Geographic Information System Techniques for the Mapping of Access Routes, Habitat Suitability & Variations in the Distributions of Common Carp (Cyprinus carpio) Throughout Malheur National Wildlife Refuge.

By

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A Thesis

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Abstract

Common carp (Cyprinus carpio) present a threat to biodiversity throughout the world. They have the potential to create a monoculture by out-competing the endemic species. Habitat degradation through turbation and resuspention of sediment through feeding processes creates a transition from a macrophyte-dominated clear water state to a phytoplankton-dominated turbid water state.

Within the Harney Basin in southeast Oregon lies Malheur National Wildlife Refuge. It is composed of about 187,000 acres of diverse habitat, mostly falling under the wetland classification. This northern cold desert, characterized by low precipitation and the wetlands in the region are subject to feast-famine water regime, receiving around nine inches of precipitation annually. Malheur National Wildlife Refuge is a cornerstone in the Pacific Flyway for transitional habitat as well as breeding habitat for many species of waterfowl and colonial nesting birds. It is Oregon's most important waterfowl production area.

Common carp pose a very significant threat to the integrity of the waterfowl and nesting bird habitat. The first carp were reported around 1950 and now out compete the native species for food and habitat. There have been constant effort to mitigate the issue of carp in Malheur's waters but the myriad of waterways and desirable feeding and spawning habitat and the relatively durable common carp make it an ongoing battle for effective management. One problem is the lack of data on carp distributions and habitat use.

The advancements in geographic information systems and an abundance of spatial data creates an opportunity to apply ecological, habitat, and infrastructure data to the carp deterrence process. In this study, an application of the Habitat Suitability Model will be used to identify the most desirable habitat for carp in two stages of the year: high water and low water.

By combining the available data, it is possible to identify acreages of suitable habitat for common carp during the high water season and with an updated dataset of the water delivery system, suitable areas for the common carp during the low water season can be identified.

In this study, acreages of suitable spawning habitat for carp are identified as well as areas, which are inhabited by carp, and areas that are not. Five pilot areas are identified where carp barriers are being used to identify the possibility of a carp-free water delivery system. These models are to be utilized in the ongoing effort to minimize the common carp distributions, numbers and impacts on waterfowl habitat to the greatest extent possible.

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1.1 Malheur National Wildlife Refuge

Physical Information

Malheur National Wildlife Refuge, located in the Harney Basin in southeast Oregon, consists of roughly 187,000 acres of diverse habitat. The refuge spans 27 miles east to west and 41 miles north to south.

This northern cold desert is characterized by low precipitation and wetlands which are subject to feast-famine water regimes. A substantial amount of the acreage falls under the wetland classification with variable characteristics. The Silver Creek, Donner und Blitzen and the Silves Rivers are the main water sources for Malheur National Wildlife Refuge. The Donner und Blitzen (Blitzen) River's headwaters are located atop Steens Mountain, which is located just beyond the southern portion of the refuge. Each year seasonal deposits of snow on Steens Mountain melt, causing the Donner und Blitzen River to have increased flows; inundating sections of the refuge and eventually dead ending in Malheur Lake, located in the northeastern portion of the refuge. The Silvies River originates in the Blue Mountains and empties into the north side of Malheur Lake. Silver Creek also originates in the Blue Mountains, but flows through the Double-O Ranch into the West side of Harney Lake (USFW 1982). Since there is no natural outlet for the water and soil is poorly drained volcanic material, the water, which culminates in Malheur Lake, is only dispatched by methods of evaporation. From October 1971 through Sept 1973, the Blitzen River provided 57 percent of the inflow, the Silvies River provided 20 percent, 17 percent came from direct precipitation, and 6 percent came from Sodhouse Springs (Hubbard 1975).

History

What is now Malheur National Wildlife Refuge had been settled for the purpose of raising cattle in 1872 by Peter French. Under Peter French, sections of what is now the present day refuge had been irrigated by digging canals and creating water diversions to better utilize the land for ranching purposes. Between 1907 and 1920, the Eastern Oregon Livestock Company intended to settle the Blitzen Valley. So, much of the Blitzen River was then channelized and wetlands were drained. The mid 1930s brought about much more manipulation of refuge lands by the Civilian Conservation Corps (CCC). The CCC dug canals, built dams, constructed dikes and levees, and added irrigation structures, which allow for increased control of the seasonal water flow. The changes in water management plans throughout the years has led to the placement of many more water control structures, culverts, river restoration structures, and invasive species control structures.

Significance of the Area

Malheur National Wildlife Refuge is a cornerstone in the Pacific Flyway serving as a transitional area for migrating birds and waterfowl as well as historically productive nesting grounds. The area's water-bird population is even more diverse, supporting one of the largest breeding colonies in Oregon, including the only breeding ground in Oregon for Franklin's Gulls (Littlefied

& Thompson 1981). Other breeding colonial nesting birds include: American White Pelican, double crested cormorant, great blue heron, great egret, snowy egret, cattle egret, black-crowned night heron, white-faced Ibis, Caspian tern, ring-billed gull, and California Gull(OR Joint Venture Report). Birds use the wetlands in the Closed Basin as stepping stones during Migration. Historically, Malheur Lake was utilized by up to 35% of the Pacific Flyway's Canvasback population, was the second most important redhead production site in the West, and its peak produced, over 100K ducklings annually(DOI/FWS Malheur's Aquatic Health Article). This community of wetlands meets the requisites of a wide variety of birds, providing food, rest and cover for nesting and migration. Conserving the quality and connectivity of wetlands in this region is very important to maintaining healthy populations of wetland birds (Haig et al. 1998). A major problem facing breeding waterfowl and other water-birds in the area is the scarcity of summer water, which reduces survival of young(OR Joint Venture). Wetland basins contain very diverse wetlands, which are very important production and migration areas for the Pacific Flyway waterfowl, shorebirds, and marsh and riparian birds (Cornely J. USFW 1982/ Waterfowl Production, 1942-1980). They also provide habitat for endemic fishes, amphibians, and other native fauna and flora (OR Joint Venture).

1.2 Malheur NWR Water Delivery System

The purpose of Malheur National Wildlife Refuge is to provide habitat to migrating waterfowl and colonial nesting bird habitat. The average annual precipitation is approximately nine inches per year making water a highly valuable resource. A period of flooding or high water in the spring is attributable to the snowpack on Steens Mountain melting as well as a higher frequency of seasonal precipitation. The summer and fall months are classified as dry with variable winds which is the cause of evaporation of the accumulated water in the internally drained Harney Basin.

Since the establishment of Malheur National Wildlife Refuge, much has been done to find a way to utilize the small amounts of water and find ways to manipulate the natural water movement in order to create suitable habitat for waterfowl and colonial nesting birds. In the refuge's one-hundred plus years of operation, there has been many changes to the water delivery system. Channels were dug and water control structures have been placed to slow, stop, or divert the water moving toward Malheur, Mud, and Harney Lakes. Water control infrastructure located on the refuge includes simple culverts, tide-gates, screw-gates, flash-board risers, and dams. Below is a map of the many locations of the water control structures on Malheur National Wildlife Refuge (***Insert Graphic***).

1.3 Presence of Carp

There are problems facing the refuge concerning invasive species. These problems are not strictly anomalous to Malheur National Wildlife Refuge. The constant influx of non-native species is an issue which concerns many areas throughout North America as well as on the global scale. These issues range from invasive plants such as pepper weed, reed canary grass,

buck-thorn, and the submergent types of vegetation including Eurasian Milfoil. There are also concerns with invasive fish populations such as the widely known species of Carp including Silver Carp, Common Carp, and Bighead Carp.

Common Carp, first imported to the U.S. from Germany in 1877 and was distributed to most states from 1889 to 1897 by the U.S. Bureau of Fisheries (Ivey et al. 1998). Carp, first introduced into the Silves River in the 1920s, were not apparent in Malheur Lake until the early 1950s. Apparently, large numbers of adult carp had been flushed into the lake during high water in 1952 (USFW 1957). In the 1950s, the refuge began to document the presence of carp in their waters. Since then, carp have invaded the majority of the refuge, from Double-O Ranch, Bridge Creek, most of the Blitzen River, and the biomass has become established in Malheur Lake to the point to which they have outcompeted most other types of fauna.

1.4 Thesis Overview

Chapter two of this document includes information on the common carp (Cyprinus carpio) in three segments. The segments will cover the general biology of the common carp, their capability of being "Invasive Engineers", as well as the recorded impacts manifested by the introduction of common carp to the waters of Malheur National Wildlife Refuge.

Within the literature review, habitats types found throughout the refuge is discussed in depth including the general concepts of the flooding stages and the impacts and importance of flooding for providing habitat to waterfowl and colonial nesting birds. The data used in this document pertaining to habitat will be included in this section as well as mentioned in chapter 3.1.1.

Section four of chapter two will discuss the applications of geographic information systems (GIS) in the management of invasive species. This section will address the national and local efforts in mitigating invasive species as well as discuss some applied studies using geographic information systems (GIS) as a tool for combating the increasing influx of invasive species to new areas.

Chapter 3 will specifically address the data and processes used in this analysis. This will be in three sections including coverage on the data used and collection processes, habitat suitability methodology, and the data processing.

Literature Review

2.1 Invasive Species Background

The US Department of Agriculture's National Invasive Species Information Center provides a definition of Invasive Species as it is defined in Executive Order 13112 (1999): "A non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause environmental harm or harm to human health."

Invasive species can be plants, animals, and other organisms (e.g., microbes). Human actions are the primary means of invasive species introductions. For the use of this document, the definitions for invasive plants and invasive animals will be congruent with the working definition in Executive order 13112.

Invasive Plants: Invasive plants are introduced species that can thrive in areas beyond their natural range of dispersal. These plants are characteristically adaptable, aggressive, and have a high reproductive capacity. Their vigor combined with a lack of natural enemies often leads to outbreak populations (National Invasive Species Council (2010).

Aquatic Species: Aquatic Species includes both aquatic plant and aquatic animal species. Invasive aquatic plants are introduced plants that have adapted to living in, on, or next to water, and that can grow either submerged or partially submerged in water. Invasive aquatic animals require a watery habitat, but do not necessarily have to live entirely in water (National Invasive Species Council).

Invasive Animals: Invasive animals are introduced multicellular organisms of the kingdom Animalia, such as mammals, birds, reptiles, and insects (National Invasive Species Council).

The state of Oregon has 262 Noxious Weeds listed by the National Invasive Species Council from Common Ragweed (*Anbrodia artemisiifolia*) to Perennial Pepperweed (*Lepidium latifolium*). Invasive species are but not limited to a terrestrial habitat. According to the United States Geological Survey's Non-Indigenous Aquatic Species Program, Oregon is the home to around 227 non-indigenous aquatic species. These species range from the Common Carp (*Cyprinus carpio*) to the New Zealand Mud-snail (*Potamopyrgus antipodarum)*.

Non-Indigenous Species ranked second only to habitat loss in the agent that threatens biodiversity, however the geographic distribution of these species is poorly understood (NASA/USGS, 2002). The potential for species distribution is very high when the human element is added to the equation. There are many different mechanisms for invasive species to be introduced into new areas. These methods can include but are not limited to shipping, stocking, "hitch-hiking", pet release, aquaculture, or general dispersal by natural mechanisms such as flooding. According to the USGS Non-Indigenous Aquatic Species Program(2009), the number one mode of introduction to the state of Oregon is through shipping and fish are the number one group which has been introduced into Oregon. The impact of these invasive species costs the United States approximately $120 billion dollars a year (Juliet Eilperin, 2010).

2.1.2 Malheur National Wildlife Refuge Planning and Management

Open water within the refuge is largely void of aquatic vegetation, such as sago pondweed (P. pectinatus), due to increased turbidity caused by high densities of common carp. Due to the relatively long lifespan and high fecund of common carp, it may be only possible to remove common carp from small portions of the refuge.

Goal & Evaluating Success

The primary goal of the Harney Basin common carp management plan is to restore Malheur Lake by reducing common carp biomass and improving water quality. The level of carp biomass necessary to restore Malheur Lake to a stable macrophyte dominated state is unknown but for the purpose of planning we will use the theoretical value of <100 kg/ha (Bajer, Sullivan et al. 2009). A timeline for meeting milestones is not practical considering that the project is largely unfunded. Instead, evaluations of success will be constructed after the initial removal phase is complete via estimated biomass reduction (<100 kg/ha) and at least a 2.5x improvement in Secchi depth compared to pretreatment yearly averages based on averaged monthly Secchi depths.

The goal of the current plan will vary from previous management plans by including the entire Harney Basin and acknowledging that complete eradication is not practical therefore requiring annual removal. The refuge's mandate is to provide habitat for colonial nesting birds and migratory birds and one of the greatest threats to the productivity of Malheur National Wildlife Refuge is the invasive common carp.

Table 1: MNWR Priority Management Units

Priority Level	**Unit**
1	Malheur Lake
2	Blitzen River Valley
3	Silves River
4	Double O Ranch

The most ecologically important portion of the basin impacted by carp is Malheur Lake and funding should be based on connectivity and potential impacts to water quality within the lake. The above prioritization follows this premise.

In addition to water quality measures, monitoring of macrophyte coverage (total ha in Malheur Lake) would be a useful indicator of recovery. The extreme variability and complexity of the common carp habitat within Harney Basin will require intensive knowledge of habitat use to make informed decisions on harvest rates. It is likely that during periods of abundant habitat (high lake levels) common carp will move very little. When habitat is reduced and common carp densities are high, fish are likely to migrate to other areas in search of resources.

Creating a dynamic model based on estimated carp immigration, emigration, growth and recruitment (population structure and habitat use data) would be a powerful tool for the management of carp in the Harney Basin. There is a need for improvement in the infrastructure. The Blitzen Valley water delivery system is likely a detriment to the overall health of the Malheur National Wildlife Refuge as it is currently operated. The system blocks access to spawning sites to native fish, provides excellent foraging habitat to carp, likely

provides rearing habitat for carp and is of limited value to wildlife due to degraded infrastructure and common carp damage.

