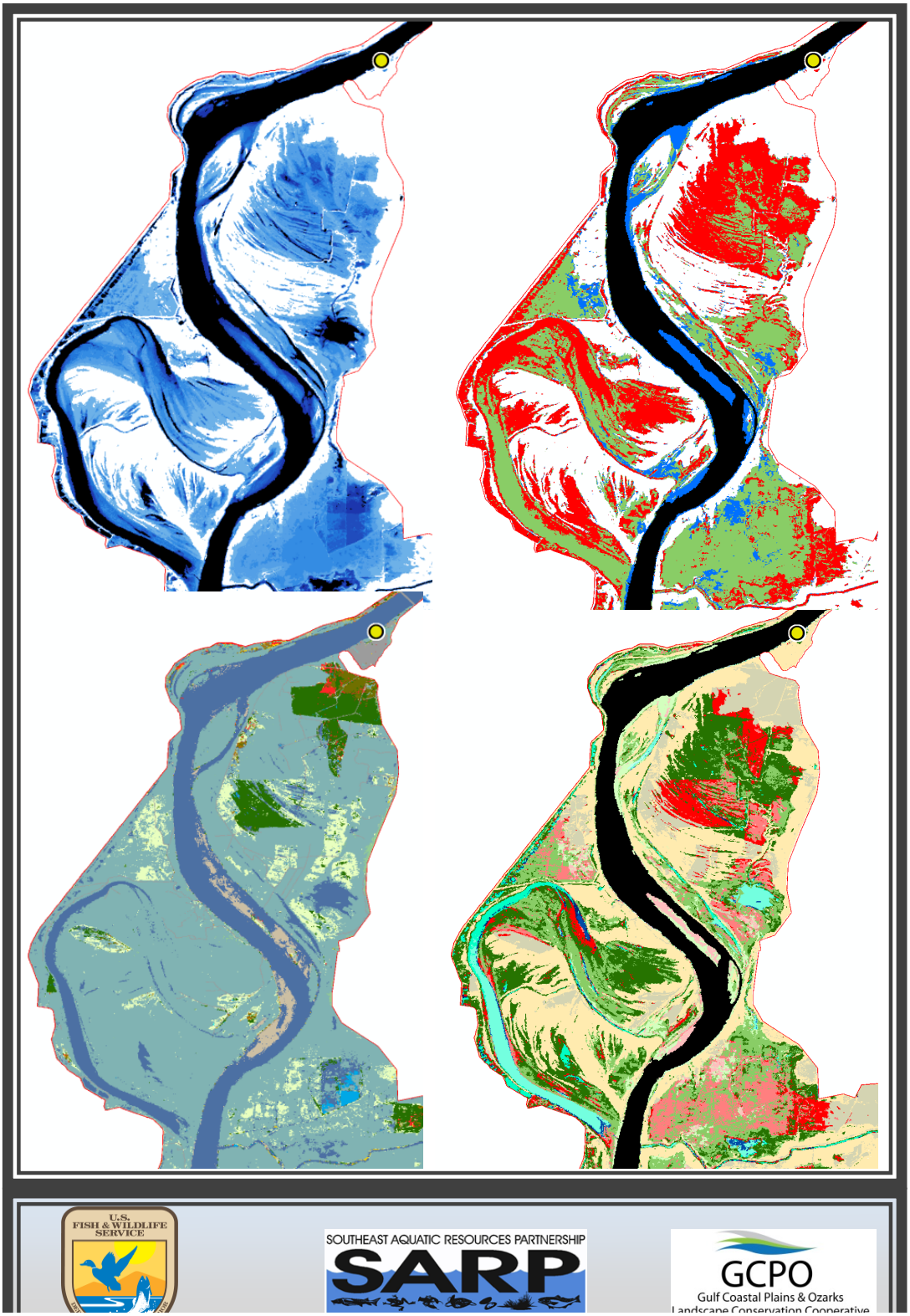
Using remote sensing to assess alligator gar spawning habitat suitability in the Lower Mississippi River



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Please cite as:

Allen, Y.C., K.M. Kimmel, and G.C. Constant 2014. Using remote sensing to assess alligator gar spawning habitat suitability in the Lower Mississippi River. U. S. Fish and Wildlife Service. Baton Rouge Fish and Wildlife Conservation Office report.

Companion geospatial data products may be found on the Gulf Coastal Plains and Ozarks Conservation Planning Atlas. This project was supported by funding from the U.S. Fish and Wildlife Service Fisheries Program, Refuge Inventory and Monitoring Program, the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative and the Southeast Aquatic Resources Partnership.

Table of Contents

List of Figures 2
List of Tables 2
Introduction 3
Methods 5
  Inundation Extent and Frequency 5
  Thermal Characteristics 6
  Physical Structure 6
Results and application of landscape data layers to define AG spawning habitat suitability 7
    Inundation Frequency 7
    Thermal Refuge 8
    Physical Structure 9
    Habitat Suitability Index: 9
Discussion 10
References 11

List of Figures

Figure 1. Location of Landsat scenes used in the analysis 18
Figure 2. High water Landsat image from 16 Feb 2010 when Natchez river stage was 49 feet. 20
Figure 3. Comparison of St. Catherine Creek NWR at low and high Mississippi river stages. 21
Figure 4. Distribution of all observed river stages at Natchez, MS compared with the distribution of observed river stages during Arpil-June at Natchez, MS and river stages associated with Landsat imagery used in this study. 22
Figure 5. Example of Landsat thermal band from 4 March 2010 masked to the approximate inundation extent at the time of acquisition. 23
Figure 6. Frequency of inundation based on 23 Landsat images from 1985-2011. 24
Figure 7. Area of inundation in two National Wildlife Refuges based on Landsat imagery. 25
Figure 8. Landsat Image captured 7 March 1988. 27
Figure 9. Occupancy of alligator gar at the Bluehole during 2012 and 2013. 28
Figure 10. Demonstration of how to relate relative inundation frequency to long term gaging station information. 29
Figure 11. Average thermal difference of wetted areas from river temperature based on Landsat thermal imagery. 30
Figure 12. Average temperature difference from the mainstem Mississippi River in the St. Catherine Creek NWR based on Landsat thermal imagery 31
Figure 13. Landscape analysis for potentially suitable AG spawning habitat. 32

List of Tables

Table 1. Preliminary estimate of variables and thresholds important to AG spawning _____ 15
Table 2. Scene-specific thermal thresholds (degrees C) for categorizing the average temperature difference from the mainstem Mississippi River._____ 16
Table 3. Assessment of alligator gar spawning habitat suitability area by ownership type. _____ 17

Introduction

The floodplain is an integral part of large river ecosystems where seasonal high flows provide connectivity from the mainstem river to the floodplain (Welcomme 1979) and seasonal inundation of the floodplain drives system productivity (Junk et al. 1989). Floodplain dependent aquatic species frequently take advantage of seasonally inundated floodplains for spawning and nursery habitat (Welcomme, 1979, Bayley 1988, Kwak 1988, Agostinho et al. 2004, Balcombe et al. 2005) where there is elevated primary productivity, more moderate environmental conditions and the physical structure of vegetation that offers refuge from predation. River regulation and other hydrologic alteration including levee construction, dam building, channel training and natural patterns of deposition and accretion have altered the magnitude, frequency, duration, timing, rate of change, and connectivity of many rivers with the adjacent floodplain. These anthropogenic changes are impacting the function of wetlands on the floodplain and in turn, impacting the mainstem river function (Poff et al 1997). On the lower Mississippi River, extensive levee construction during the last 150 years has separated over 90% of the historical floodplain from the main river channel (Baker et al. 1991). This reduction in habitat is particularly detrimental for riverine species that have evolved to depend on a much larger Mississippi River floodplain. The floodplain on the St. Catherine Creek National Wildlife Refuge (SCC; Figure 1) is one of the few areas of broad low-relief floodplain that is still directly connected to the lower Mississippi River. As a result, variation in Mississippi River level directly influences inundation extent and duration on the floodplain. The refuge lies on a narrow corridor between the Mississippi River to the west and high elevations to the east. Levees were likely not constructed to the east of the river in this location because the relatively small protected area did not justify construction and maintenance costs.

