federal levels which GGB members and agricultural groups can come together on, to expand restoration initiatives and broaden impacts of these kinds of steppingstone stock pond corridors.

Partnership opportunities that would be especially powerful for the GGB would be to connect more deeply with Resource Conservation Districts (RCDs) who have established and effective programs for restoration work including stock ponds projects. These groups also work with both public organizations and private landowners. One example of this is the Marin RCD, whose Permitting Program contains information regarding pond restoration and best management practices. The Marin Permit Coordination Program (PCP) is a significant model for a coordinated, multi-agency regulatory review process which ensures resource-protection mandates while also maintaining environmental compliance. This process is also more accessible to private landowners and other agency partners than traditional routes.

The GGB has multiple access points to build from existing PCP Best Management Practices. For example, additional practices within the ranking criteria may include explicit mention of corridors and buffer distances of wildlife movement as priorities in choosing projects and gaining funding.Applying a steppingstone corridor strategy within this program would have some key benefits, for example access to funding sources may increase as many federal, state, and local organizations account for larger scale impact as part of the criteria for selecting awardees.

Outside of the GGB, projects and programs similar to the Marin RCD permitting program may provide some insight and models for Biosphere partners to act on. The Alameda County RCD's Wildlife-Friendly Pond Restoration Program offers Alameda County farmers and ranchers cost-share funding for pond restoration (Charbonneau & Connelly, n.d.). Ranchers only need to apply to one agency for all the required permits, cutting the approval wait time by 85%. This program also offers regulatory assurances for landowners, this is particularly significant as it incentivizes restoration work which targets the California Red-Legged Frog. Ranchers who enroll gain protections under the "Alameda County Stock Pond Safe Harbor Agreement", leading to less restrictions on their property associated with the Endangered Species Act (ACRCD, n.d.). Along with this, the management strategies covered by this program extend around each restored pond, taking into account the movement patterns of target species. With that, this program's benefits may go beyond Alameda County, as this framework is well-suited for adoption elsewhere and highlights potential for protecting connected steppingstone habitat for GGB target species. Similar agreements may be added to policy and programs for RCDs within the GGB.



PERMITTING

US ARMY CORP OF ENGINEERS	CLEAN WATER ACT
STATE WATER RESOURCES CONTROL BOARD - Division of Water Rights	WATER RIGHTS
CALIFORNIA STATE LEGISLATURE	CALIFORNIA ENVIRONMENTAL QUALITY ACT - CEQA
CALIFORNIA WATERBOARDS: Region 1 & 2 North Coast & San Francisco Bay Area	AGRICULTURAL PLANS GRAZING WAIVERS BASIN PLANS
CALIFORNIA FISH & WILDLIFE (CFWS)	COOPERATIVE AGRICULTURE
US FISH & WILDLIFE SERVICE (USFWS)	ENDANGERED SPECIES ACT

GRANTS & FUNDING

ENVIRONMENTAL PROTECTION AGENCY (EPA)	• SF BAY WATER QUALITY IMPROVEMENT FUND
CALIFORNIA NATURAL RESOURCES AGENCY - Environmental Enhancement	• CONSERVATION RESERVE PROGRAM • WETLAND RESERVE EASEMENTS • AGRICULTURAL LAND EASEMENTS
FARM SERVICE AGENCY (FSA)	
USDA - Natural Resource Conservation Service	• WATER BANK PROGRAM • ENVIRONMENTAL QUALITY INCENTIVES PROGRAM • CONSERVATION STEWARDSHIP PROGRAM • AGRICULTURAL MANAGEMENT ASSISTANCE • REGIONAL CONSERVATION PARTNERSHIP PROGRAM
COASTAL CONSERVANCY State of California	

FARM BILL PROGRAM

PARTNERSHIP OPPORTUNITIES

CALIFORNIA COUNCIL OF LAND TRUSTS — PRIVATELY OWNED

- MARIN AGRICULTURAL LAND TRUST
- SONOMA AGRICULTURAL LAND TRUST
- CALIFORNIA RANGELAND TRUST
- COASTSIDE LAND TRUST
- MARIN COUNTY OPEN SPACE TRUST

CALIFORNIA OPEN SPACE DISTRICTS — PUBLICLY OWNED

- MIDPENINSULA REGIONAL OPEN SPACE DISTRICT
- SONOMA COUNTY AGRICULTURAL PRESERVATION & OPEN SPACE DISTRICT

CALIFORNIA RESOURCE CONSERVATION DISTRICTS

MARIN RCD → MARIN PERMITTING PROGRAM - COORDINATED CEQA COMPLIANCE → AQUATIC HABITAT IMPROVEMENT
Pond Restoration (378[R]), Stream Habitat Improvement (395), Channel Bed Stabilization (584), Aquatic Organism Passage (396), Streambank Protection (580) → REQUIRED BEST MANAGEMENT PRACTICES (BMPs) FOR PCP ACTIVITIES

- MRCD shall ensure that, if wildlife habitat benefits are incorporated into a project design, care shall be taken to avoid creating small isolated zones that could become population "sinks"
- Aquatic organism passage concerns shall be addressed.