2. Common Carp (Cyprinus carpio)

2.2.1 General Information

Common Carp, scientific name Cyprinus Carpio, belongs to the family Cyprinidae. It can be identified by the two pairs of barbells on each side of the upper jaw. Common Carp is one of the largest members of the minnow family. They can range from 1-10+ pounds and anywhere from 12-25+ inches in length. Common Carp are distributed throughout the world and can be found from central Canada to central Mexico on the North American Continent. Common Carp is known as one of the most widely dispersed fish in North America. Carp can tolerate a variety of environmental conditions and habitat types which has allowed them to invade such a large geographical area. The Common Carp is a warm water species and flourishes in muddy, eutrophic waters. Known to live in channeled environments, such as rivers and streams, Common Carp are also very well suited to flourish in a shallow lake environment which makes Malheur National Wildlife Refuge an ideal location for carp due to the presence and abundance of this habitat type.

Figure 1: Common Carp (*USGS Non-Indingenous Aquatic Species. http://nas.er.usgs.gov/queries/factsheet.aspx?speciesID=4)*

Regions of North America and Australia that suffer from a superabundance of carp are characterized by large, spatially connected aquatic habitats, and environmental instability, which severely influences ecological integrity of their shallow basins. Common carp (Cyprinus carpio), native to the Ponto-Caspian region (Balon 1995), is well established throughout Europe, North America, South America, Australia, and Africa (Lever 1996).

2.2.2 Impacts and Studies of Common Carp (Cyprinus carpio)

Many studies have shown the negative impact carp have on their surroundings. Many of which are relevant to this document due to the similarity to Malheur Lake and its surrounding areas. The first study is located in Utah Lake. Utah Lake is a large (388 km2) and shallow with an average depth of 2.9 meters and a maximum depth of 4.2 meters. It is slightly saline, highly eutrophic and turbid with a secchi depth of 12 cm. Maps and species lists from the early 1800s confirm that the lake was once covered widely with many different emergent and submergernt macrophyte taxa [(Brotherson, 1981; National Archives Marcofilm Publications (RG48: Utah, 1850-1902'M428, six rolls')]. This study was done using two experimental procedures. In the first procedure, cages were used in which carp from the lake were placed to identify their

impact on the surroundings. The second study also used a cage design but was used to keep carp out.

In the small cage experiment, carp significantly affected species composition, abundance, and diversity of macrophytes relative to the controls. Both the total macrophyte biomass and species diversity were significantly lower when carp were present. Both macrophyte taxa C. demersum and S. validus had significantly decreased whereas P. pectinatus was unaffected by carp. The total benthic macro invertebrate diversity decreased by 67% in the presence of carp relative to the controls.

The small-scale cage experiment showed that continuous presence of carp directly affected plant species composition and abundances and indirectly affected macro invertebrate community composition. The results from both experiments demonstrated that carp negatively affect macrophyte species but whether because of direct or indirect effects of carp remains uncertain.

The second example is Lake Kasumigaura, it can be categorized as a shallow eutrophic lake with a relatively large surface area, much like Malheur Lake. Several experimental ponds are connected to the lake by small-channelized canals. The experiment site is in the central pond where sediment from Lake Kasumiguara has been spread thinly on the bottom of the pond, including seeds from the seed bank. Twenty-one enclosures were used in the central pond to reduce wind and wave action.

Enclosures containing no carp or crayfish served as the controls. For carp and crayfish enclosures, large (carp) and small(crayfish) plastic pipes were added as shelters to prevent cannibalism and intraspecific interactions. Carp enclosures were stocked with one, two, or three individuals of juvenile fish per enclosure.

The data collected includes water samples to determine levels of suspended solid, chlorophyll, total nitrogen, and total phosphorus concentrations. Zooplankton were collected from each enclosure and identified to the lowest possible taxonomic unit using an optical microscope. Benthic macro invertebrates were collected using a cylindrical PVC sampler (50mm diameter). Six core samples were taken from each enclosure on each sampling date. At the end of the experiment, we attempted to collect all of the submergent macrophytes form each enclosure. The plant samples were dried to determine the total submergent biomass. Also collected was the top 10mm layer of the sediment from each enclosure to determine percent organic matter as the measure of the biomass of the benthic algae and detritus.

In the control treatment, submergent macrophytes germinated from the seed bank and plants had established by the final sampling date. Both carp and crayfish had negative impacts on the seedling emergence and establishment of submerged macrophytes; the biomass of submergent macrophytes decreased with the increasing animal biomass. Suspended solids increased significantly with increasing animal biomass in both the carp and crayfish treatments. Carp reduced the concentrations of total phosphorus and chlorophyll but the relationships between carp biomass and the response variables varied. When all carp biomass treatments were

pooled, total nitrogen concentrations were significantly higher in the carp treatments than in the controls. Carp but not crayfish had significant impacts on zooplankton. Rotifers and copepods were significantly more numerous with an increasing carp biomass. Carp and crayfish significantly influenced benthic macro invertebrates. Both carp and crayfish reduced Chirominae but biomass-dependent relationships were different between the two species. When carp treatments were pooled, the percentage of sediment organic matter in the carp treatments was significantly higher than that in the controls.

Many studies have shown that carp can directly reduce the biomass of submergent macrophytes through feeding (Sidorkewicj et al. 1996) and uprooting (Crivelli 1983; Sidorkewicj et al. 1996) and indirectly reduce it through bioturbation and excretion (Lougheed et al. 1998; Williams et al. 2002; Parkoset al. 2003; Matsuzaki et al. 2007). Carp likely modified the water quality and increased phytoplankton biomass through excretion because benthivorous fish feed on benthic organic matter and release a portion of the consumed nutrients via excretion (Schaus & Vanni 2000). Driver et al. (2005) demonstrated that small carp with high mass-specific excretion rates tended to influence turbidity and phytoplankton biomass through excretion rather than bioturbation. Invasive ecosystem engineers not only modify or destroy the habitats of other species, but they also alter the flow of nutrients, physical resource or energy, and thereby change the character of the invaded systems (Crooks 2002; Carlsson et al. 2004; Byers et al. 2006).

2.2.3 Carp Affects on Malheur National Wildlife Refuge

Malheur National Wildlife Refuge is the largest wildlife refuge managed as a waterfowl production and migration habitat in the west. The refuge is the most important waterfowl production area in Oregon and is among the major migratory bird production sites in the Pacific Flyway. Malheur lake is the most prominent feature on Malheur National Wildlife refuge and has been important to migratory birds since prehistoric times. Historically the lake was famous for dense stands of sago pondweed (P. pectinatus) and other submergent plants (USFWS 1957). Sago pondweed is the preferred food for the canvasback and other waterfowl. Carp were introduced into the Silvies River in the 1920's but were not apparent in Malheur Lake until the early 1950's. It is believed that large amounts of adult carp were flushed into the lake by high water flows in 1952 (USFW 1957). Refuge biologists noted concerns about the large numbers of carp which apparently caused an 80% decline in sago pondweed (P. pectinatus) between 1953 and 1954. By 1955, no sago pondweed was evident in the lake and carp were abundant. This led to the U.S. Fish and Wildlife Service to undertake a major carp control project in the Malheur Lake drainage in 1955 (USFW 1957).

Carp control methods began in 1955 and continue today. Rotenone treatments were the primary means of carp eradication in the early stages of carp management (USFW 1998). This method was costly and indiscriminant. It killed many carp but failed to completely remove them from the water delivery system of Malheur National Wildlife Refuge.

Table 2: Historical Rotenone Treatments

Rotenone Treatments (Year)	Carp Killed
1955	~ 1.5 Million
1959	58,000
1960	400,000
1961	150,000
1968	240,000
1969	No Record
1977	50,000+
1992	100,000
Total: 8 Treatments	~2.5 Million Total Removed

Due to the presence of carp in Malheur National Wildlife Refuge wetlands, the refuge's potential for waterfowl production and maintenance has been lowered to about 25% or its historical capability: >101,00 ducks in the 1940's & <38,000 ducks in the 1950's. Although carp control projects failed to eliminate carp from Malheur National Wildlife Refuge, they successfully enhanced habitat for waterfowl for a few years or until the carp population rebounded. Sago pondweed (P. pectinatus) acreage in Malheur Lake increased substantially after each major carp control project. In both 1955 and 1992, no sago pondweed was found in Malheur Lake, compared with an estimated 16,900 and 10,000 acres, respectively, in the years following the carp control projects. Other increases were documented after the other major carp control projects. Diving duck use also increased from 50-70 percent following carp control projects (Ivey, 1998).

2.3 Habitats & Environments

2.3.1 Habitat Types

The habitat types to be analyzed will be aggregated into two categories: suitable spawning habitat for carp, and non-suitable spawning habitat for carp. The habitat data is a product of research done using data from Landsat 7 and ground data validation done by Nick Wilson in the summer of 2010.

The major suitable areas for the common carp during high water times include moist/wet meadow, hemi-marsh, emergent marsh, water, and riverine. Each of these habitat types will have a weighted value in the Habitat Suitability model which will be discussed in Chapter 3.3.1.

The common carp (Cyprinus carpio), are opportunistic feeders but feed predominately in the benthic zone of the aquatic environment. The term benthic refers to anything associated with or occurring on the bottom of a body of water. Benthic habitats are defined as bottom environments with distinct physical, geochemical, and biological characteristics. Benthic habitats vary widely depending upon their locations and depth, and dominant structural features and biological communities often characterize them (NOAA Coastal Services Center, 2010). The significance of the benthic zone within the confines of this analysis is that the fluctuation of water levels in each of the management fields to provide optimal habitat for the focal species of the refuge. The fluctuating water levels create a seasonal benthic zone which may be invaded by the common carp during the high water stages of the year depending on the water management plan.

The U.S. Fish and Wildlife Service Biologists have determined an accurate assessment of the various habitat types found at Malheur National Wildlife Refuge.

Biological Integrity, Diversity, and Environmental Health (BIDEH) for Malheur National Wildlife Refuge (U.S. Fish and Wildlife Service *Cite Appropriately).*

Habitat Type: Malheur Lake

Characteristics of the Community

(structure, seral stage, species composition, age class)
Malheur Lake fluctuates greatly in size from a minimum pool of 500 acres (completely dry in 1934) to approximately 180,000 acres (mid 1980s).
Historically, a chemical and physical gradient could be observed from west (Mud Lake and directly east of Hwy 205) to east. The far west side consisted of a complex network of ponds, islands, and peninsulas. The center of the lake was dominated by emergent (e.g., hardstem bulrush) marshes and interspersed open water areas. The eastern side is highly alkaline and contains large areas of open water.
Common emergent species included hardstem bulrush, cattail, burreed, Baltic rush, and various sedges. Open water with submergent plants including water milfoil, sago pondweed, horned pondweed, coontail, small and leafy pondweed, white water buttercup, bladderwort, and widgeongrass.
Soil surveys indicate that emergent vegetation responded to existing water levels and did not persist in specific areas with the exception of river inlets and significant spring sources.

Natural Processes Responsible For These Conditions
Inflow sources include the Blitzen and Silvies rivers and Sodhouse Spring. River flows are predominantly influenced by snow pack on Steens Mountain and Malheur Forest.
Shallow water levels, annual and seasonal fluctuations in water depth, and a mosaic of permanent and cyclical water levels.
The prevailing chemical gradient and variable water depths determined the composition of plant communities throughout the lake.

Ice movement/scouring following flood events impact topography and reduce the presence and cover of emergent vegetation.

Limiting Factors
Common carp (introduced to the system in the early 1900s) has decimated the productivity of this marsh/lake system. They root up submergent vegetation and dramatically increase turbidity.
Hydrological inputs to the lake, particularly from the Silvies River, have been reduced by upstream flood irrigation practices.
Climate change may further alter the amount of water that flows into this lake system from the Blitzen and Silvies Rivers.

Habitat Type: Playa

Characteristics of the Community
(structure, seral stage, species composition, age class)
Virtually no vascular plants reside within Harney and Stinking Lakes with the exception of spring areas where steady freshwater inflows modify water chemistry.

High water events provide temporary opportunities for aquatic plants and animals (i.e. sago pondweed and tui chub) to increase.
These systems are rich in invertebrates such as brine flies and brine shrimp.

Natural Processes Responsible For These Conditions
Evaporation of closed basin water results in high levels of alkalinity and associated pH.
Dilution during high water events stimulates temporary production of aquatic species.
Soils are typically very deep and poorly drained and were formed in volcanic lacustrine deposits. Texture commonly consists of silty clay loam and is strongly alkaline (10.5), with pH dropping to 8.0 at approximately 50 inches in depth.

Limiting Factors
Evaporation of closed basin water results in high levels of alkalinity and associated pH.
Dilution during high water events stimulates temporary production of aquatic species.
Soils are typically very deep and poorly drained and were formed in volcanic lacustrine deposits. Texture commonly consists of silty clay loam and is strongly alkaline (10.5), with pH dropping to 8.0 at approximately 50 inches in depth.

Habitat Type: Palustrine Open Water

Characteristics of the Community
(structure, seral stage, species composition, age class)

These open water habitats are semi-permanently flooded at depths that preclude the development of extensive stands of emergent vegetation.

Submerged and floating plants such as common and greater duckweed; Canadian waterweed; coontail; water milfoil; common bladderwort; white water crowfoot; and sago, longleaf, and small pondweed regularly occur in open water. Emergent plants (e.g., bulrushes, cattails, sedges, rushes, spikerushes) occupy shallow areas within and alongside of open water communities.