The alligator gar (*Atractosteus spatula;* AG) is a large, long-lived, physostomous fish that is dependent on floodplains inundated floodplains or wetland vegetation for spawning and nursery habitats and AG have frequently been observed using the floodplain on SCC during spring spawning months. Historically, AG were distributed throughout the central U.S., ranging from Oklahoma southward to the Gulf of Mexico but more recently, abundances have declined and AG is now considered vulnerable to localized extirpation. Several authors have cited habitat alteration and overexploitation as the most important factors in the pervasive decline in abundance (Robinson and Buchanan 1988; Simon and Wallus 1989; Etnier and Starnes 1993; Metee at al. 1996; Warren et al. 2000; Ferrara 2001; Jelks et al. 2008). Hydrologic alterations over the past century have disconnected much of the lower Mississippi River from floodplain and backwater spawning areas and this action has likely hindered reproductive success (Simmon and Wallus 1989; Etnier and Starnes 1993; Boschung and Mayden 2004). Due to concern for decreased population sizes, AG has been identified by the American Fisheries Society (AFS), the US Fish and Wildlife Service, many state fisheries programs, and the Gulf Coastal Plain Ozarks Landscape Conservation Cooperative (GCPO LCC) as a species of concern in the Mississippi Alluvial Valley (MAV).

In December 2010, members of the AFS Alligator Gar Technical Committee convened in Vicksburg, MS to identify variables and thresholds that may be most critically limiting AG populations in the lower

Mississippi River. Variables related to spawning habitat were seen to be the most limiting - specifically variables related to floodplain inundation extent and frequency, connectivity, temperature, and the availability of suitable physical structure (Table 1). The current study sought to find landscape level geospatial data that would adequately capture these variables at a landscape scale to determine locations throughout the lower Mississippi river that may offer suitable spawning habitat for alligator gar. The selection, development and application of landscape level data was guided by results from a related field effort to document AG movement and water quality conditions throughout the flood cycle on SCC (Allen et al. 2014). This field effort also provided observational data which helped to confirm and refine the variables and thresholds outlined by the AG technical committee.

Landsat satellites have provided an invaluable library of images documenting changing landscape and environmental conditions with repeat observations over the same location every 16 days. This library of imagery can assist scientists, managers and the public in understanding not only dynamics of land conditions, such as urbanization, drought, storms and fires, but it can also capture the dynamics and impacts of changing water conditions. Remotely sensed imagery has been widely used to identify the extent and frequency of floodplain inundation during peak flood events. Imagery from the first versions of the Landsat satellite (Earth Resources Technology Satellite 1) was used to document inundation extent along the Mississippi River during the historic 1973 flooding event (Deutsch et al 1974, Moore and North 1974). In Australia, Landsat imagery acquired during peak flood events has been linked to discharge measurements to provide estimates of expected inundation extent (Frazier et al. 2003, Overton 2005, Frazier and Page 2009, Wiens et al. 2009, Thomas et al. 2011). Huang et al. (2014) used multi-temporal Moderate Resolution Imaging Spectroradiometer (MODIS) imagery to provide flood inundation estimates at a landscape scale. In the southeastern US, Benke et al. (2000) used aerial images to delineate the extent of inundation at six different discharge stages for a small (7.5 km^2) watershed. Allen et al. (2008) used multiple Landsat images to characterize the extent and frequency of inundation and turbidity at a variety of river stages in the Atchafalaya Basin floodway (2,571 km^2) in south Louisiana.

For the current study, a multi-temporal analytical approach based on Landsat imagery was used to develop novel landscape scale spatial information related to inundation frequency and thermal conditions on the floodplain. These data products were combined with an existing geospatial assessment of physical structure (landcover mapping) to determine a habitat suitability measure for spawning by AG on the lower Mississippi River. While the thresholds developed for this application are specific to AG spawning, the landscape level data products of inundation frequency and thermal habitat character combined with various evaluations of land cover are potentially applicable to a wide variety of both terrestrial and aquatic species. They may, for example, be used to provide a finer resolution for evaluating the availability of waterfowl habitat during critical migration periods, to describe the potential for forest survival and regeneration under variable flooding regimes, or to determine the distribution of suitable habitat for ground nesting birds.

Methods

Landsat 5 and 7 CDR imagery was used to determine the extent of inundation at a variety of river stages. Recently, the U.S. Geological Survey has made available the surface reflectance Climate Data Record (CDR; USGS 2013). These images provide an atmospherically corrected surface reflectance product that may be more effectively used to support land change studies. Preliminary analysis focused on the Landsat scene containing SCC (Path 23, Row 38; Figure 1), but the final analysis was extended to Landsat scenes covering the entire lower Mississippi River corridor (Path 23, Rows 34-39). Only cloud-free and snow-free images captured from December-March were used in the analyses. Under leaf-off conditions, the extent of inundation is readily apparent using Landsat imagery. These selection criteria minimized the obscuring effects of tree canopy and floating vegetation and allowed for accurate classification of inundation extent. For the Landsat scene covering SCC, 23 images were found to satisfy these conditions. An example of a Landsat image captured during high water on the Mississippi river (16 Feb 2010) may be seen in Figure 2. Protection levees to the west and natural high elevations to the east limit the extent of direct inundation from the Mississippi River to its current, constrained floodplain. Figure 3 shows the extent of inundation on SCC during extremes of very low and very high water. The boundaries of the floodplain area along the Mississippi river that is still subject to direct influence from the river was defined using a combination of levee locations (USACE 2013), elevation, USGS HUC-12 boundaries, and inundation mapping (described below).

Inundation Extent and Frequency

Water increasingly absorbs light in the near and shortwave infrared wavelengths and sensors that are sensitive in this spectrum have increased capacity to delineate water boundaries. Band 5 of Landsat (1.55–1.75 µm) has been widely relied upon to discriminate water bodies from dry land. Frazier and Page (2000) determined that a simple thresholding of this band produces highly accurate results in delineating water bodies. For each image, thresholds of Landsat band 5 were used to classify categories of dry land and wet areas including flooded land and open water. This technique worked well in floodplain areas that are dominated by deciduous woody vegetation - but misclassified dense pine forests which also have very low band 5 reflectance. For this reason, a Normalized Difference Vegetation Index (NDVI; a measure of vegetation health) was also calculated for each image and pixels having NDVI > 0.42 were recoded as dry land. Simple thresholding of band 5 also misclassified shadows which have low band 5 reflectance. Since shadows are associated with high relief and this rarely occurs in broad floodplain environments, locations having low band 5 reflectance and slopes greater than 10 degrees were re-classified as dry land. Locations having dense floating aquatic vegetation were also frequently misclassified as dry land. This was not problematic within the Landsat scene including St. Catherine Creek, but it is a common problem across coastal Louisiana including the extensive Atchafalaya Basin floodplain, where dense mats of water hyacinth (*Eichhornia crassipes*) and *Salvinia* persist - even during winter and early spring – and may be frequently misclassified as land (Allen et al. 2008). It is also an issue in coastal wetlands which have dense emergent vegetation such as *Spartina alterniflora*.