SONOMA RCD

[illegible]

SAN MATEO RCD

[illegible]

Pond to pond proximity related to wildlife connectivity opportunities shall be [illegible] [illegible] restored ponds.

CONCLUSIONS

This report develops a framework for wildlife corridor planning in the Golden Gate Biosphere. Through a combination of literature review and case studies, foundational criteria for wildlife corridor categories creates a collective knowledge base of corridor options and outcomes. Along with this, corridor modeling tools and tests of spatial analysis set up a step-by-step process by which future planning and design strategies can build from. This project demonstrates an opportunity to create a collective process for wildlife corridor management in the face of climate change.

The model study I presented here, using a steppingstone pond corridor, highlights an opportunity for working lands conservation. With the threat of climate change, regions cannot rely solely on protected areas to preserve biodiversity and conserve the movement ranges and core habitat of target species. These sites may also become increasingly isolated, leading to widespread habitat loss and environmental degradation. Hence, managing the landscape as a matrix to maintain biodiversity and wildlife connectivity is not only necessary for conservation of wildlife but also essential for human productivity.

With these opportunities there are also some clear drawbacks of this study. Crossing scales sets a framework for planning, however the relatively low-resolution datasets associated with regional studies lack the detail needed for site-specific implementations. Along with this, complex relationships between organizations, and individual landowners are not accounted for in the speculative planning and design suggestions outlined in this report. Attention to the details of individual situations and relationships is necessary for proper planning of wildlife corridors that are intended to account for both human and wildlife needs. In addition, there is currently a general lack of data for the target species of the GGB, including the two species I focused on here. Many agencies use data gaps like this as a reason to refuse the widening of corridors (especially physical landform overpasses or underpasses), citing lack of evidence of animal usage (Beier, 1992). In future, restoration and pond placement projects will require more fine-resolution data to truly pinpoint barriers within the landscape. Site visits across seasons will also be necessary to ground truth any spatial modeling performed for the GGB.

Any additional steps would also require ongoing management and monitoring. GGB partners may look to groups utilizing existing surveying protocols and techniques to record the number of individuals of a population moving through these steppingstone corridors. Studies performed in areas surrounding the GGB, including pond surveys in EBRP, have included quantitative analysis (Riensche, 2017). In that study, recording the number of California Red Legged Frogs led researchers to definitively show a boost in their local population.

This project has presented a set of wildlife corridor options and corridor modeling software resources for connectivity and climate adaptation planning in the Golden Gate Biosphere. I offer a model for an interdisciplinary analysis method, setting up a framework which develops opportunities for expanded research, a collective foundational knowledgebase regarding the GGB's unique ecological setting, as well as pathways for partnerships, funding, and cooperation that help to expand the goals of the Golden Gate Biosphere.

Selected Resources

Arcari, P., Probyn-Rapsey, F., & Singer, H. “Where species don’t meet: Invisibilized animals, urban nature and city limits.” Environment and Planning E: Nature and Space, 2021. 4(3), 940–965. https://doi.org/10.1177/2514848620939870

Barrows, Cameron W., et al. “Identifying Habitat Linkages to Maintain Connectivity for Corridor Dwellers in a Fragmented Landscape.” The Journal of Wildlife Management, vol. 75, no. 3, 2011, pp. 682–91. JSTOR, http://www.jstor.org/stable/41418089. Accessed 10 Aug. 2022.

Beier, Paul & Loe, S. “Checklist for evaluating impacts to wildlife movement corridors.” Wildlife Society Bulletin. 1992. 20. 434-440.

Brooks, Robert P., and W. James Davis. “Habitat Selection by Breeding Belted Kingfishers (Ceryle Alcyon).” The American Midland Naturalist, vol. 117, no. 1, 1987. pp. 63–70. JSTOR, https://doi.org/10.2307/2425708. Accessed 11 May 2023.