Natural Processes Responsible For These Conditions
With the exception of small natural depressions next to springs (i.e. Double O Spring), this community type has been maintained through active and intensive management (the creation of diversion dams and supporting infrastructure (dikes, ditches, etc.).
Occasional drawdowns (drought) oxidize and consolidate substrates to facilitate the germination of submergent vegetation such as sago pondweed. When pond and lake bottoms are exposed, production of smartweed and th dibl

Limiting Factors
Aging infrastructure and management of vegetation within water delivery systems pose challenges in ensuring ready and consistent water availability.
Invasive species such as carp and reed canary grass.
Historic ditches and canals and the removal of beaver have altered hydrology.

Habitat Type: Dune

Characteristics of the Community
(structure, seral stage, species composition, age class)
Open sand dunes host widely-spaced shrubs, grasses, and forbs located adjacent to playa basins.
Shrubs include shortspine horsebrush, fourwing saltbush, bud sagebrush, green and gray rabbitbrush, and Basin big sagebrush. Grasses include Indian ricegrass, needle-and-thread, bottlebrush squirreltail, and alkali sacaton. Forbs include tufted evening primrose, Paiute suncup, Geyer's milkvetch, sharpleaf penstemon, and various lupines.

Natural Processes Responsible For These Conditions
These landforms and associated plant communities are created by wind erosion off nearby dry playa bottoms (i.e. Stinking Lake and Harney Lake).
As sites deteriorate (loss of vegetative cover and increased wind erosion), a shift toward black greasewood and inland saltgrass is possible.
Soils are formed by lacustrine sands and are neutral to moderately alkaline (8.2). They are moist in the winter and spring and are usually dry June through October.
Low available water capacity on or near the soil surface limits the survival of seedlings.
Drought-prone

Limiting Factors
Susceptible to invasion by halogeton, povertyweed, and Russian thistle
Agricultural practices have altered plant community composition and succession in many dune areas by influencing competition between plant species and community succession.

Habitat Type: Marsh

Characteristics of the Community
(structure, seral stage, species composition, age class)
This habitat type commonly exists within mosaics of wet meadow and open water. Stand density varies greatly and has a maximum height of approximately three meters.
Common emergent plant species include burreeds, bulrushes, cattails, sedges, rushes, and spikerushes. Submergent plants such as pondweeds, bladderworts, waterweeds, and duckweeds occur in nearby open water. Willow species can occur along elevated ecotones along marsh perimeters.

Natural Processes Responsible For These Conditions
Emergent vegetation can typically tolerate fluctuations in water availability, ranging from approximately one meter above to 10-12 cm (4-5 inches) below the soil surface. Extended periods of standing water aid in preventing the transitions to mesophytic plant communities.
Emergent marshes existed throughout the lower Blitzen and became less extensive north of Buena Vista.
Associated with very deep, very poorly drained soils that formed in alluvium, alluvium over lacustrine deposits derived from igneous rock, or organic matter. These soils are located on low stream terraces and their depressions as well as lake basins.
The natural hydroperiod for most marsh communities likely existed from spring through mid-summer.

Limiting Factors
The current maintenance of existing emergent communities is artificial, requiring extensive infrastructure and active water diversion from the Blitzen River, its tributaries, and springs. All water delivery in the Double O, including Silver Creek flows, is highly manipulated.
Increased densities of emergent vegetation reduce edge habitat for wildlife and decrease the diversity of this community type.
Historic livestock grazing and haying practices favored the establishment of meadows. Altered hydrology via river channelization and the creation of irrigation ditches created conditions that favored the establishment and maintenance of vast meadow habitats hosting introduced forage species.

Habitat Type: Riparian

Characteristics of the Community
(structure, seral stage, species composition, age class)

The refuge hosts a variety of riparian systems, ranging from those associated with the Blitzen River itself to various tributaries that flow into it from neighboring valleys and canyons on the northern side of Steens Mountain.
Although many plant associations are found within this broader community, the principle woody riparian species include various species of willow, red-osier dogwood, Wood's rose,

golden currant, common snowberry, Lewis' mock orange, water birch, and alder. Herbaceous groundcover is characterized by Nebraska sedge, yellow monkey-flower, Northwest cinquefoil, American speedwell, wooly sedge, slender-beaked sedge, meadow barley, tufted hairgrass, western yarrow, and Baltic rush.

Natural Processes Responsible For These Conditions
Streambank soils consist of gravel and cobble due to flooding disturbance, alluvial bars, and very little soil development.
Within the active floodplain, the soils are deep and consist of pluvial deposits on alluvium.

Limiting Factors
Reed canarygrass, hemlock, perennial pepperweed, and other invasives are able to outcompete native vegetation following most disturbances.
River channelization
Historic livestock grazing
Lowered groundwater table
Infrastructure (ditches, dams, roads)
Water quality impairments
Altered hydrology and minimum flows
Broad scale loss of functional connectivity between rivers and streams and their floodplains
Most floodplains no longer functionally active as a result of altered hydrology, from ditching, diversions, and dams along river.

Habitat Type: Riverine

Characteristics of the Community
(Structure, seral stage, species composition, age class)
The hydrologic floodplains are intact with balanced pool/riffle/glide ratios depending on slope and substrate. Water turbidity is typically low with an appropriate level of sediment storage which buffers against the sediment loading of critical rearing pools and spawning gravels for native fishes.
Boulders, undercut banks, logs, and vegetation provide ample hiding cover for native fishes and other aquatic species. Eddies and other slow current areas contain abundant populations of various aquatic invertebrates.
Low turbidity also allows a variety of native aquatic vegetation to establish and propagate in suitable micro niches.

Natural Processes Responsible For These Conditions
Streams such as Bridge and Mud had 1-4% gradients and were dominated by boulders, cobbles, and gravel. The Blitzen River had a low gradient (<1%) and was dominated by gravel and silt substrates. Sediment discharge and particle size as well as stream flow and slope were in balance.
Balance between sinuosity and percent slope maintained the physiological integrity of the channel by reducing velocity while intact floodplains disperse energy.

Limiting Factors
Common carp
A loss of riparian plant diversity due to past management and competition with invasive plant species.
Channelization of the Blitzen River has compromised in-stream habitat and the system's ability to disperse energy during high flow events.
Incised channel.
Most floodplains no longer functionally active as a result of altered hydrology, from ditching, diversions, and dams along river.

Habitat Type: Wet Meadow

Characteristics of the Community
(structure, seral stage, species composition, age class)
Wet meadows typically occupy the transition zone between marsh and moist meadow plant communities.
Native vegetation includes Baltic rush, woolly, Nebraska, and slender-beaked sedge, arrowgrass, meadow barley, tufted hairgrass, Nevada bluegrass, western yarrow, slender cinquefoil, large-leaf avens, Oregon checker mallow, and fringed willow-herb.

Natural Processes Responsible For These Conditions
Surface water is generally present during the growing season (at least 2 months). Only isolated depressions or sloughs hold water into the early fall.
Soils are derived from alluvium and are very deep and poorly drained (pH of 6.6-7.0).

Limiting Factors
Introduced species such as Kentucky bluegrass and common timothy have become become "naturalized" within these communities, but offer habitat structure similar to many native species.
Invasive species such as reed canarygrass (an introduced cultivar), phragmites, and perennial pepperweed displaced native species.
Cattail appear to encroach areas that are inundated for periods greater than two months.
Altered hydrology through river channelization and ditching has largely compromised its natural occurrence.
The extent of wet meadow areas dominated by introduced forage species has increased following settlement.

Habitat Type: Moist Meadow

Characteristics of the Community
(structure, seral stage, species composition, age class)
Moist meadows typically occupy the transition zone between wet meadow and upland plant communities.

Dominant native grass species include creeping wildrye, Oregon bentgrass, shortawn foxtail, American sloughgrass, bluejoint, and tufted hairgrass. Native forbs include slender cinquefoil, western yarrow, and lanceleaf goldenweed.

Natural Processes Responsible For These Conditions
Soils are similar to those of wet meadow communities, but are generally located in slightly elevated areas with increased aerobic conditions during the growing season.
Naturally inundated with shallow water from early spring to early summer.
Variable topography with pockets of deeper water.

Limiting Factors
Smooth brome, redtop, creeping bentgrass, orchardgrass, meadow foxtail, and other non-native grasses were introduced during the early 20th century to enhance forage production in meadows. As a result, little or no native grasses . Native forb understory has been greatly decreased through increased irrigation, competition with cultivars, and invasive species competition, and noxious weed treatment.
These communities are highly susceptible to invasion by perennial pepperweed.
Due to the introduction of irrigation infrastructure and the leveling of some meadows in the early 20th century, the extent of this community has likely been reduced.

Habitat Type: Alkali Flat

Characteristics of the Community
(structure, seral stage, species composition, age class)
This plant community resides in barren alkali flats or alkaline valley bottomlands. It consists of widely spaced shrubs with dense patches of rhizomatous grasses with low densities of other annual and perennial grasses and succulent forbs.
Plant species include black greasewood, inland saltgrass, alkali sacaton, alkali cordgrass, and alkali bluegrass. Mat muhly and Sandberg's bluegrass may be present in mosaics which exhibit more moderate conditions (lower pH.).

Natural Processes Responsible For These Conditions
Infrequent inundation of outer playa areas or wind erosion from these playas distributes salts to nearby low-lying areas, causing elevations in alkalinity and pH which favor this community association.

Limiting Factors

Heavy livestock grazing may compromise plant species diversity in more moderate areas within this plant community type.

Habitat Type: Basin Big Sagebrush Island

Characteristics of the Community

(structure, seral stage, species composition, age class)
Commonly found in swales, toeslopes, the base of alluvial fans, and adjacent to moist meadow communities within the Blitzen Valley.
Native plant species include native shrubs (e.g., basin big sagebrush, rabbitbrush, bitterbrush, and horsebrush) interspersed with bunchgrasses such as basin wildrye, needle-and-thread, Indian ricegrass,
These sites are typically forb-poor.

Natural Processes Responsible For These Conditions
Sites are moist or wet in the spring and dry by mid summer.
Associated species are fairly tolerant of high soil sodium content and alkalinity.
Soils are generally deep and have moderate water holding capacity (sandy loams).

Limiting Factors
Susceptible to invasive plants such as cheatgrass and perennial pepperweed invasion.
Historic livestock grazing decreased plant species diversity in many of these areas.

Habitat Type: Sagebrush Steppe

Characteristics of the Community
(structure, seral stage, species composition, age class)
This community is dominated by shrubs with an understory of various bunchgrass and forb species found within interspaces. It can be found above greasewood/ basin big sagebrush communities on various aspects, slopes, and soil types.
Plant species include Wyoming and low sagebrushes, bluebunch wheatgrass, Sandberg's bluegrass, bottlebrush squirreltail, Idaho fescue, needle-and-thread, Thurber's needlegrass, western yarrow, arrowleaf balsamroot, and various locoweed and phlox species.

Natural Processes Responsible For These Conditions
A gradient in soil depth determines whether Wyoming big sagebrush or low sagebrush dominates a site. Low sagebrush sites typically host higher densities of forbs due to higher concentrations of available soil moisture due to shallow, rocky conditions.
These communities depend on natural fire cycles or equivalent disturbance to maintain a balance between shrub, grass, and forb components. A lack of disturbance lends itself to high shrub densities with sparse vegetation in the interspaces.

Limiting Factors
Invasive plants (especially cheatgrass) has compromised many sites from recovering naturally from wildfire.
Livestock grazing
Juniper encroachment from historic fire suppression greatly reduced native shrub densities and increased soil erosion.
Medusahead infests clay sites and is capable of outcompeting native grasses and forbs in the understory.
Much of this habitat is composed of crested wheatgrass monocultures after wildfires.

2.3.2 Spawning Habitat

Research suggests that the success of the common carp is attributable to their longevity, mobility, and propensity to exploit peripheral unstable areas as spawning/nursery habitat. The significance of this life-history strategy and its dependence upon environmental instability was exemplified by aging analysis strongly suggesting that cap reproduced successfully only in outlying habitats that experienced recent, severe winter hypoxia. Carp may maximize their reproductive success by exploiting severely disturbed peripheral habitats because such areas likely have reduced densities of native egg and/or larval predators (Bajer and Sorenson, 2008).

Fundamental similarities in the biology of carp in their native habitats, Austarlia, and the Midwest allow us to suggest a more general hypothesis to explain carp abundance in these locations. In all those regions, carp have been shown to reproduce in outlying habitats subject to environmental instability. While in Minnesota, carp appear to reproduce successfully in lakes that experience winter hypoxia, in Australia and the Caspian region, carp use periodically inundated floodplain habitats as spawning sites and nurseries (Kobllitskaya 1977; Balon 1995); King et al. 2003; Stuart and Jones 2006). These freshly inundated floodplains might also be expected to have very low densities of egg and larval predators due to their rapidly expanding areas and shallow depth. Anecdotal reports describe sexually active carp moving into shallow outlying areas in the spring (Swee and McCrimmon 1966). The reproductive success of carp is linked with its strong migratory drive to gain access to the outlying shallow spawning habitats. Radiotelemetry showed that adult carp aggressively moved into spawning habitats each spring, and that most of them returned late each summer of fall (Bajer and Sorneson, 2008).

Spring aggregations of adult carp were observed in association with spawning. Adults exhibited the greatest mobility during this period, and some individuals moved up to 6.5 km between consecutive tracking days. Results support previous reports that shallow areas with abundant macrophytes or inundated areas of terrestrial vegetation (e.g., marshes, wetlands, and floodplains) are the preferred spawning habitat of common carp (Swee and McCrimmon 1966; Lougheed et al. 1998; Stuart and Jones 2006). Common carp exhibited selection for shallow, vegetated habitats during all seasons and showed a clear attraction to adjacent Ventura Marsh before the spawning period (Penne, 2008).