All 23 classified images for this scene were then summed to determine an index of inundation frequency at each pixel location based upon these 23 images. The index was standardized by dividing by the total

number of images used in the analysis. Values for each pixel therefore indicate the frequency or proportion of observation as "wet" based on 23 observations.

Each Landsat image was associated with a key Mississippi River stage at the date and time of image capture (Figure 1). For the Landsat scene covering SCC, the key river gage is located at Natchez, MS (USACE 2012, USGS 2012), 24 km upstream from SCC. The distribution of Mississippi River stages observed at Natchez on all imagery dates was similar to the distribution of all observed river stages from 1985-2011 (Figure 4). Note that this compares the distribution of Landsat imagery with the total annual distribution of Natchez river gage data and not just with the distribution of Natchez gage data during Dec-Mar.

Thermal Characteristics

Land cover type and the fraction of vegetated cover greatly influences thermal properties of the landscape (Lillesand et al. 2004), and remotely sensed thermal data are useful in accurately characterizing the important landscape factors that determine species distribution. The Landsat thermal band from the same 23 image dates was used to determine the thermal properties in floodplain areas. An example of the Landsat thermal band masked to the approximate inundation extent on 4 Mar 2010 is shown in Figure 5. Large interannual variability in absolute temperature over wetted areas did not allow for an accurate characterization of average conditions either in the mainstem Mississippi River or on the adjacent floodplain. To reduce this variability, the long term thermal characteristics were instead calculated as the average thermal difference from the mainstem Mississippi River temperature.

The average mainstem river temperature for each image was determined by taking the average temperature for the permanently inundated portion of the river in each image (zonal statistics). The temperature at the other inundated locations was then subtracted from the average river temperature to derive a "difference from river temperature". A single composite image was then created by averaging "difference from river temperature" over all images. To reduce errors associated with taking an average from very few observations, this composite image included information only from locations that were inundated in at least 20% of all images.

Physical Structure

AG also require suitable physical structure for spawning. On 25 April 2013, AG eggs were observed adhered to submerged woody thin vegetation adjacent to shrubs and forested area on SCC. AG were also observed spawning on SCC on 22 April 2014 an area of open canopy and light vegetation. In addition, three recent reports have also observed AG spawning over submerged herbaceous vegetation with open canopy. Oklahoma Department of Wildlife Conservation observed spawning in a shallow, vegetated-backwater area of Lake Texoma, Oklahoma on March 11, 2007. On June 17, 2007 spawning was also documented in Arkansas in a tributary of the Arkansas River in tributary backwaters having open canopy with submerged vegetation (USFWS Arkansas Field Office). On May 2, 2012 Delta National Wildlife Refuge (near the mouth of the Mississippi River) documented hundreds of alligator gar spawning in four ponds. Spawning locations again appeared to be over submerged herbaceous vegetation in open canopy. Each of these reports seems to indicate that vegetated, open canopy locations appear to be preferred habitat for AG spawning.

The 2012 Cropland data layer (USDA 2012) was used to define physical structure because it offered the most current landcover evaluation. It includes details about low cover croplands that may be important in defining spawning habitat suitability, and also includes standard national land cover categories.

Results and application of landscape data layers to define AG spawning habitat suitability

Evidence from the field effort generally confirmed the importance of suitable inundation, temperature, and physical structure for AG spawning as outlined by the alligator gar technical committee in Table 1. The application of suitable thresholds to determine optimal spawning habitat based on landscape data was however adjusted somewhat based both on field observations and the most appropriate application of the remotely sensed data.

Inundation Frequency

Figure 6 shows the results of the inundation frequency analysis for the Landsat scene covering SCC. On the SCC floodplain, the extent of inundation was strongly related to river stage at Natchez, MS (Figure 7). An adjacent refuge, Bayou Cocodrie, lies west of the federal protection levees and is therefore not directly influenced by variation in Mississippi river levels. The floodplain on SCC begins to become influenced by the river above a Natchez stage of 30 feet. Figure 8 shows a Landsat image of the northern part of SCC at 30 feet - just before the point when extensive inundation begins on the floodplain. Observation of AG movement patterns based on telemetry (Allen et al. 2014) also showed that AG were increasingly restricted to deep water refugia (the Bluehole) as river levels at Natchez dropped below 40 feet (Figure 9). At and above this river level, AG were found at locations throughout the SCC floodplain. Patterns of inundation extent on SCC also shows good connectivity throughout most of the SCC floodplain when the Mississippi river at Natchez is greater than 40 feet. Because SCC is the only known location on the lower Mississippi River that provides documented suitable habitat for AG spawning, the preferred inundation threshold used to determine habitat suitability was adjusted to 42 feet to agree with actual AG use on the refuge. This threshold was chosen to represent core habitat that provides an optimal return frequency of inundation. Analysis of recent (1980-2012) river stages at Natchez, MS during the AG spawning season (April-June) showed that river stages of at least 42 feet lasting 10 days or more occurred in 23 of 33 years (70% of all years); river stages of greater than 42 feet lasting 60 days or more occurred in 12 of 33 years (36% of all years). This inundation threshold also corresponds to 50% of the cumulative observed gage heights during the AG spawning season.

To determine the relationship between mapped inundation frequency and actual river stages, the frequency of observed gage heights at Natchez, MS during the AG spawning season was compared with the frequency of gage heights observed on the dates Landsat imagery was captured. Mapped inundation extents greater than Natchez=42 feet are only observed in 20% of the images (Figure 4). Locations having an inundation frequency of less than 0.8 were therefore chosen as potentially optimal spawning habitat and coded as 1. Locations having an inundation frequency of greater than 0.8 were coded as zero.

The same techniques used to determine optimal inundation extent and frequency for a single Landsat scene (above) were then expanded to 5 other Landsat scenes up and down the Mississippi River corridor (Figure 1) to determine all locations on the lower Mississippi River that have comparable inundation frequency patterns.

To determine the appropriate threshold for other scenes, the distribution of gage heights on imagery dates in each scene were compared with the long term temporal gaging history at key gaging stations (USACE 2013, Figure 1) along the Mississippi River. For each scene, an inundation frequency threshold was chosen that represents locations that are expected to be inundated at least 50% of the time during the spring spawning months (Figure 10). Locations that were inundated at or below this threshold were identified as habitat that has optimal inundation frequency.

Telemetry and observational data on SCC also confirmed that only temporarily inundated locations were selected for spawning. Locations that were persistently inundated (in 90% of all images) were therefore coded as non-preferred habitat (zero). All locations within the mainstem of the Mississippi River were also excluded because flow conditions in the river were considered to be unsuitable for successful spawning. Locations satisfying all the above inundation requirements were coded as suitable, any other locations were coded as unsuitable. Based on these definitions, 15% of the entire lower Mississippi river corridor has optimal inundation frequency.