Carroll, C., Dunk, J.R. and Moilanen, A., “Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA.” Global Change Biology, 2021. 16: 891-904. https://doi.org/10.1111/j.1365-2486.2009.01965.x

Ebel, Jonathan D., Lowe, Winsor H. “Constructed Ponds and Small Stream Habitats: Hypothesized Interactions and Methods to Minimize Impacts”. Journal of Water Resource and Protection. 2013. https://www.umt.edu/lowe-lab/documents/publications/ebel_and_lowe_2013_jwrap.pdf

Hess, George R. and Richard A. Fischer, “Communicating clearly about conservation corridors, Landscape and Urban Planning”, Volume 55, Issue 3, 2011. Pages 195-208, ISSN 0169-2046, https://doi.org/10.1016/S0169-2046(01)00155-4. https://www.sciencedirect.com/science/article/pii/S0169204601001554

Huntsinger, Lynn & Sayre, Nathan & Wulfhorst, J.D. “Birds, beasts and bovines: Three cases of U.S. pastoralism and wildlife. Pastoralism: Research, Policy, and Practice.” 2012. 1. 12. 10.1186/2041-7136-2-12.

Kremen, Claire & Merenlender, Adina. “Landscapes that work for biodiversity and people.” Science. 362. 2018. eaau6020. 10.1126/science.aau6020.

Larson, Stephanie & Barry, Sheila. “Understanding Working Rangelands Bay Area Ranching Heritage: A Continuing Legacy”. University of California Cooperative Extension. 2015. Retrieved from, https://anrcatalog.ucanr.edu/pdf/8528.pdf

Norden, Elsa. “Comparison between three landscape analysis tools to aid conservation efforts.” Department of Physical Geography and Ecosystem Science Lund University. 2016. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8893499&fileOId=8893500

Riensche, D.L., Tutino C.D., and Koenig, L. “California Red Legged Frog Response to Pond Restoration”. East Bay Regional Parks. 2017. “ https://www.ebparks.org/sites/default/files/CA-Red-legged-Frog-Response-to-Pond-Restoration-2019-9-24.pdf”

Store, Ron & Jokimäki, Jukka. “A GIS-based Multi-scale Approach to Habitat Suitability Modeling.” Ecological Modelling. 2003, 169. 1-15. 10.1016/S0304-3800(03)00203-5.

Swistock, Bryan. “Pond Measurements: Area, Volume and Residence Time” PennState Extension. 2022. https://extension.psu.edu/pond-measurements-area-volume-and-residence-time#:~:text=The%20volume%20of%20water%20in%20the%20pond%20

USDA “Part 650 Engineering Field Handbook”. National Engineering Handbook. Chapter 11 Ponds and Reservoirs. 2021. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=46292.wba

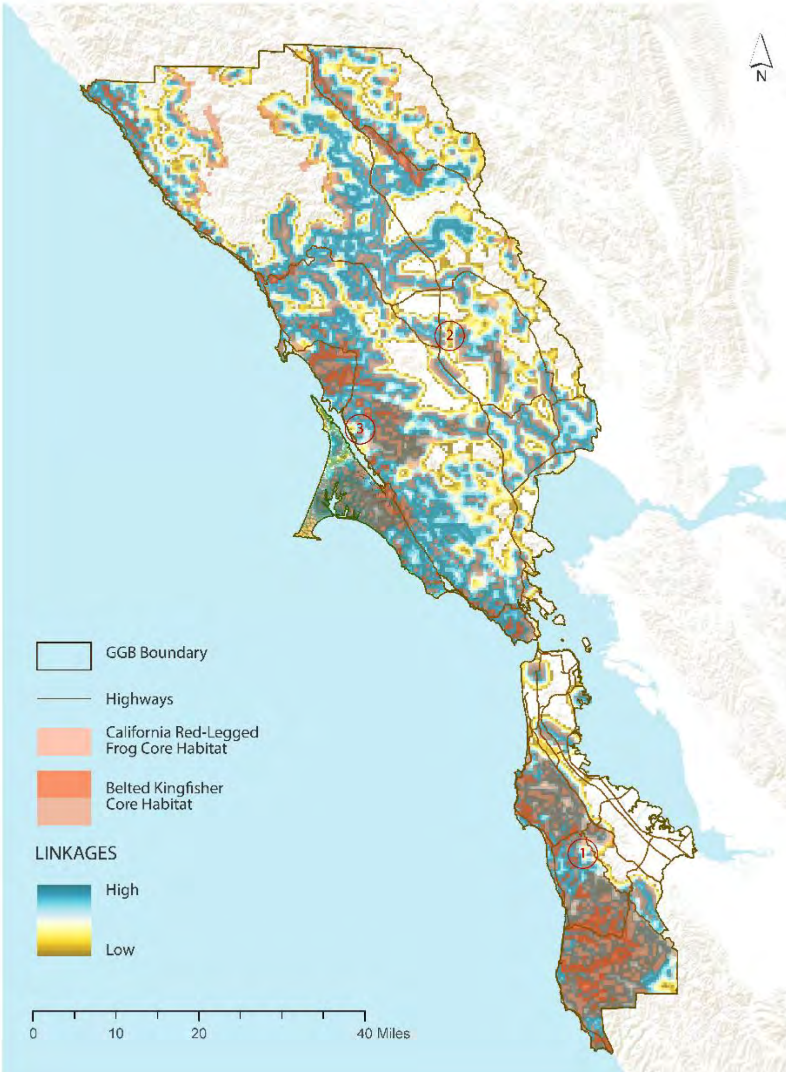
USDA “Agricultural handbook 590, Ponds — Planning, Design, Construction” National Resources Conservation Service. 1997. https://nrcspad.sc.egov.usda.gov/distributioncenter/product.aspx?ProductID=115