2.3.3 Flooding Concepts and Roles

The use of inundated floodplain for fish recruitment is likely to be influenced by a number of interrelated factors, such as the degree of coupling of high flows and temperature, the predictability of the flood pulse, the rate of rise and fall of the hydrograph, duration of the inundation period, and the amount of the inundated floodplain. Generally, fish spawn during the warmest months of the year, partly because of increase growth rates when temperatures are high and partly, at least in temperate systems, because this is also the period of maximum production of food for larvae and juveniles (Jobling 1995). In temperate systems, the timing of spawning is more likely to be controlled by temperatures and light regimes than flooding cycles. The flood pulse concept emphasizes on the importance of a coupled rise in flow and

temperature in maximizing the use of the floodplain for fish recruitment as it provides the best conditions for spawning and successful rearing of their larvae (Junk et al. 1989). A slow to moderate increase in water level is likely to produce stronger year classes, as fish are thought to respond to the increased production of vegetation and associated food and habitat as the moving littoral zone traverses the floodplain (Junk et al. 1989; Bayley 1991). The length of time that flood waters remain on the floodplain can also dictate the strength of biotic responses to the flood (Boulton and Lloyd 1992; Poff et al. 1997). Several weeks to several months is considered the optimum period of floodplain inundation that is required for fish to spawn and larvae to hatch and then feed and develop into juveniles.

In a reproduction analysis done in the Ovens River system, the only species to receive a "high" likelihood of using the inundated floodplain for recruitment was the common carp. Common carp have a number of life history characteristics that allow them to take advantage of unpredictable flood conditions. Importantly, however, common carp are known to both spawn and recruit in the main channel of floodplain rivers when flows are well within the banks (King 2002; Humphries et al. 2002).

Flood Pulse Concept

The effect of the flood pulse on biota is principally hydrological. If no organic material except living animals were exchanged between floodplain and channel, no qualitative and, at most, limited quantitative changes would occur in the floodplain (Bayley 1989).

Floodplains are defined as areas that are periodically inundated by the lateral overflow of rivers or lakes, and/or by direct precipitation or groundwater; the resulting physiochemical environment causes the biota to respond by morphological, anatomical, physiological, phonological, and/or ethological adaptations, and produce characteristic community structures (Junk et al. 1989). This ecological definition recognizes that flooding causes a perceptible impact on biota and that biota display a defined reaction to flooding. The floodplain area, also termed the "aquatic/terrestrial transition zone" because it alternates between aquatic and terrestrial environments, is the inshore edge of the aquatic environment that traverses the floodplain we have termed the "moving littoral (Junk et al. 1989)."

Most vertebrates use the main channel temporarily as migration routes, for spawning, as refuge during droughts or freeze-up, or for hibernation. Life cycles of biota utilizing floodplain habitats are related to the flood pulse in terms of its annual timing, duration, and the rate of rise and fall. Timing is important in temperate rivers where seasonal temperature and light cycles also regulate productivity. The predictability of the flood pulse is important because it favors the utilization of the floodplain by terrestrial and aquatic biota. Spawning of many species occurs at the beginning or during some period of the rising flood, resulting in timely colonization of the floodplains for feeding and shelter (Bayley 1983, 1988; Holland et al. 1983; Welcomme 1985). Conversely, when the water recedes, fish find refuge in the main channels, in residual floodplain water bodies, or in permanent tributaries (Welcomme 1979).

National & Refuge Initiatives

The presence of invasive species has been a large part of history. There are species throughout the United States which have been here as long as the first European settlers came to shore. Some invasive species have a greater impact on the ecology than others but one thing is certain, they threaten biodiversity in many ways. In the global economy we live in it can be understood that globalization has only increased the threat of invasive species. "The direct cost to the American economy alone is estimated at $100-200 billion per year, greater than all natural disasters combined." The cost of infestations of leafy spurge alone to agriculture producers and taxpayers is $144 million a year in the Dakotas, Montana, and Wyoming. Aggressive invasive fishes in the Great Lakes threaten a commercial fishery valued at $4.5 billion that supports 81,000 jobs. The US Federal Govt. has mounted an organized effort to address the invasive species threat, coalescing around Executive Order 13112 (1999). The National Biological Information Infrastructure has several regional programs developing invasive species information systems.

NIFSF efforts recognize the central role of NASA's space-based sensors and advanced computational, modeling, and information technologies in addressing invasive species science and policy on a national and global scale.

A wide range of existing and emerging NASA Earth Science Enterprise technologies will be central to a better understanding of invasive species risks. NASA's Office of Earth Science and the USGS are developing a National Invasive Species Forecasting System for the management and control of invasive species on all DOI and adjacent lands.

High-resolution mapping of biological resources is central to confronting the invasive species threat.

> "We must be able to identify dominant plants and veg. structures with a reasonable ability to distinguish between species."

The USGS uses geostatistical methods, many derived from NASA's Earth Science Enterprise support, to integrate satellite, airborne, and ground data into predictive models that account for both large- and small-scale variability in landscape structure and biological resources. National Invasive Species Council has noted, "no comprehensive national system is in place for detecting and responding to incipient invasions." The potential for movements of invasive species and susceptibility of sensitive habitats to new invasive species are known to be strongly influenced by climate warming and by changes in rainfall, soil moisture, and runoff, and are increasingly driven by extreme events.

2.4 GIS Applications Involving Invasive Species

Geographic Information Systems (GIS) and Global Positioning Systems (GPS) provide a mechanism to digitally pinpoint a location on earth, view the location on a map, and use the location and ancillary data in spatial analyses (Holcombe et al. 2007). Due to the wide a variety of applications of geographic information systems (GIS) and the myriad of spatial data available, we can create models applicable to invasive species at local and regional levels. This is important due to the fact the no two areas or situations are completely alike. This creates a situation for a local analysis in order to have more applicable and accurate results. The flexibility of modeling procedures allows for data processing that can suit the desired location and scope of the analysis.

Ecological data, in most cases, contains a spatial component. Where an animal spends its time and the patterns of its movements can be important clues to its biology. Biological information of non-native species provides insight to explaining expanding distributions and provides a watch list of spreading invasive species to managers for early detection and rapid response (Holcombe et al. 2007). Ecological data is used as an indicator that can be used to express the potential for a species to inhabit an area.

A growing number of statistical models, called Species Environmental Matching (SEM) models are being used to determine current and potential distributions and abundances of harmful invasive species (Stohlgren and Schnase 2006). SEM models relate observed species distributions to environmental (climatic, topographic, edaphic) envelopes. Then, assuming the same stable relationships, they project species spatial shifts (local, enrichment, or extinction) in response to envelope changes under current conditions. Statistical models used current species distribution data to try and predict potential habitat. Conceptually, the SEM models assume the fitted observational relationships to be an adequate representation of the realized niche of a species under a stable equilibrium or quasi-equilibrium constraint. As such, the SEM model results only in a first approximation of future distributions of individual species (Peterson and Dawson 2003). SEM model results are also determined by other processes such as dispersal, adaptation, competition, succession, fire and grazing pressure (Austin 2002).

An important consideration for invasive species management is that recent invaders may not have filled all suitable habitats, while species naturalized long ago may have filled a larger proportion of suitable habitat.

In short, we will be able to better manage and assess risks associated with harmful invasive species because risk assessments require accurate modeling of current and potential species distributions (Stohlgren and Schnase 2006). No two SEM models are identical, and each has advantages and disadvantages. Logistic regression is a type of Generalized Linear Model (GLM) appropriate for data with a binary distribution such as species presence or absence (McCullagh and Nedler 1989). The Environmental Envelope Model (EEM, Jarnevich et al. 2007) was developed as a rapid assessment technique to estimate the potential distribution of a species

given its present location and associated environmental attributes. Envelope models use environmental variables, chosen by the modeler that are relevant to the species of interest or species growth in general, to determine locations within the environmental envelope where the species of interest may be able to become established.
The model can include several different environmental layers to determine suitable habitats.

2.4.1.1 Environmental Niche and Distributional Modeling

Most modeling approaches developed for prediction of plant or animal species distributions have their roots in quantifying species-environment relationships (Guisan and Thuiller, 2005). Species Distribution Models are empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces (Guisian & Zimmermann 2000). Species data can be simple presence, presence-absence or abundance observations based on random or stratified field sampling, or observations obtained opportunistically, such as those in natural history collections (Graham et al. 2004a). Usually chosen to reflect three main types of influences on species (modified from Guisan & Zimmermann 200; Huston 2002; Fig. 1):

1) Limiting factors (or regulators), defined as factors controlling species eco-physiology (e.g. temp., water, soil composition).
2) Disturbances, defined as all types of perturbations affecting environmental systems (natural or human-induced).
3) Resources, defined as all comounds that can be assimilated by organisms (e.g. energy and water).

These relationships between species and their overall environment can cause different spatial patterns to be observed at different scales, often in a hierarchal manner (Pearson et al. 2004). Patchy distribution observed over a smaller area and at fine resolution is more likely to result from a patchy distribution of resources, driven by micro-topographic variation or habitat fragmentation (See examples in Scott et al. 2002).

Species distribution models and their output habitat suitability maps have been used with relatively good success to investigate a variety of scientific issues.
As both species and environmental data are usually sampled during a limited period of time and or space, models fitted using these can only reflect a snapshot view of the expected relationship. This is an assumption behind models and the niche concept.
The Niche Concept in Species Distribution Models: A striking characteristic of SDMs is their reliance on the niche concept (Guisan & Zimmermann 2000).

Distributional models and ecological niche models are being used not just to understand species' ecological requirements, but also to understand aspects of biogeography, predict existence of unknown populations and species, identify sites for translocations and reintroductions, plan area selection for conservation, forecast effects of environmental change,

etc. A basic dichotomy that pervades both the list of uses to which these methods are put and even the terminology used to refer to them is that of ecological niche modeling (ENM) versus distributional modeling (DM). Niches and distributions of species were visualized as a set of three intersecting circles, representing three classes of determinants: physical conditions necessary for a species' survival and reproduction (abiotic niche), biotic conditions necessary for a species' survival and reproduction (biotic niche), and accessibility (Peterson, 2006).

Environmental niche proponents are interested in using distributional information to estimate ecological niches and potential distributions of species, which then provides a means of understanding and anticipating ecological and geographic features of species distribution biology (Soberton and Peterson 2005). Distribution model proponents, on the other hand, include effects of abiotic, biotic, and accessibility considerations in their models from the outset. Distributional information is an expression of a realized ecological niche, as such the realized niche is the target of modeling. Meaning a distribution modeling proponent would often include in the modeling approach independent variable that summarize biotic considerations and that bring in spatial considerations that may be relevant to dispersal ability and accessibility (Leathwick 1998; Latimer et al. 2006). Whereas, distributional modeling is simpler in producing estimates of species' actual geographic distributions directly, productivity across scenarios of change is largely lost, and assumptions regarding accessibility of areas may still be required (Soberon and Peterson 2005). As such, environmental niche modeling applications, a Grinnelian view of niches has generally been adopted: a species' ecological niche can be defined as the set of conditions that permits it to maintain populations without immigrational subsidy. Certainly, an appreciation of the basic tenets of historical biogeography would suggest that species will not inhabit all areas that meet their niche requirements, rather, barriers to dispersal will often restrict species to a subset of these areas (Peterson 2003a; Peterson et al. 1999).

The functionalities and possibilities of environmental niche modeling are vast. All of the rich detail of natural history, ecology, and behavior can be essentially unknown, but some information can be inferred from ecological niche models. The can help understand distributions, biogeography and dispersal barriers. Meaning we can identify potential barriers, which limit the influx of the focal species into a new but suitable area. Environmental niche models, in its simplest manifestations, provide a framework by which one can interpolate between known populations of a species to anticipate existence of other, unknown populations. They can be used to plan conservation efforts for methods or reintroduction or eradication efforts. Further advancements in this realm can be derived from the use fo nich modeling to identify areas of high probability of population persistence (Araujo et al. 2002) and identifying optimal dispersal corridors.

Fundamental Niche

The fundamental niche has been estimated in two ways: direct measurement or physical modeling of responses of individuals to temperature, humidity, and other physical parameters, and inferring from them fitness values of different combinations of physical variables. Niches

may be reconstructed by relating data on species' occurrences with data sets summarizing climatic, topographic, edaphic, and other ecological dimensions (in the form if GIS layers).

There are four classes of factors determining areas in which a species is found or could potentially be found. The first are the abiotic conditions, including aspects of climate, physical environment, edaphic conditions, etc., that may impose physiological limits on species' ability to persist in the area. The second are the biotic factors. This is the set of interactions with other species that modify the species' ability to maintain populations. These interactions can either be positive or negative depending on the relationship the focal species has with the other present species. By limiting or enhancing population processes, interactions can obviously affect distributions. The third class is the regions that are accessible to dispersal by the species from some original area. This factor is extremely useful in distinguishing a species' actual distribution from its potential distribution. This can be based on landscape and the species' dispersal abilities. The final class is the evolutionary capacity of populations of the species to adapt to new conditions. It can be assumed that a species will be present at a given point where the three conditions are met (Peterson and Soberton, 2005).

Ecological Niche

Joseph Grinnell was the first investigator to propose a concept of an ecological niche (Grinnell 1917, 1924). The Grinnellian niche focused on the range of ecological conditions within which a species can maintain populations, and therefore by nature was geographic in focus.

Individuals inhabiting conditions within the niche are generally able to replace themselves, and thus contribute genes to the next generation.

The ecological niche model can then be projected onto landscapes to identify geographic regions that present ecological conditions inside and outside of the specimen's niche, producing a hypothesis of a potential geographic distribution for the species. It is critical to distinguish this two-step approach: modeling the niche in ecological space and then projecting the model onto a landscape in geographic space.

2.4.1.2 Habitat Suitability Modeling

Techniques involved in Habitat Suitability Models are a five-step process: (1) set objectives, (2) identify model variables, (3) structure the model, (4) document the model, (5) verify the model.

Phase One: Set Model Objectives

Setting the model objectives involves the following: (1) defining the ideal and acceptable model outputs; (2) defining the geographic area to which the model is applicable; and (3) defining the season of the year for which the model is applicable.