The current analysis of comparable inundation relies on a relationship between inundation extent and a representative gaging station for a particular watershed; in this case, an examination of areas directly influenced by the mainstem Mississippi River. For that reason, locations outside of the direct influence of the Mississippi River were excluded from consideration of AG spawning habitat suitability. A separate analysis of inundation frequency for other locations is possible using the same inundation mapping product, but a new relationship would need to be established to relate Landsat inundation with long term gaging data at a key stations for that watershed.

Thermal Refuge

Thermal imagery showed that floodplain habitats offer a thermal advantage compared to mainstem Mississippi river temperatures during the winter-early spring months (Figure 11). Based on this imagery, the floodplain in SCC appears to be on average 3-4 degrees warmer compared with the river (Figure 12). Furthermore, comparison of individual thermal images suggests that the floodplain in northern half of SCC is largely protected from direct river influence under even under very high river conditions. Visual inspection of thermal imagery later into the growing season also showed that temperatures over dry open fields and lightly vegetated areas were higher compared with surrounding forested habitats having denser canopy cover. Observations from the combination of the thermal imagery with observations of AG movement patterns and *in situ* temperature loggers indicated that AG may be selecting the warmest habitats on the SCC floodplain.

For those reasons, locations were coded into three classes based on their thermal difference from the river. For the Landsat scene covering SCC, locations that were <=2 degrees Celsius warmer than the

river were coded with zero; locations that were >2 degrees and <= 3.25 degrees Celsius warmer than the river were coded with 0.5; locations that were >3.25 degrees Celsius warmer than the river were coded with one.

Because of latitudinal differences, floodplain locations in Landsat scenes north of SCC did not offer the same magnitude of thermal refuge. In an effort to still identify those locations on the entire lower Mississippi river floodplain that may offer some degree of thermal refuge, scene specific thresholds were used to categorize the average thermal difference from the river into categories of cool, acceptable, and good (Table 2). In establishing these thresholds, an attempt was made to ensure that locations in overlapping scenes were classified comparably.

Physical Structure

Each habitat type in the USDA cropland data layer was assigned either a one or zero depending on the value of that habitat to provide open or low canopy vegetation that may be most suitable for AG spawning. Since spawned AG eggs were found adjacent to shrub-scrub, these locations were also included as preferred habitat. Active croplands, pasturelands, fallow croplands, shrubs and herbaceous wetlands were all coded as preferred habitat; woody wetlands and deciduous forest were coded as non-preferred habitat. Based on the 2012 Cropland data layer alone, 62% of the total non-open water area within the lower Mississippi river corridor (70,367 km^2) is forested, 3% is developed, and the remaining 35% has low/no canopy physical structure.

Habitat Suitability Index:

A landscape level AG spawning habitat suitability data layer was developed using a combination of inundation frequency, land cover, and thermal characteristics derived from related landscape level analyses (Figure 13). In an effort to identify the factors that may be most limiting, the results were grouped into categories based on the outcome from each landscape evaluation. Because the ground observation data, inundation frequency and thermal parameters are strictly related to observations in environments connected with the mainstem Mississippi River, each data layer was masked to include only locations that are directly affected by the Mississippi River.

For all Mississippi river locations within the 23/38 Landsat scene, SCC contained the greatest prevalence of highly suitable AG spawning habitat. A comparison of habitat suitability results within the entire lower Mississippi River corridor and ownership type is shown in Table 3. 83% of highly suitable habitat (inundation good, habitat good and temperature good) within the lower Mississippi River corridor is currently under private ownership. 12% of highly suitable area is under federal ownership. The floodplain on SCC alone represents 8% of all highly suitable AG spawning habitat within the lower Mississippi River corridor. GIS data layers for the AG HSI along with input data layers of inundation, thermal refuge and physical structure for the entire Mississippi river corridor may be found on the GCPO LCC Conservation Planning Atlas (http://gcpolcc.databasin.org/galleries/a9f79c067d114f9fb6b75ba5cdf651b1). This analysis may be used to screen for locations in the lower Mississippi river corridor that may be suitable for AG spawning.

Discussion

Large river floodplains are widely recognized to provide important habitat for a large diversity of fish and invertebrates but until now, they has been very little spatially complete information available to characterize this habitat. The current study presents a detailed documentation of the development of novel data layers that may be used to characterize the extent, inundation frequency, and thermal character of floodplain habitats. It also demonstrates the application of these and ancillary data layers to identify locations that may offer suitable spawning habitat for AG – a species that has seen significant declines in range and abundance. Typically, managers of large river floodplains have relied on only a limited set of spatial information that mainly characterizes terrestrial features like land cover type and geomorphology. Land cover datasets provide extremely valuable information related to the physical structure of habitats that may be seasonally inundated. However, in the absence of a detailed numerical hydraulic model, spatial data products describing the timing, frequency, duration, and spatial extent of floodplain inundation are typically not available for the Mississippi River. Inundation frequency is a primary driver of floodplain function and habitat quality and the tools presented here may provide needed information to improve conservation and management of AG and other many other floodplain dependent species.

Although the application presented here defines AG spawning habitat in the lower Mississippi river, inundation frequency may be applied to evaluate habitat for many different species – only details about location, scale, season and thresholds will change. The current study identified locations within the Mississippi river corridor that are inundated at least 50% of the time during the months of April, May and June. In another application, Piazza et al. (2014) used a similar inundation frequency product based on Landsat imagery to define locations within the Atchafalaya basin that may be optimal for cypress seedling regeneration. They used the historical records for a local gaging station and the same inundation frequency approach presented in this study to find locations within the basin are expected to have greater than 100, but less than 180 consecutive dry days during the growing season of 1 April – 31 October. Similarly, the focus of the current study was on a warm water species that may be looking for these warmest locations to optimize growth. Other analyses may use a similar approach using Landsat thermal band data to focus on the frequency of extreme summer temperatures to define the current habitat distribution of cool and cold water aquatic species.

Analysis using remotely sensed thermal imagery has consistently demonstrated that open dry land with low or no tree canopy experience higher temperatures than forested locations (Lillesand et al. 2004, Rogan et al. 2013). On the Mississippi river, mainstem temperatures are cool during the spring spawning season. Adjacent open canopy floodplains that experience regular inundation may offer the highest temperatures for egg incubation and larval growth while also providing suitable physical structure for egg adhesion and larval refuge.

Currently, the most suitable AG spawning habitat within the lower Mississippi river corridor is extremely limited. In the lower Mississippi river, the floodplain on SCC represents some of the last remaining area having a combination of broad, low-relief floodplain, adjacent areas of permanent inundation, large areas of low/open canopy and moderate connectivity to the Mississippi river. In most locations, federal

protection levees have isolated areas having broad, low relief floodplain from the Mississippi river, but the AG habitat suitability map can provide managers with needed information to identify remaining high value opportunities for conservation. Other floodplain locations may also be targeted to improve AG spawning habitat suitability through alterations to inundation regime, connectivity with the Mississippi or physical habitat structure. For example, some locations appear to be unsuitable because they lack the appropriate inundation frequency. In these locations, structural modifications may be possible to improve connectivity with the mainstem Mississippi River and/or increase the extent and duration of inundation on the floodplain. Detailed examination of inundation patterns at higher river levels, for example, may reveal whether opportunities exist to increase inundation at a given location through barrier removal or addition.