Weller, Richard, Drozdz, Zuzanna & Padgett Kjaersgaard, Sara. “Hotspot cities: Identifying peri-urban conflict zones” Journal of Landscape Architecture, 2019. 14:1, 8-19, DOI: 10.1080/18626033.2019.1623542

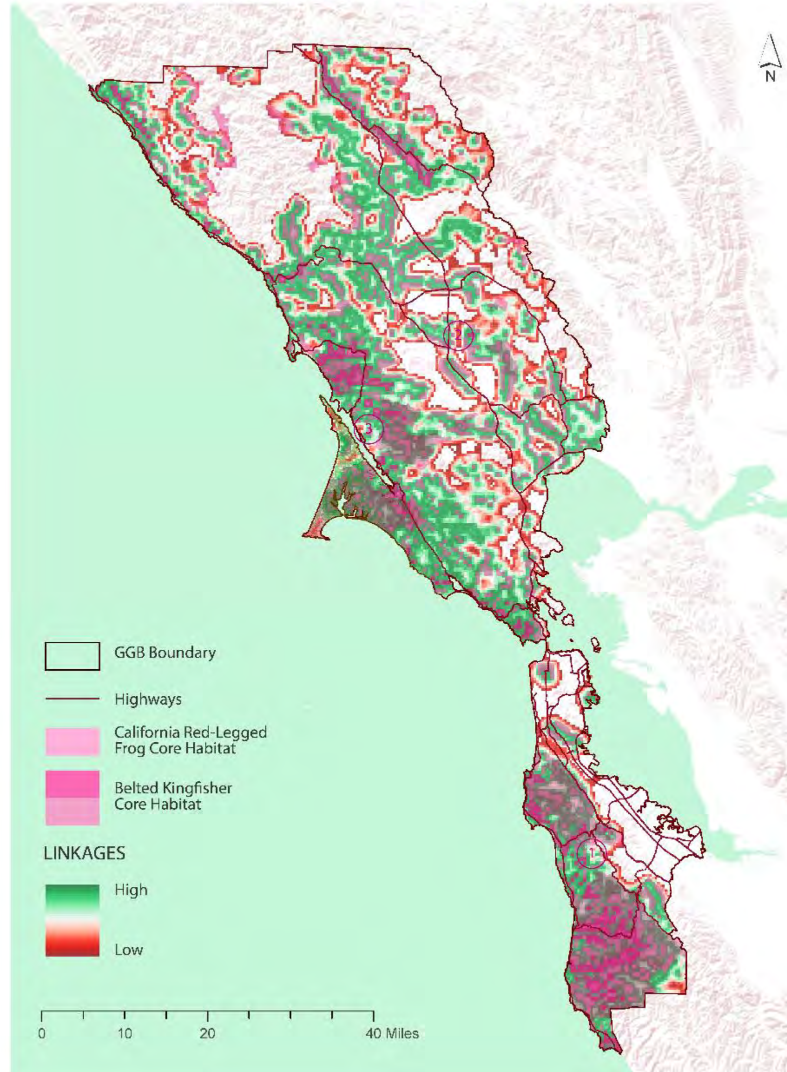
Refer to full thesis report for Data Sources (Stern, 2023).

COLOR ALTERNATIVES

REGIONAL CONNECTIVITY ANALYSIS



REGIONAL CONNECTIVITY ANALYSIS



THE 13 PARTNERED SITES OF THE GOLDEN GATE BIOSPHERE