Step One. Define the ideal and acceptable model outputs. The ideal output of an HIS model is a 1-1.0 rating that has a direct linear relationship to carrying capacity. Example output acceptance can be based on the model outputs based on sample data appear reasonable to the

evaluation team, or model outputs based on sample data appear reasonable to a species authority.

Step Two. Define the geographic area of model applicability. The geographic area of model applicability should be clearly defined for each species and may include the entire range of the species. The area of model applicability should be referenced to some standard units such as watersheds, state boundaries, or ecoregions.

Step Three. Define the seasonal applicability of the model.

Phase Two: Identify model variables.

Habitat variables are the building blocks of a habitat suitability model. This phase of model construction answers the question: "What environmental variables, if modified, would be expected to affect the capacity of the habitat to support the evaluation species?"

The intended application of the model needs be considered when identifying model variable. The potential variables for a typical habitat assessment using Habitat Evaluation Procedure (HEP) include measurable physical, chemical, or biological characteristics of the habitat. The generalized approach for identifying model variables consists of reviewing the literature on the species and selecting those variables that meet three criteria: (1) the variable is related to the capacity of the habitat to support the species; (2) there is at least a basic understanding of the relationship of the variable to habitat (e.g., what is the best and worst condition for the variable and how does the variable interact with other variables); and (3) the variable is practical to measure within the constraints of the model application.

There are at least four types of components used to define habitat variables for an evaluation species:

(1) Seasonable habitat is the habitat used for a particular period during a species annual life cycle (e.g., winter range or breeding season habitat). (2) Life requisites include food, cover, water, reproductive, or special resources supplied by a species habitat. Life requisite components can be further separated into categories such as seasonal foods, nesting habitat, or brood rearing habitat. (3) Life stages are typically utilized for aquatic models and include the egg, larval, fry, juvenile, and adult stages of a species. (4) Cover types are an area of land or water with similar physical, chemical, and biological characteristics that meet a specified standard of homogeneity. Cover types serve two primary purposes in a model. They segregate measurable variables into groups that simplify field data collection and are used to define spatial relationships between habitat components.

Phase Three: Structure the model

Each variable identified in the previous model construction phase must be combined with the other model variable to produce a habitat suitability index. This is accomplished by defining relationships between the variable. A relationship can be in the form of a graphical display, a

written statement, or a mathematical equation. The tree diagrams used in this chapter are examples of graphical relationships between variables.

A number of approaches can be used to establish model relationships. The approaches discussed herein are: (1) word models; (2) mechanistic models; (3) pattern recognition models; (4) Bayesian probability model; and (5) multivariate statistical models.

The word model will be the preferred method for structuring the model for seasonal habitat. A word model is constructed by making sentence statements about the variables or various combinations of the variables or various combinations of the variable. To be useful, a word model should assign a significance to particular measures of the variables. Word statements made about each functional relationship should be as clear as possible. Clear statements can be written by following a logical format that addresses: (1) the suitability of each measureable variable; and (2) the relationships between the variables.

Each variable is described by stating the general form of a relationship between a measure of the variable and habitat suitability. The general form of the relationship describes the response of habitat suitability to a change in the variable. Additional resolution can be added to the statement by defining differences between various measurements of the variable.

One approach to this is to create suitable classes. The suitable conditions of a variable may occur within a range of measurements, and the most suitable conditions may occur within a smaller sub-range of measurements.

The second step to creating a word model is to describe the relationships between variables. There are many possible relationships between variables.

When a species' life requisite resources are found in two or more cover types, spatial relationships are required to complete the habitat model. Cover types are used to define spatial relationships between life requisites.

The suitability of a variable is described with a suitability index graph that displays the relationship between the variables and the index of suitability. "Suitability" is a term that by itself has no specific meaning since one cannot go out and directly measure a suitable level corresponding to a particular variable. However, in constructing this kind of graph, an assumption is made that some observation that is indicative of habitat suitability can be related to the variable. The relationship between habitat suitability and the variable displayed on the graph is assumed independent of other variables that also can affect habitat suitability. Consultation of a species authority will be the means by which to obtain index values for the suitability graph.

Many methods can be used to simulate habitat suitability, but for this analysis, the use of an index graph will be used to obtain a habitat suitability index score. Suitability index scores are obtained by comparing existing or predictive conditions in the study area with the relationship depicted by the suitability curve.

Phase Four: Document the Model

The fourth phase in model development is to document the HSI model, its structure and assumptions, and the complete set of steps needed to implement the model. Documentation is important because: (1) the user must be able to understand the model, its objectives, its basic biological assumptions, and the basis for its construction; (2) documentation of the model aids in the understanding of how habitat is used by the evaluation species; (3) the user should know what to expect from the model; and (4) documentation provides the basic understanding how the model may be adapted to other applications.

Two levels of documentation are needed to support the model. One level represents the gathering of habitat use information about a particular evaluation species, information which ultimately will be used to construct the habitat suitability model. The second level of documentation describes how the species-habitat information is used to construct the HSI model and the step for using the model. This also describes the conditions under which the model is applicable.

Species-habitat relationships and life history information are the basic data sources used for developing the HSI model. Documentation should provide a characterization of the general and specific habitat requirements of the evaluation species.

Information pertaining to the applicability of the model should be clearly defined. The selected variables must be justified, with an explanation of why each is important. Assumptions made in defining model relationships should be explained. The method for determining suitability for each variable should be explained when suitability indices are established for model variables. There should be adequate and complete documentation of steps needed to apply the model, including when, where, and how each variable is measured in the field. Instructions for interpreting the model outputs should be provided, if appropriate.

Phase Five: Verify the Model (Recommendations Chapter)

The purpose of model verification is to ensure that the model produces an output at the acceptance level established in the first phase, setting model objectives. Verification serves as a quality check on the model and can be used to further refine or advance a model to a higher acceptance level.

Verification includes four progressive steps. The first step is a review of the model by the author. Step two is to analyze the model with sample data. Step three is to review the model with a species authority. The final step is to test the model with field data and field observations.

This model example incorporates eight variables grouped into three components: habitat composition, spatial arrangement of habitats, and human use. Each variable used a Suitability Index (SI) value as a measure of its relative value (between 0 and 1.0, with 1.0 being optimal) to the bird. SI values within each model component were combined to compute a Component

Index (CI) value, and the CI values were used to derive a Habitat Suitability Index (HSI) value for the site.

Two variables were used to represent the optimal spatial arrangement of the four habitat types. The first was the linear amount of edge/hectare. The second variable measured the interspersion of the four habitat types. This was the minimum distance encompassing all four-habitat types, measured from a random set of points. The closer the four habitats that provide life requisites, the shorter distance the turkey must travel to meet its needs. Therefore, the minimum distance SI was a decreasing linear function.

The four habitat composition variables and the percentage composition human-use variable were measured from land-use data using a dot grid. The minimum distance human-use variable and the minimum distance spatial variable were measured from land-use data by computing the mean minimum distance from sampling points in an area to all four habitat types or human use, respectively (U.S. Fish and Wildlife Service 1981).

Results of this model test indicate that the Habitat Suitability Index model is useful in evaluating the relative value of habitat suitability. In analyzing the performance of the component index, two factors appear to be important in development of GIS-based HIS. The first is the compatibility of the scales or resolution of information that is used in model development and that are available on the GIS. The second is the feasibility of generalizing habitat requirements so that GIS-based variables can adequately represent the life requisites of a species. The effectiveness of this model is based on the ability to generalize habitat requirements so that GIS-based variables adequately represent the life requisites of the species.

2.5 Research Goals

The ultimate goal of this research is to identify all suitable areas for Common Carp during the spring months when seasonal water levels are high. There will be two outcomes to this analysis. The first outcome will be the fundamental niche which will include all areas believed to be capable of meeting life requisites for the Common Carp. The second output will be more refined and will identify the realized niche. These will be the areas in which the habitat suitability and the distribution are combined to show all areas in which the Common Carp are found or have direct access.

This research will focus on, but is not limited to five areas throughout Malheur National Wildlife Refuge. These areas include:

-The Double “O” Ranch Unit
-Stubblefield Ditch/Canal
-Ram Ditch off Boozy Dam
-Western Diversion off Sodhouse Dam
-Western Diversion off Grain Camp Dam

Each of these areas will serve as a pilot study for Malheur National Wildlife Refuge in determining existing access routes throughout the refuge for the Common Carp (Cyprinus carpio).

To meet the criteria set forth by the Habitat Suitability Index Model, four objectives will need to be accomplished. The first objective is to define the access routes (linear) and access points (discrete) found throughout Malheur National Wildlife Refuge. This process will be a combination of utilizing available hydrology data, bridging gaps in the data, and combining the data with water control structures which will serve as discrete access points to suitable habitat. Each access point will be defined as either free-access, meaning no barriers, and restricted, meaning some sort of barrier is located at this access point.

The second criteria will be to define the habitats found on the refuge and define the habitat types which meet the Common Carp life requisites. The BIDEH table, noted earlier, will serve as the list of all habitat types.

The third criteria will be to define the relationship between the Common carp and the habitats found on the refuge. The life requisites are defined in the Biology section and will be condensed in modeling this criterion. Each habitat type will be ranked based on a scale of 0-1 to represent whether the habitat type is suitable to sustain a carp population.

The output of modeling and defining these criterions will be a Habitat Suitability Index Model. The final set of steps of this analysis will be to couple the model outputs with a presence/absence of the Common carp.

3. Methods

3.1.1 Water Delivery Network and Field Access Points

The first step of the research will be to create a water delivery network within ArcMap 10. Using the data collected by Jordan Miller from the summer of 2010 to identify the directional flow of water through the water control structures will be a core component of this analysis. This data allows for the creation of water flow models for assistance in identifying how the water delivery system works throughout each canal or river source to any management field. Data regarding dikes and levees will serve as ancillary data to show where and how water will move through the system. This will serve as an initial network model to show potential passages for carp throughout Malheur National Wildlife Refuge.

Along with ***Step 1***, the incomplete data found in the rivers layer will completed or "linked together" using National Agricultural Imagery Program (NAIP 2005) data for the areas listed. The rudimentary remote sensing method or "heads-up digitizing" is the preferred method for this aspect of the research. "Heads-up Digitizing" is a method used to create point, line, or polygon features to represent natural features. Since the water delivery network is so diverse, extensive, and important to this analysis, we must use every possible technique available to fill

the gap in the status quo of rivers and creek data. The NAIP imagery allows us to look for distinct features of the myriad of waterways throughout the refuge and begin to make some decisions on where it is appropriate to add new line data. Another method used in conjunction with digitizing, was to use the data collected pertaining to the water delivery infrastructure. This allows us to make accurate decisions in where new features need to be added to the rivers layer as well as directional flow through the water control structure.

Due to the nature of Malheur National Wildlife Refuge, there are vast amounts of ephemeral streams and creeks found throughout the refuge. In addition to the existing data had for the rivers of the refuge, it was imperative to complete this network using the aerial imagery and editing using digitizing techniques to complete the dataset. Within ArcMap 10, the base data for the rivers network was "stacked" on top of the 2005 NAIP imagery and from which point the incomplete segments of the Rivers data were able to be connected as well as any new or missing features which belong to the Rivers layer could be created. The majority of the new features include ephemeral or intermittent streams which flow seasonally but do provide the Common Carp with access to various breading and feeding habitat. Thus, by creating new line data to complete the original Rivers layer we are now able to identify the majority of channelized water movement paths that the Common Carp may use to access different parts of the Malheur National Wildlife Refuge.

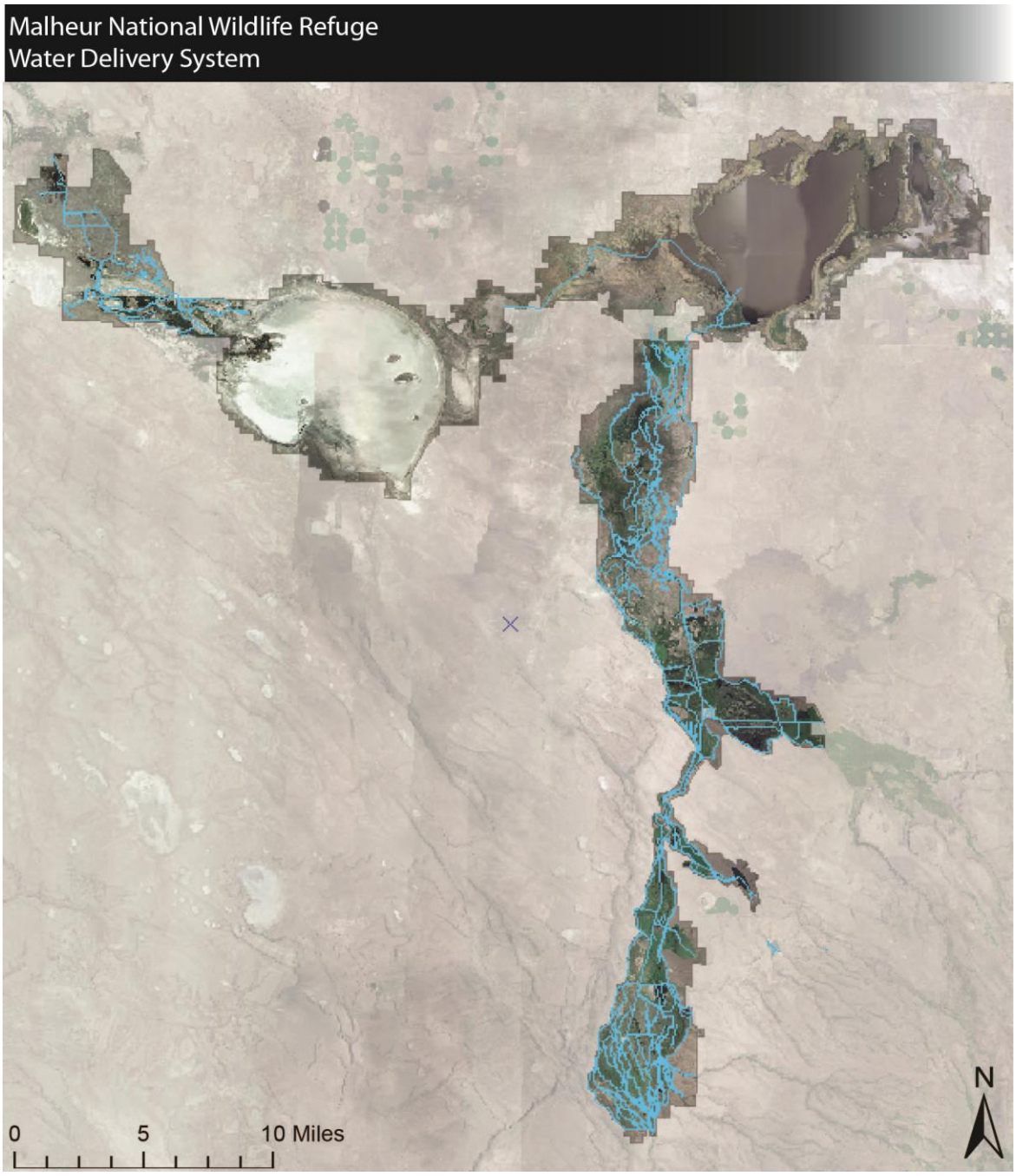


Figure 2: MNWR Water Delivery System

3.1.2 Habitats & Suitability Index

The goal of this analysis is to identify all areas, preferred by the Common carp, for spawning purposes. The habitats found on the refuge will get a rank of 0 to 1 based on the researched capacity of each habitat to meet the spawning requisites of the carp. An index of "1" will be a habitat type, which is optimal for meeting the requisites of carp for spawning, and an index value of "0" will be an area that is not suitable.