Conservation measures designed to increase inundation frequency, however, should also consider the potential impact that increased connectivity might have on the thermal suitability of available deep water refuges. During low water periods on SCC, AG were most commonly found in a small, confined deep water refuge high on the SCC floodplain. Field observations (Allen et al. 2014) demonstrated that temperatures at this location (Bluehole) were also, on average, 4-5 degrees C warmer than the mainstem Mississippi river throughout the winter and spring. Adult AG were less frequently found in other permanently inundated water bodies (Butler and Salt Lakes) which are located more proximate to the Mississippi River. These lakes and their adjacent floodplains are more directly connected with the mainstem Mississippi river and as a result, they more commonly experienced sharp declines in temperature with rapid increases in river level. This thermal differential may allow not only for increased spawning success, but also for increased adult growth potential in floodplain lakes that have moderate connectivity with the Mississippi river compared with lakes that have more direct year round influence from the river.

Opportunistic observations of spawning behavior and egg deposition on SCC and at other locations seem to suggest that open-canopy, low vegetation floodplains are preferred over densely forested habitats for AG spawning. In the current analysis, therefore, locations classified as “woody wetland” or “forest” were coded as poor habitat for AG spawning. Within the currently constrained corridor of the lower Mississippi River floodplain, there are many locations that have the appropriate inundation and thermal requirements for AG spawning, but are not considered “optimal” in this analysis because they are forested. The importance of this physical habitat requirement has significant conservation and land management implications that may be at odds with requirements for other species in need of conservation. For this reason, future species-level studies should carefully evaluate the importance of open-canopy physical structure requirements for AG spawning.

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Table 1. Preliminary estimate of variables and thresholds important to AG spawning as defined by the AG technical committee (AGTC) compared with final thresholds used to define AG spawning habitat suitability mapping product in the lower Mississippi river corridor. Modifications were made to the AGTC thresholds based on field observations of habitat use and the most suitable application available data layers.

Variable	**AGTC Threshold**	**AG HSI**	
		Data Layer	**Threshold**
Water presence	X	Inundation frequency mapping product	wet
Water class	Temporarily flooded	Inundation frequency mapping product	Flooded in <90% of imagery
Flood frequency	100% of all years = optimal 14% of all years = minimum	1) long term gaging information 2) Inundation frequency mapping product	1) River stage that is attained at least 50% of the time during April-June based on cumulative distribution at a key gaging station 2) Corresponding inundation frequency for that river stage threshold based on cumulative distribution of observed Landsat imagery
Flood duration	60 days = optimal 10 days = minimal		
Water depth	1'-4'	n/a	n/a
Connectivity	X	Viewable in mapping product	n/a
Water temperature	65-72°F (18-22°C)	Thermal difference from river	Three categories: good, acceptable and poor that vary depending on Landsat scene
Vegetation type	Herbaceous wetlands, agriculture, and moist-soil = optimal shrub-scrub = suitable	USDA 2012 Cropland data layer	All active cropland except tree crops, fallow cropland, herbaceous wetland, grassland, shrub-scrub

Table 2. Scene-specific thermal thresholds (degrees C) for categorizing the average temperature difference from the mainstem Mississippi River.

Scene	Cool	Acceptable	Good
23/34	0-1.0	1.0-3.5	>3.5
23/35	0-0.3	0.3-1.5	>1.5
23/36	0-1.0	1.0-2.25	>2.25
23/37	0-1.0	1.0-2.75	>2.75
23/38	0-2.0	2.0-3.25	>3.25
23/39	0-2.0	2.0-3.25	>3.25

Table 3. Assessment of alligator gar spawning habitat suitability area by ownership type. Note that areas coded as mainstem Mississippi river are excluded.

Habitat Suitability Characteristics	Federal Land (km^2)	Private Conservation Land (km^2)	Private Land (km^2)	State Land (km^2)	Grand Total (km^2)	
inundation good, habitat good, temperature good	13	-	87	4	105	1.4%
inundation good, habitat good, temperature ok	16	-	83	4	104	1.4%
inundation good, habitat good, temperature poor	2	-	59	2	63	0.8%
inundation good, habitat poor, temperature good	45	-	473	23	541	7.1%
inundation good, habitat poor, temperature ok	34	0.01	504	28	566	7.5%
inundation good, habitat poor, temperature poor	7	0.01	236	9	251	3.3%
inundation too dry, habitat good, temperature unknown	21	0.00	1,983	66	2,070	27.4%
inundation too dry, habitat poor, temperature unknown	125	0.04	3,162	191	3,478	46.0%
inundation too wet, habitat good, temperature good	0	-	11	1	13	0.2%
inundation too wet, habitat good, temperature ok	0	-	9	1	11	0.1%
inundation too wet, habitat good, temperature poor	0	-	3	0	3	0.0%
inundation too wet, habitat poor, temperature good	2	-	103	4	109	1.4%
inundation too wet, habitat poor, temperature ok	3	0.00	210	9	222	2.9%
inundation too wet, habitat poor, temperature poor	0	-	29	0	30	0.4%

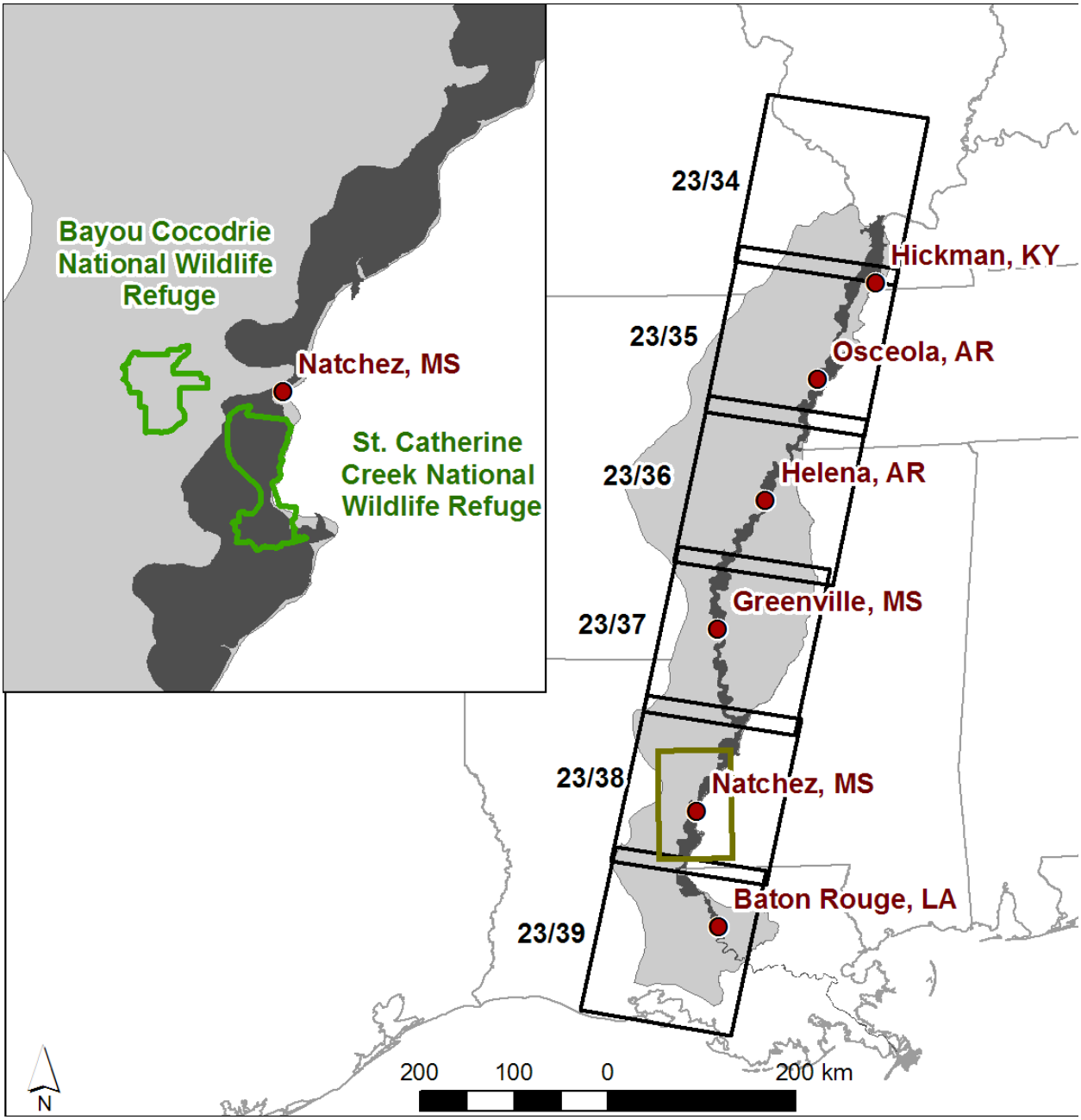


Figure 1. Location of Landsat scenes used in the analysis (black outline). The location key long term gaging stations associated with each scene is indicated with red dots. The Mississippi Alluvial Valley (MAV) is shaded in light grey. Dark grey shading shows the approximate current extent of the Mississippi River floodplain. The locations of the St. Catherine Creek and Bayou Cocodrie National Wildlife Refuges are shown in the inset map highlighted in green.

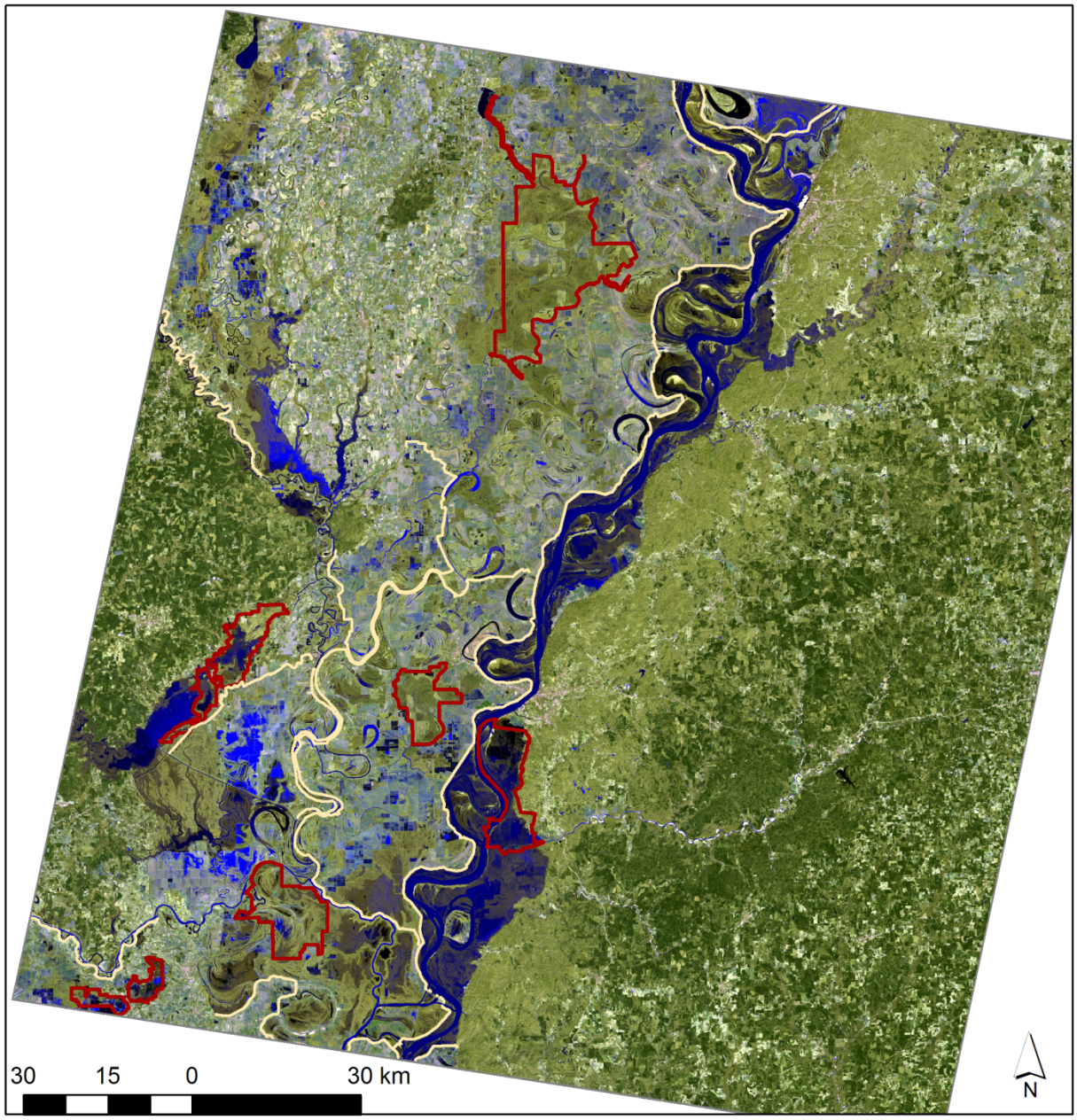


Figure 2. High water Landsat image from 16 Feb 2010 when Natchez river stage was 49 feet. Blue areas on the image are inundated. National wildlife refuge analysis boundaries are shown in red outlines. Federal protection levees are shown in light yellow.