The geographic area of the model will be the confines of the Malheur National Wildlife Refuge located in the Harney Basin of southeast Oregon. The analysis will be limited to the extent of the habitat suitable for the Common carp, which is ultimately regulated by the availability of water and the flood pulse action in the inundation of the non-traditional and traditional floodplains. The period of high water is primarily in the spring due to a higher than normal frequency of rain and the seasonal snowmelt from Steens Mountain. Spring is the time of year when the carp move into the inundated portions of the refuge to lay their eggs.

Habitat variables will be all habitat types found in the Biological Integrity, Diversity, and Environmental Health table. A habitat suitability index will be given to each habitat type located within the table. The following table is the suitability index values of each habitat type found on Malheur National Wildlife Refuge (Figure ##). The common denominator of habitat types concluded to be suitable for Common carp is some level of seasonal water.

(Below) Table 3: Habitat Suitability Index Values

Habitat Type	Suitability Value (Classification)
Malheur Lake	1
Playa	0
Palustrine Open Water	1
Dune	0
Marsh (Hemi & Emergent)	1
Riparian	0
Riverine	0
Wet Meadow	1
Moist Meadow	1
Alkali Flat	0
Big Basin Sagebrush Island	0
Sagebrush Steppe	0

3.1.3 Carp Distributions

Common carp distribution data to be used in this analysis includes presence data collected in the summer of 2010 as well as presence data collected via personal communication with species authority, Linda Beck (2010). Carp on the refuge prefer slow moving water. This is the characteristic of most of the water delivery system found on the refuge minus the area of the

Blitzen River south of Bridge Creek. Figure (###) shows the overall distribution of the common carp within Malheur National Wildlife Refuge waters. Distributions are based on the major rivers and creeks but are not limited to these areas due to the connectivity of ephemeral creeks which may serve as access routes during the spring and early summer high water periods.
In efforts to manage the movement of carp throughout the refuge, fish screens have been strategically placed in critical areas of the water delivery system. Figure (###) shows the locations of fish screens and for the purpose of this analysis, it will be assumed that these fish screens are effective and there are no carp found in areas blocked by fish screens. The distribution of carp within Malheur National Wildlife Refuge is an important component of this analysis. The realized distribution of carp will determine the overall potential of suitable carp spawning habitat to be used during period of springtime high water. The limiting factor of available water makes this process straight forward in determining what areas of the refuge can expect to see the use of suitable spawning habitats by carp but it also makes carp management quite difficult.

Common carp distribution data used in this analysis includes presence data collected in the summer of 2010 as well as carp presence data collected via personal communication with species authority, Linda Beck (2010). Carp on the refuge prefer slow moving water. This is the characteristic of most of the water delivery system found on the refuge minus the area of the Blitzen River south of Bridge Creek. Figure (###) shows the overall distribution of the common carp within Malheur National Wildlife Refuge waters. Distributions are based on the major rivers and creeks but are not limited to these areas due to the connectivity of ephemeral creeks which may serve as access routes during the spring and early summer high water periods.

To represent areas of the water delivery system where carp are present, a weighted value is assigned to segments of the water delivery system to indicate the level of carp dispersal.

Dispersal Value (Classification)	Definition
0	A portion of the water delivery system in which there has been no documentation of the presence of carp.
1	A portion of the water delivery system where there is potential for the presence of carp due to the connectivity to segments of the water delivery system which is known to have carp present.
2	A portion of the water delivery system where carp are documented as being present.

(Above) Table 4: Carp Distribution Values

3.2 Identification of Priority Management Areas

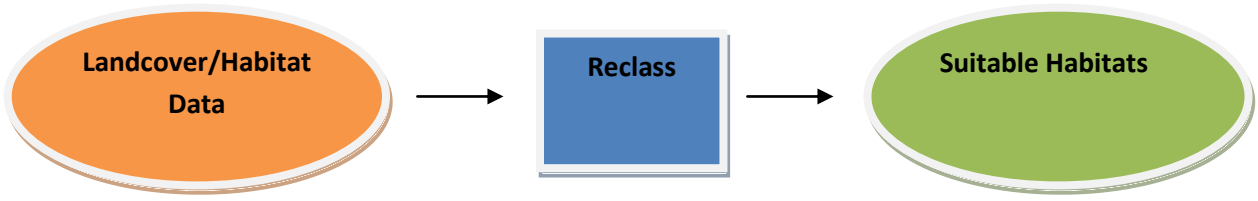
In addition to the combination of the water delivery network and the habitat layer, we can analyze areas in need of upgrades in carp management utilities. Identifying an area that has an active carp population within the water delivery network can lead to future action in investing resources to help eradicate the existing carp population and reclaim habitat for migratory waterfowl species. This analysis will lead to a prioritization of carp management actions throughout the refuge by providing accurate quantified acreages and locations of reclaimable habitat.

These areas include:

-The Double "O" Ranch Unit
-Stubblefield Ditch/Canal
-Ram Ditch off Boozy Dam
-Western Diversion off Sodhouse Dam
-Western Diversion off Grain Camp Dam

3.3 Modeling Outputs

(Below) Figure 3: Habitat Suitability Index: Refuge Wide



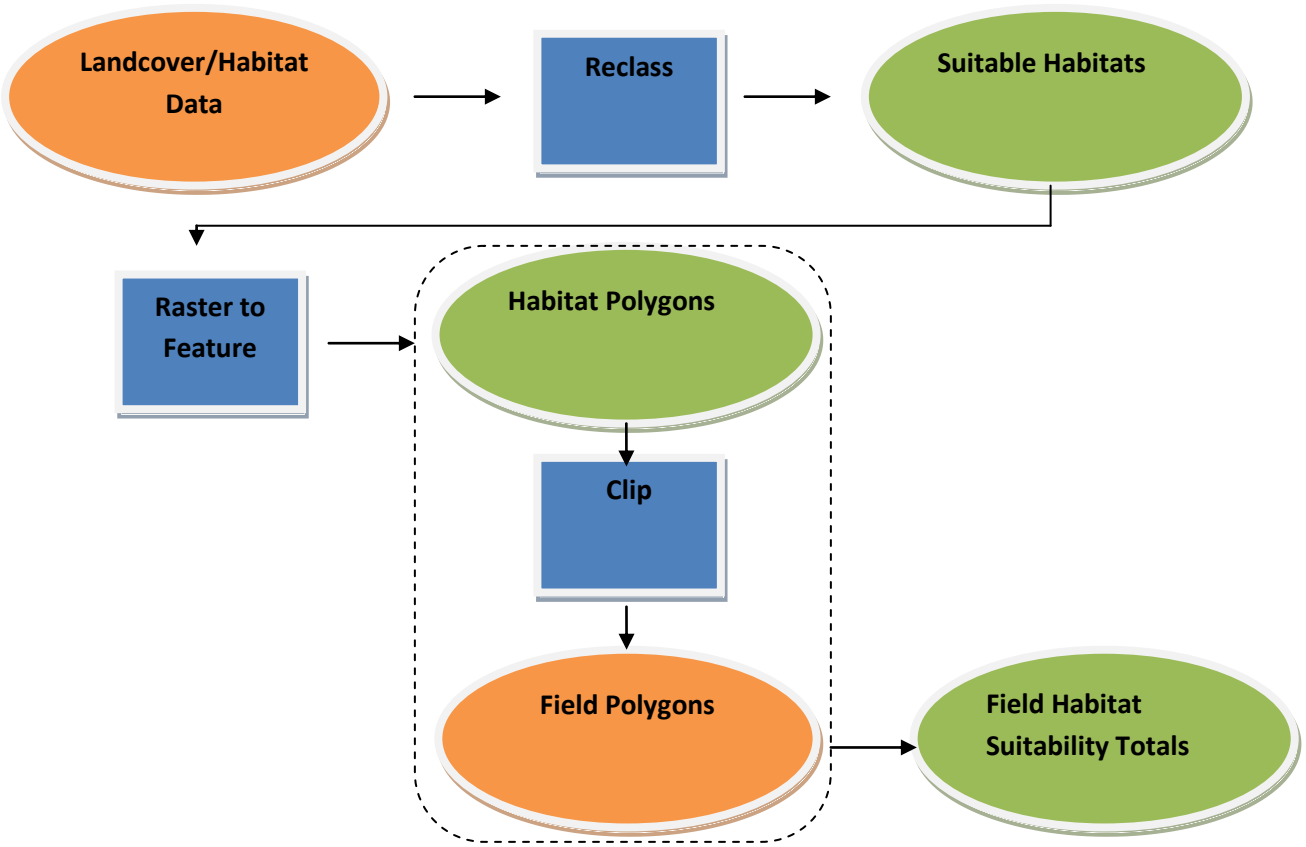
The above workflow is a high level model of the process involved working with the data in Arc. The input data is Landcover/Habitat Data collected by Nick Wilson in the summer of 2010. The habitat types included can be found in the BIDEH table in Chapter 2.3. The significance of this step in the work flow is to gain a data set in which we can extract data at a large scale or at the Fundamental Niche level.

The reclassification of habitat types follows values in the suitability index table (####). The values of "0" and "1" were used to delineate between suitable and non-suitable areas. No value of "0" is used when defining suitable areas and, accordingly, no values of "1" will be used to define non-suitable areas. The output totals for this analysis can be found below.

(Below) Table 5: Suitability Totals

Suitable Area	**102,031.13 Acres**
Non-Suitable Areas	**87,818.08 Acres**

(Below) Figure 4: Habitat Suitability Index: Local/Field Values



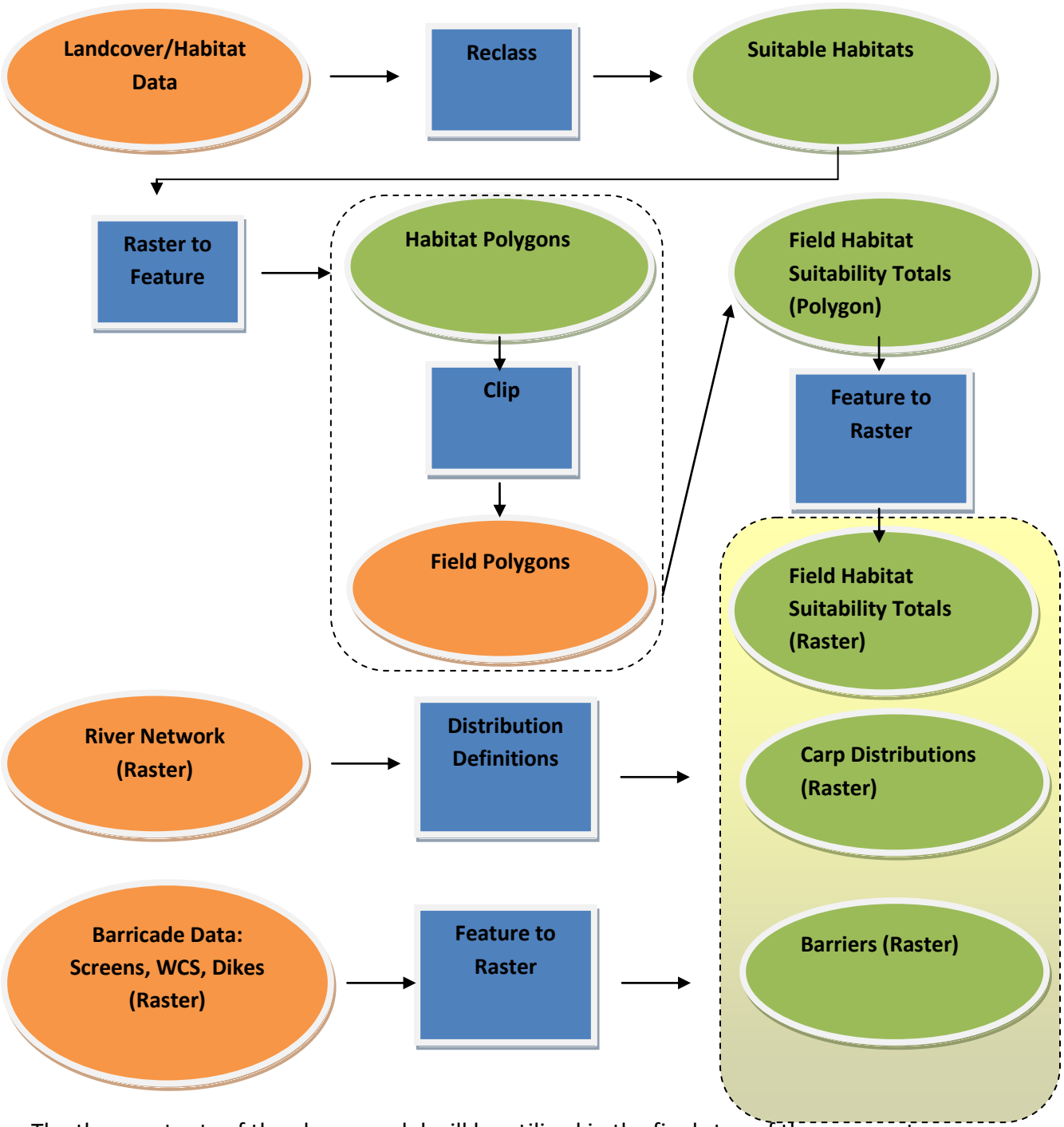
Individual field values can be found in the Malheur National Wildlife Refuge Fundamental Niche Table. Values include Suitable, Non-Suitable, and all habitat types and acres. (Table ####)