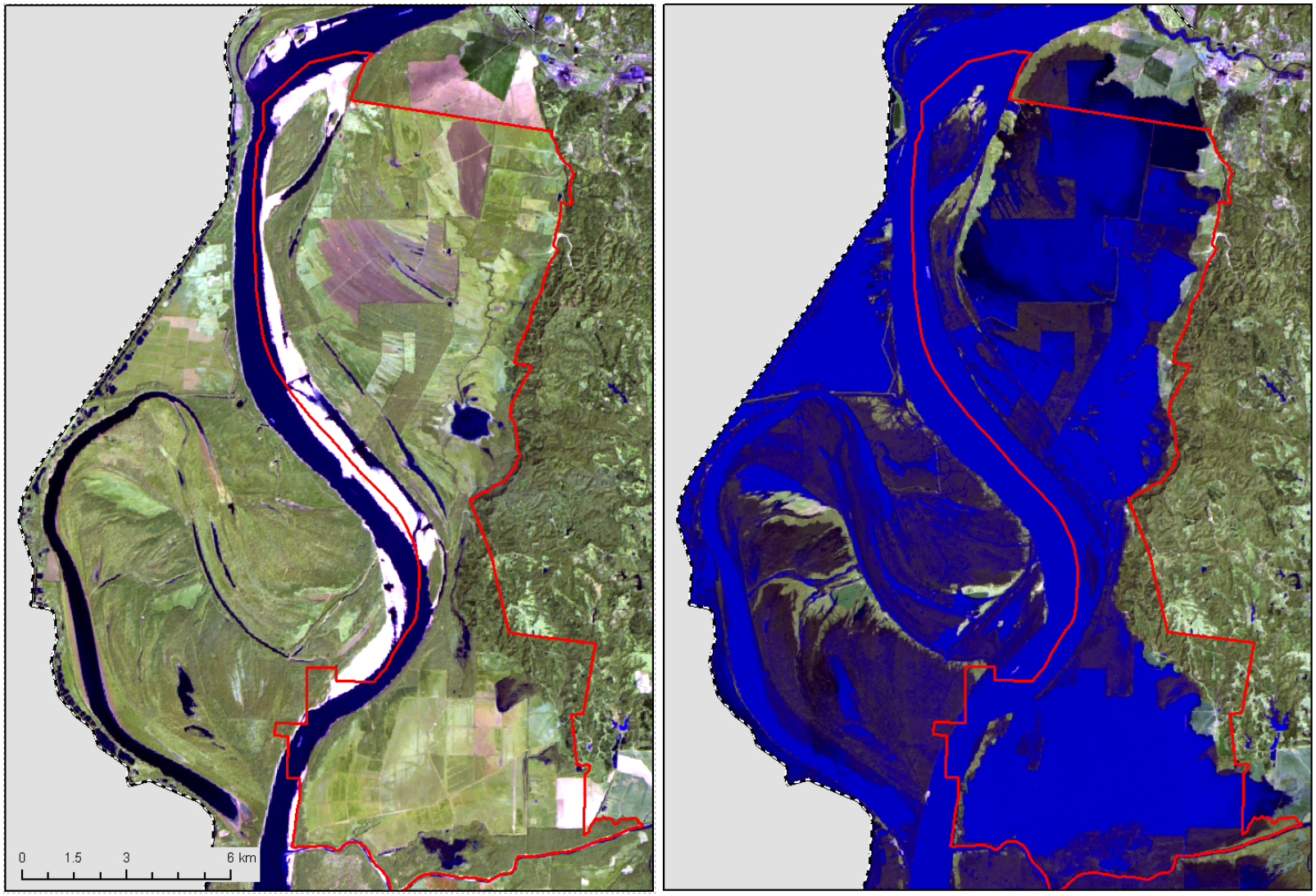


Figure 3. Comparison of St. Catherine Creek NWR at low (left; Natchez =9.5; 21 Feb 2000) and high (right; Natchez = 49; 16 Feb 2010) Mississippi river stages.

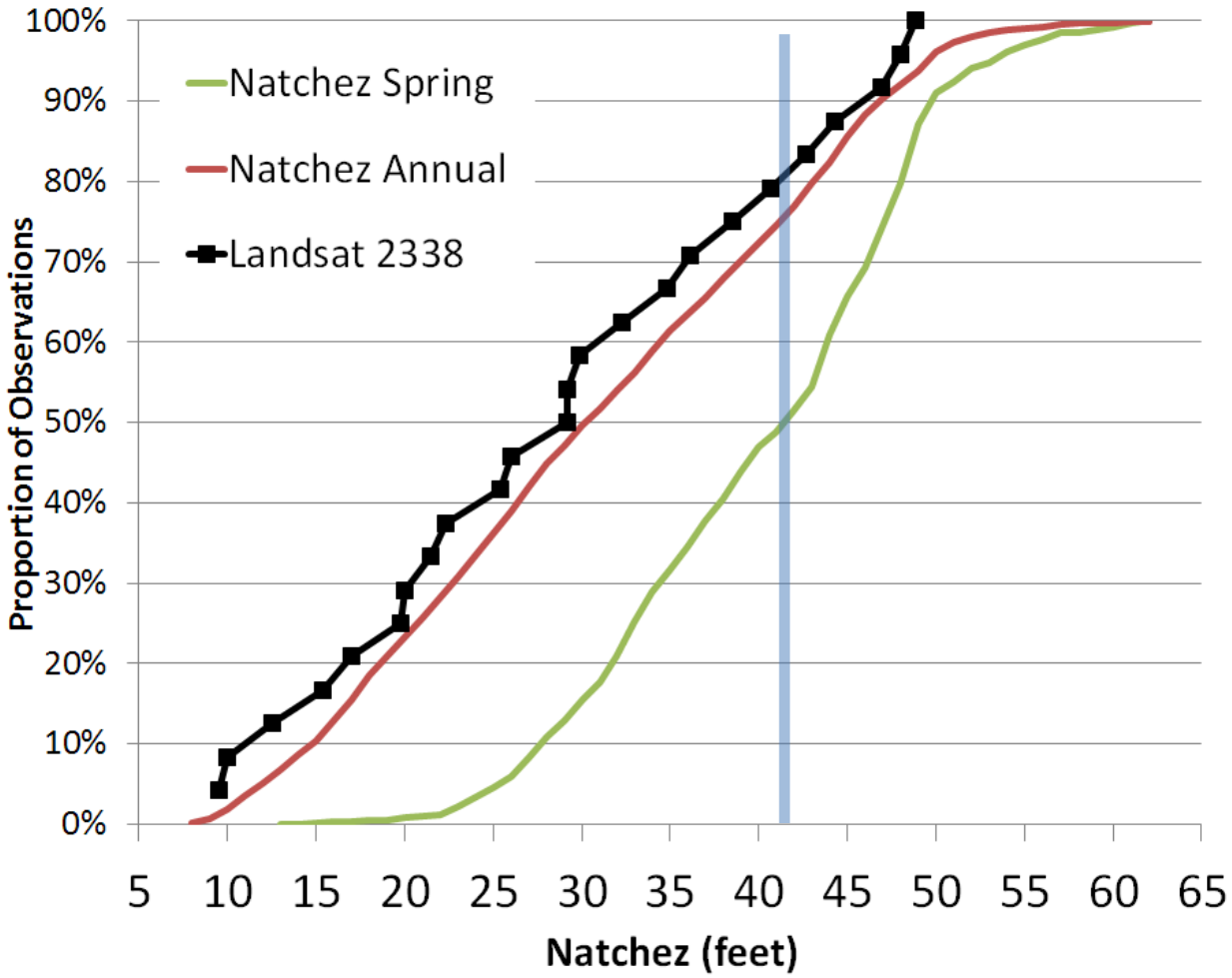


Figure 4. Distribution of all observed river stages at Natchez, MS from 1985-2010 (red) compared with the distribution of observed river stages during Arpil-June at Natchez, MS from 1985-2010 (green) and river stages associated with Landsat imagery used in this study (black). Blue line shows the threshold used to define optimal inundation extent and frequency.