Realized Niche Modeling & Data Processing

This phase of the analysis will pair the data extracted from the previous work flow and couple it with the data extracted using the presence and absence data of Common Carp. It is extrapolated that as long as there are no natural or human barricades in place(fish screens, dikes, etc.), the Common Carp will have free range of the Hydrography network to the limits of structures barricading passage or current presence or absence of the invasive species Cyprinus Carpio. With this stated the use of the water control structures as a way of inhibiting the invasive species from accessing various areas is present in some cases but not all. In the analysis, the water control devices are symbolized as a barrier and therefor any habitat that is adjacent to the linear network is considered inaccessible to the Common Carp and acres of suitable habitat are not considered in the total of suitable habitat but are classified as carrying the potential of supporting carp populations. The values used, similar to the HSIM, will be a "0"

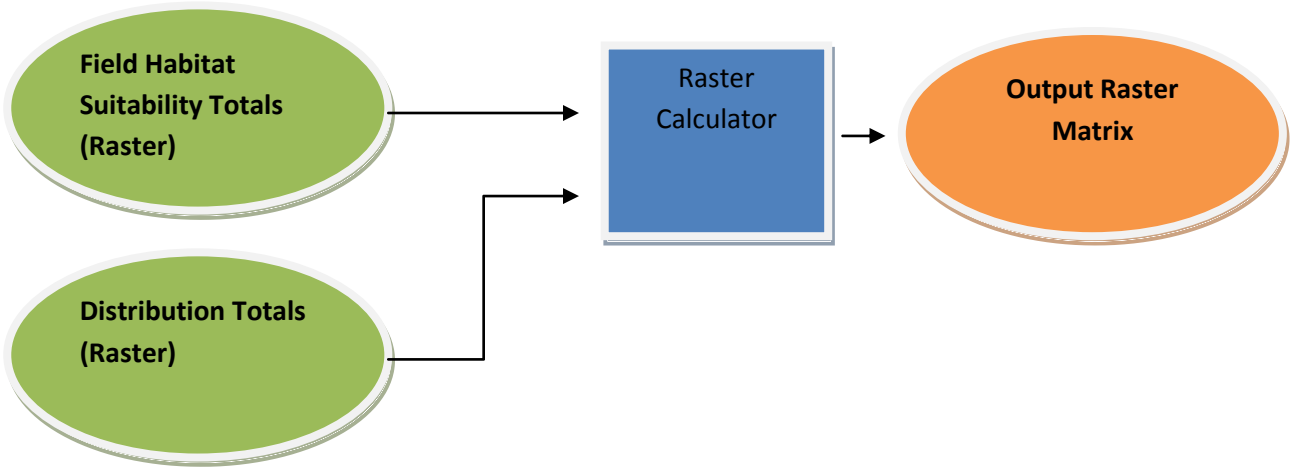
for impassable and “1” for passable. The raster values for carp distributions can be found in the Carp Distributions section.

(Below) Figure 5: Field Suitability & Access Model, Step One



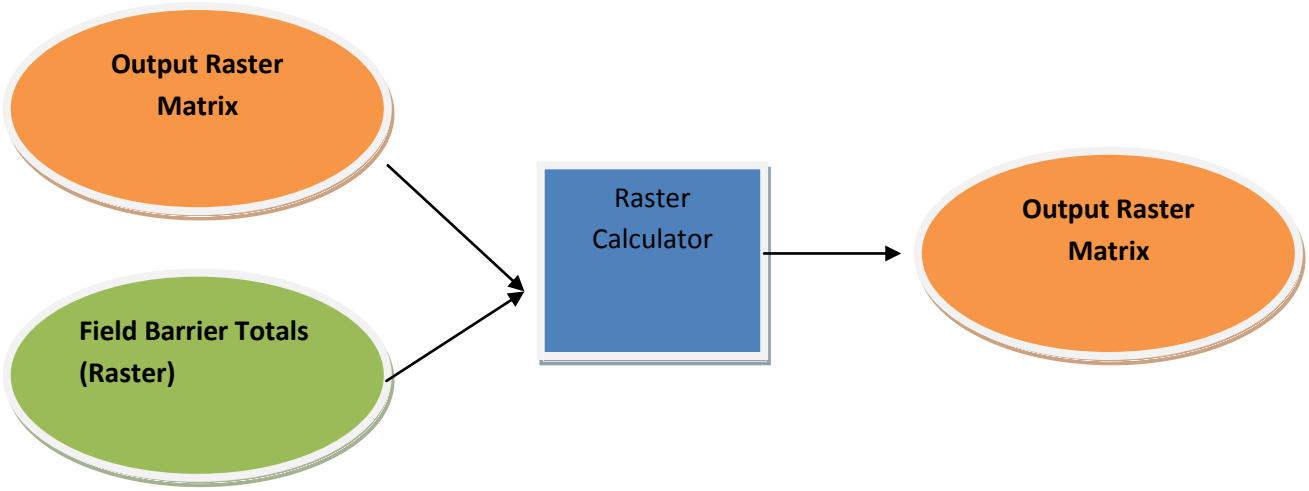
The three outputs of the above model will be utilized in the final step of the process to determine the acreage of suitable and non-suitable habitat. The final step will be processed as follows.

(Below) Figure 6: Field Suitability & Access Model, Step Two



When multiplying the suitability values there should be three potential outcomes. The value of "0" would mean that there is no suitable habitat where there are distributions of carp or it could mean that there is suitable habitat but there is no distribution of carp. Since the analysis is targeted at the realized niche, the two outcomes will be aggregated into a "No Carp" category, The second value possible is the value of "1" and this would mean there is suitable habitat but the presence of carp is recognized as having the potential due to network connectivity but there has been no documentation of carp present. The final output would be a value of "2" and this means there is a known carp presence and there is suitable habitat for the carp at high water levels provide free access to the habitat. When we add the barriers criterion to the model, we get the actual Realized Niche of the Common Carp on Malheur National Wildlife Refuge.

(Below) Figure 7: Field Suitability & Access Model, Step Three



By multiplying the output matrix to the Field Barrier totals there is the potential for two values. These values will give us the Realized Niche using the Habitat Suitability Index Model. The first outcome possibility would be "0." This value means that there is a barrier in the way of the rivers network and the desired habitat thus allowing no carp to pass. The second value is "1." This means there is no barrier for carp to access desired habitats at high water times through the water control structures.

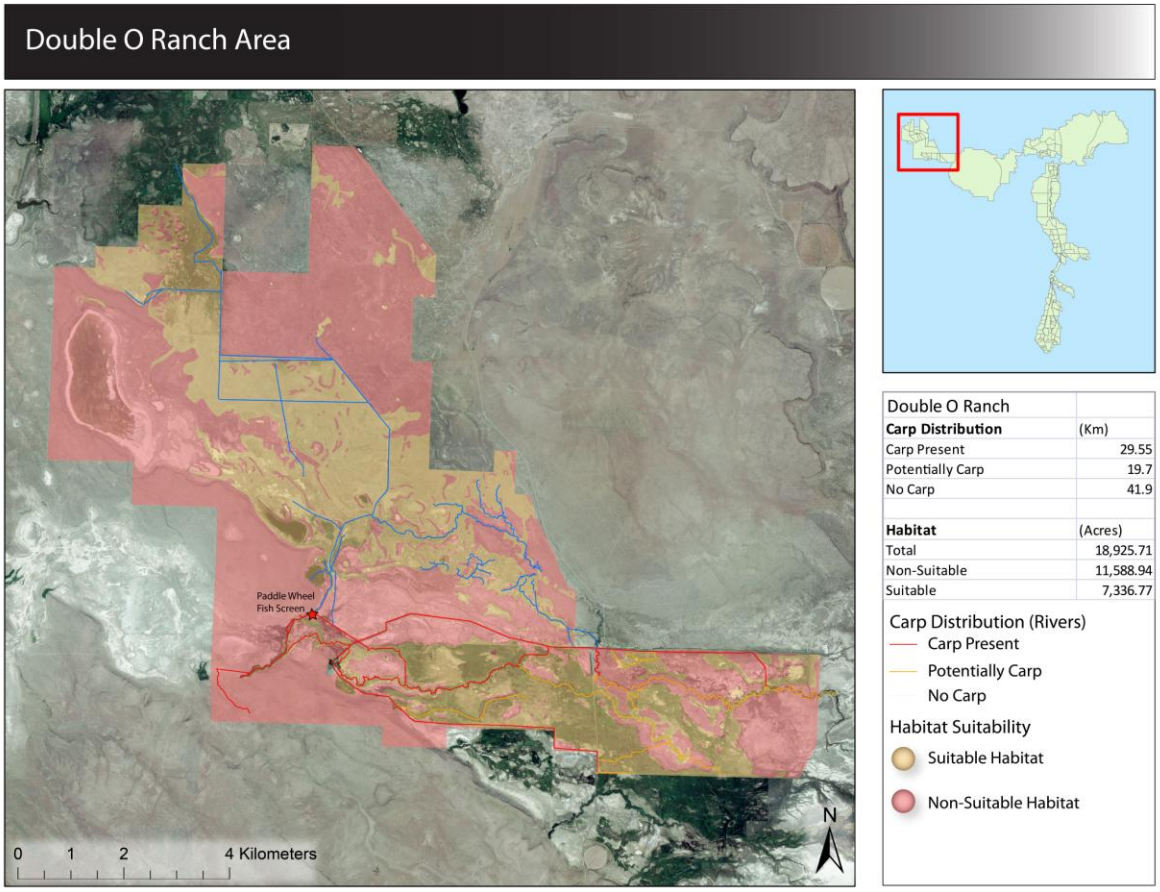
4.1 Results & Discussion

The focus of the study is for the five pilot areas

-The Double "O" Ranch Unit
-Stubblefield Ditch/Canal
-Ram Ditch off Boozy Dam
-Western Diversion off Sodhouse Dam
-Western Diversion off Grain Camp Dam

The results of the analysis can be found in the graphics below. Each are shows high level information including carp distribution and habitat suitability. Refuge wide results can be found in the table attached.

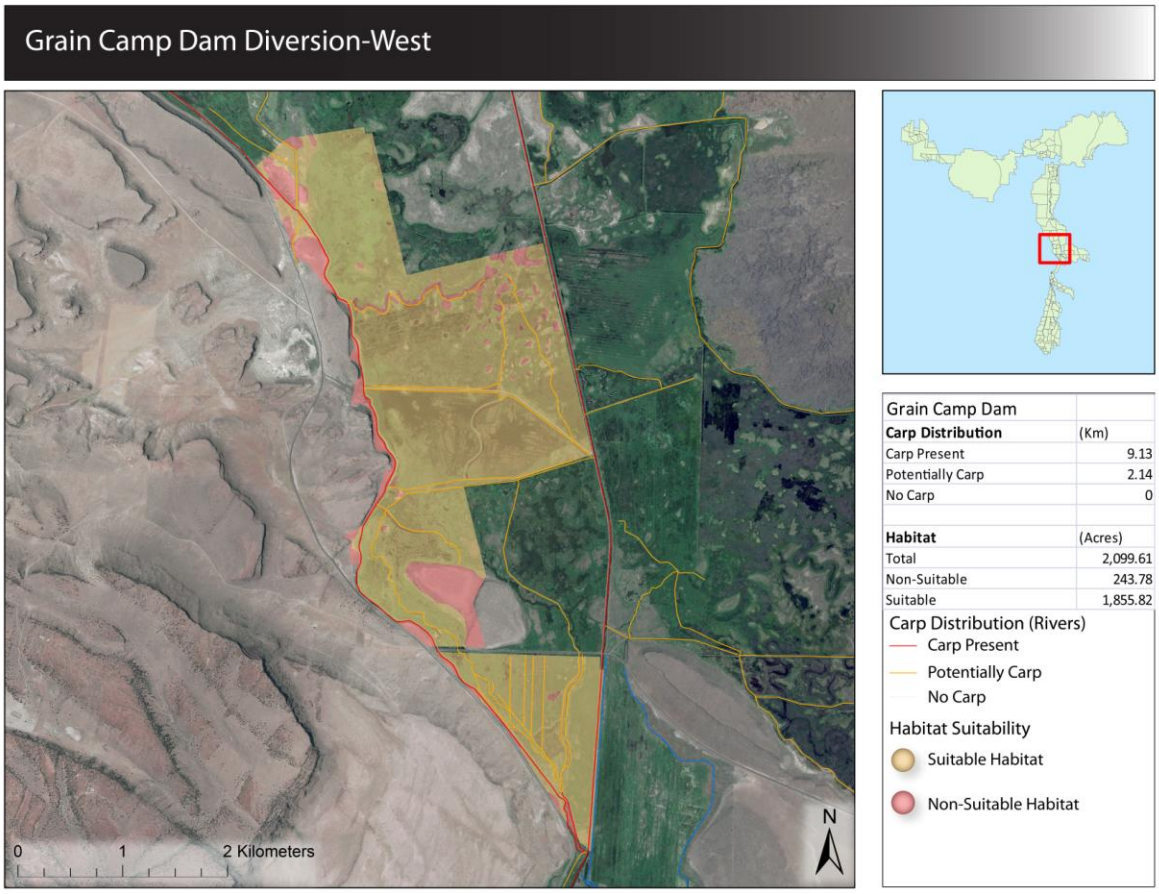
4.3.1 Double “O”



(Above) Figure 8: Double O Ranch

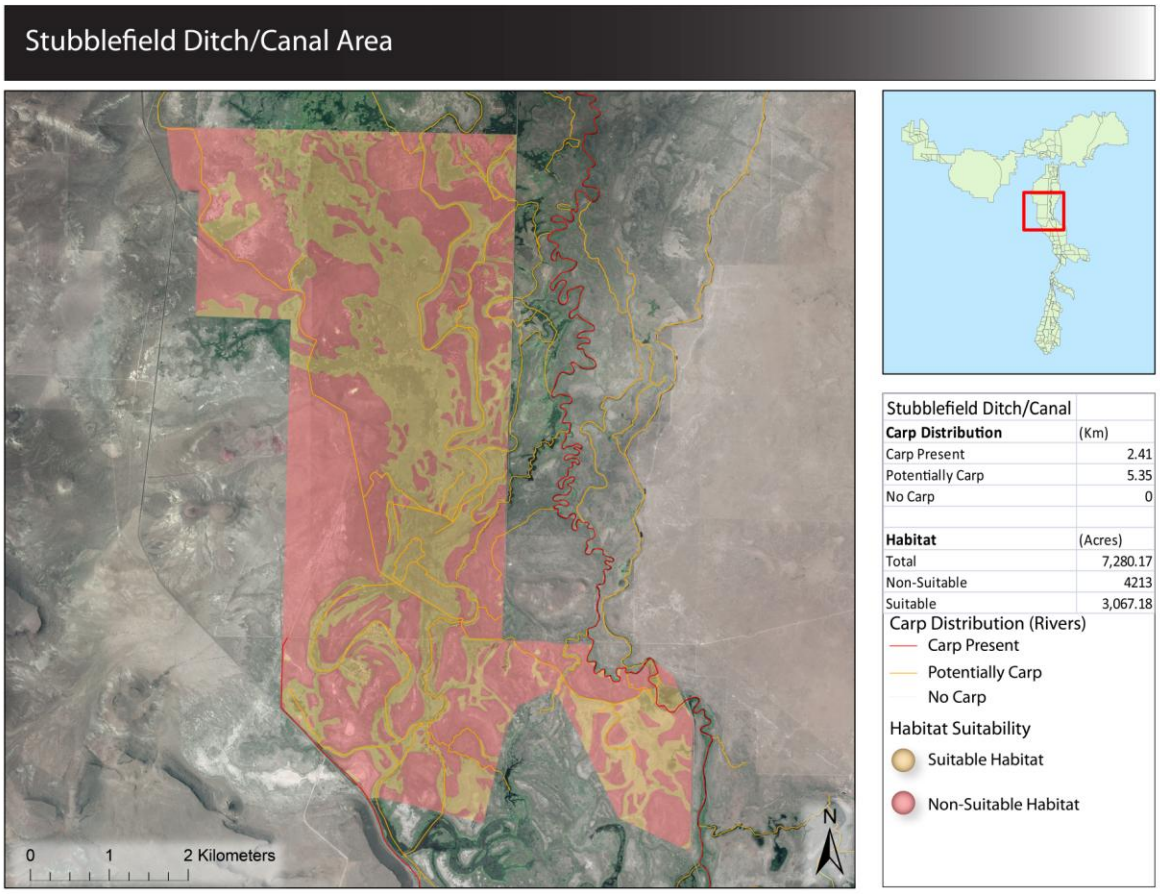
4.1.2 Grain Camp Dam

(Below) Figure 9: Grain Camp Dam Results



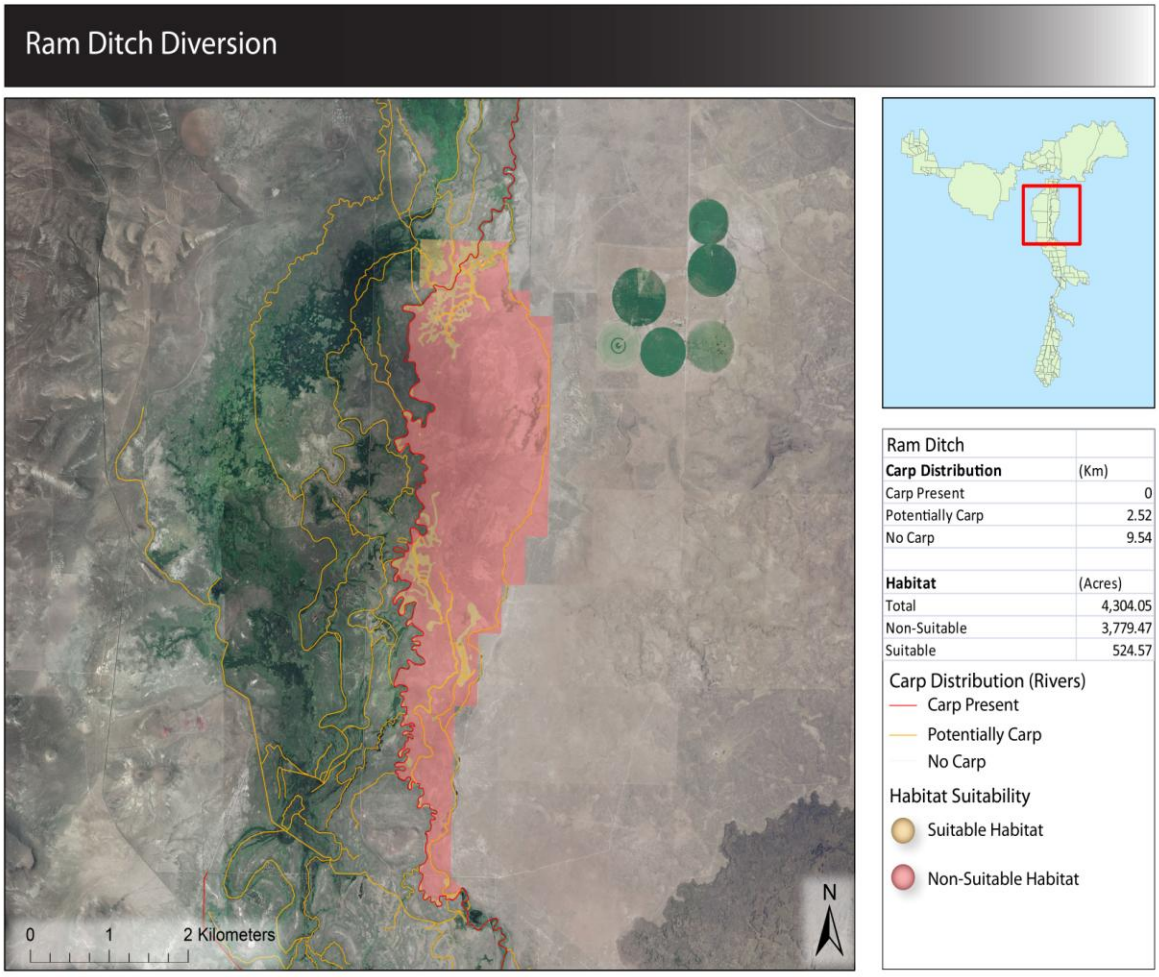
4.1.4 Stubblefield Canal

(Below) Figure 10: Stubblefield Ditch Results



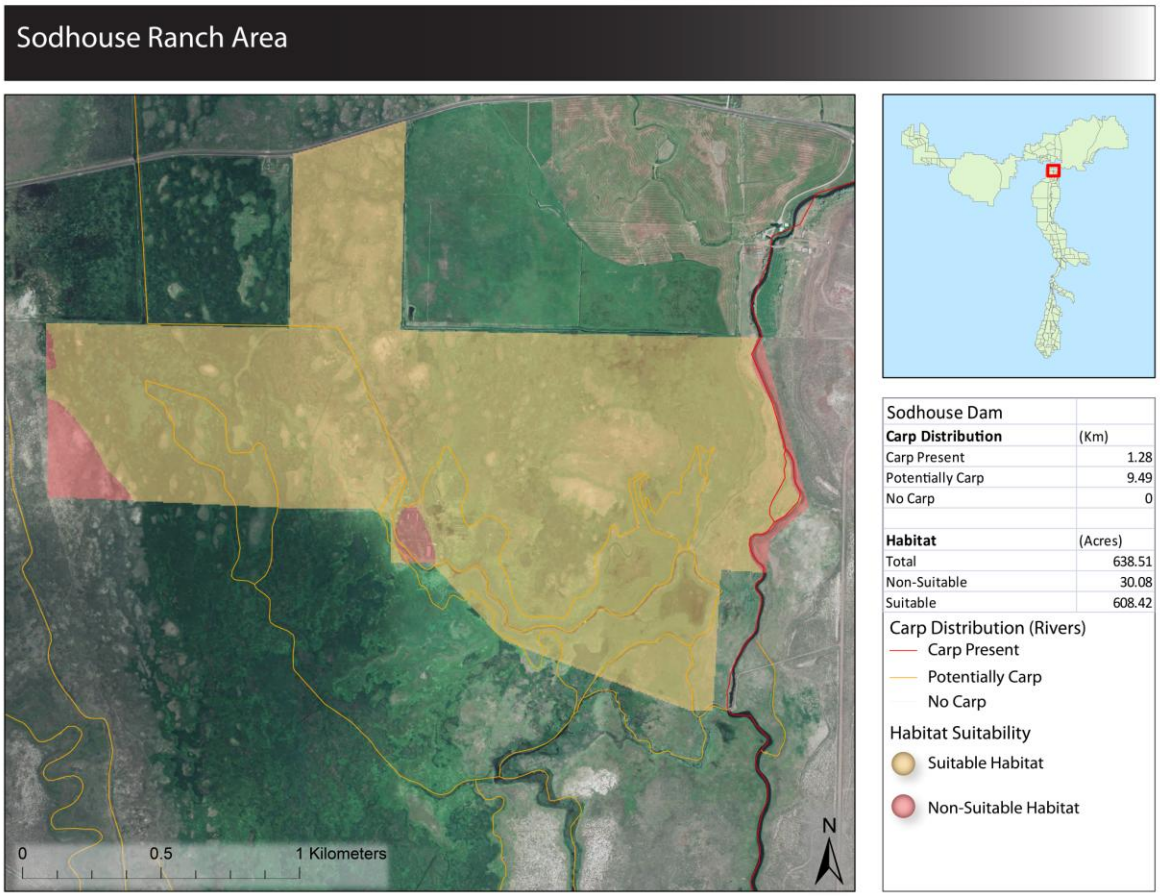
4.1.5 Ram Ditch

(Below) Figure 11: Ram Ditch Results



4.1.6 Sodhouse Ranch

(Below) Figure 12: Sodhouse Diversion



4.2 Summary

The use of GIS to benchmark and model habitat and distributions of invasive species is a powerful tool in the battle against invasive species. We know that carp move into inundated areas from the areas which have year round water to lay eggs and rear their young. They prefer vegetation to attach their eggs and the macro-invertebrates to feed on. We can use all of the life characteristics to model the potential locations in which they will move into. Malheur National Wildlife Refuge an excellent example of an area where we can prove this. By defining the realized and fundamental niche of the species, applying the Habitat Suitability Index Model, and utilizing Geographic Information tools, we can continue to model and track progress in invasive species management.

5. Conclusions

A completely sustainable ecosystem has biodiversity. By introducing invasive engineers to the mix, we begin to move toward monocultures. These invasive species will out-compete all native flora and fauna. Man is responsible for the majority of the spread of invasive species. This is true for Common Carp at Malheur National Wildlife Refuge as well as throughout the world.

Using this data as a benchmark in the progress toward reducing the amount of carp found in the refuge waters is paramount to success. The suitable acreage can be used to prioritize areas where there lies the most potential for carp to move into. It can show what sections of the rivers network have populations of carp and therefor guide management to make decisions on where to apply fish screens to trap the invasive species and then exterminate them in a safe way. Doing this will lead to the opportunity to conduct GAP analysis to measure the actual success versus the potential success of habitat reclamation.

The paradigm behind this modeling procedure can be used for measuring success as well. We can measure how many acres of habitat have been reclaimed from carp and therefor show return of investment when trying to allocate funding for these projects.

It is important to continue to monitor and document the presence and distributions of Common Carp throughout Malheur National Wildlife Refuge and apply this model again and again in an aggressive attempt to return these lands into a fertile area in the Pacific Flyway.

6. Sustainability Opportunities

The most substantial sustainable opportunity is the strengthening of the environmental leg of the three-legged stool. There are also opportunities for future work that can incorporate the social and economical legs. Much research has been done in the area of use of raw materials, in this case carp, for processing as fertilizer, gasses, and potentially as a food source. Work done in eradicating the common carp could create jobs at many levels of skill. The addition of screens and barriers would create jobs for a workforce that depends highly on Federal employment. An influx of funding and spending in the area would then benefit the local economy.

The social leg of the stool would be strengthened as well. The native people of the area are historically known to use the refuge lands for traditional uses. These include the harvesting of Tui Chub and native flora. If the chub are lost due to the common carp out competing them for habitat, these traditions may be lost and heritage inherently damaged.

There are many opportunities to be had with the problem surrounding the common carp on refuge lands/waters. Planning and implementation of management schemes can have very positive impacts on the area, not only environmentally, but socially and economically.

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