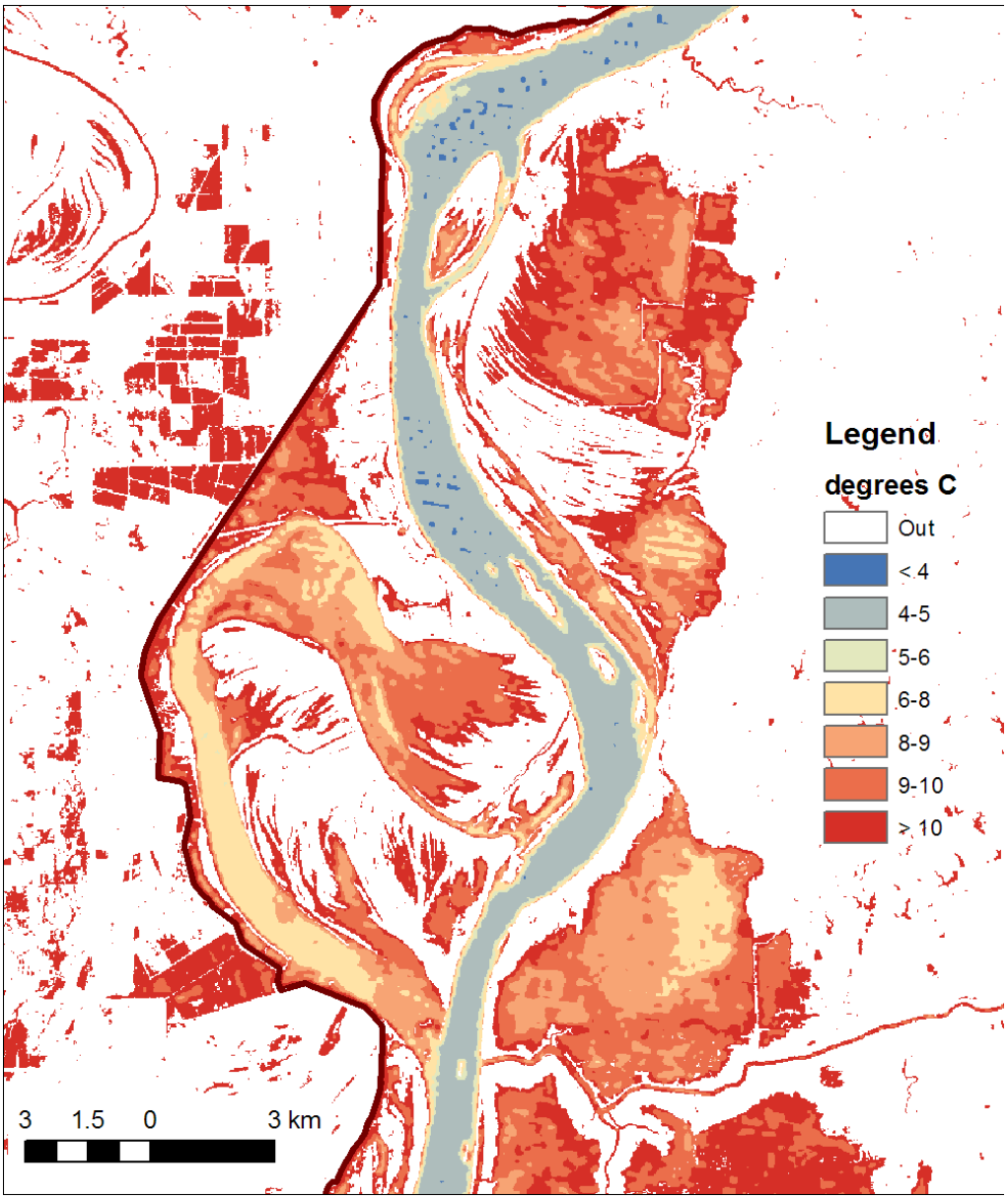


Figure 5. Example of Landsat thermal band from 4 March 2010 masked to the approximate inundation extent at the time of acquisition. Note cooler water in floodplain waters that are more directly connected with Mississippi river water inputs.

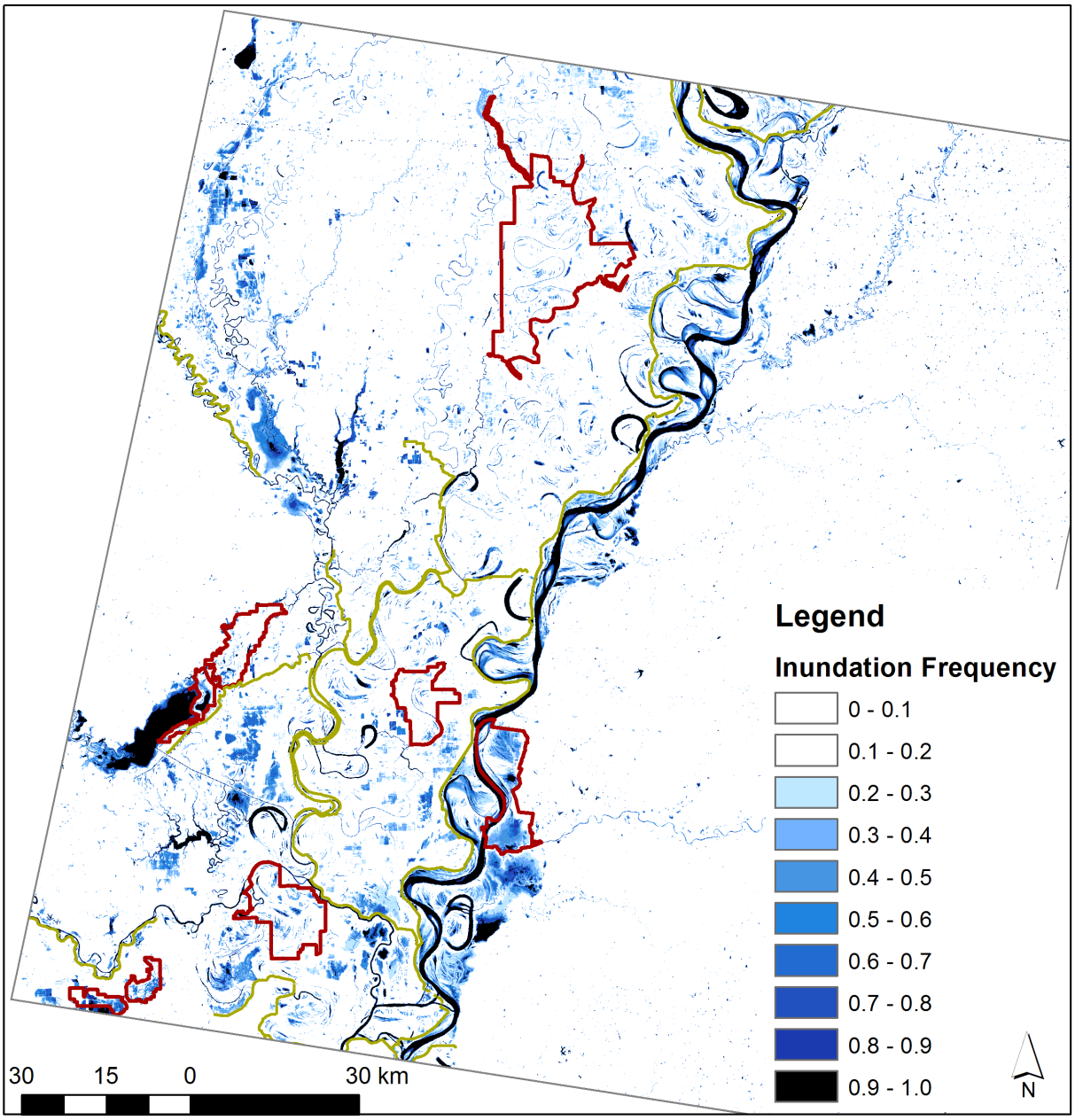


Figure 6. Frequency of inundation (both open water and flooded land categories) based on 23 Landsat images (Path 23 Row 38) from 1985-2011. National wildlife refuge analysis boundaries are shown in red. The location of federal protection levees is shown in yellow.

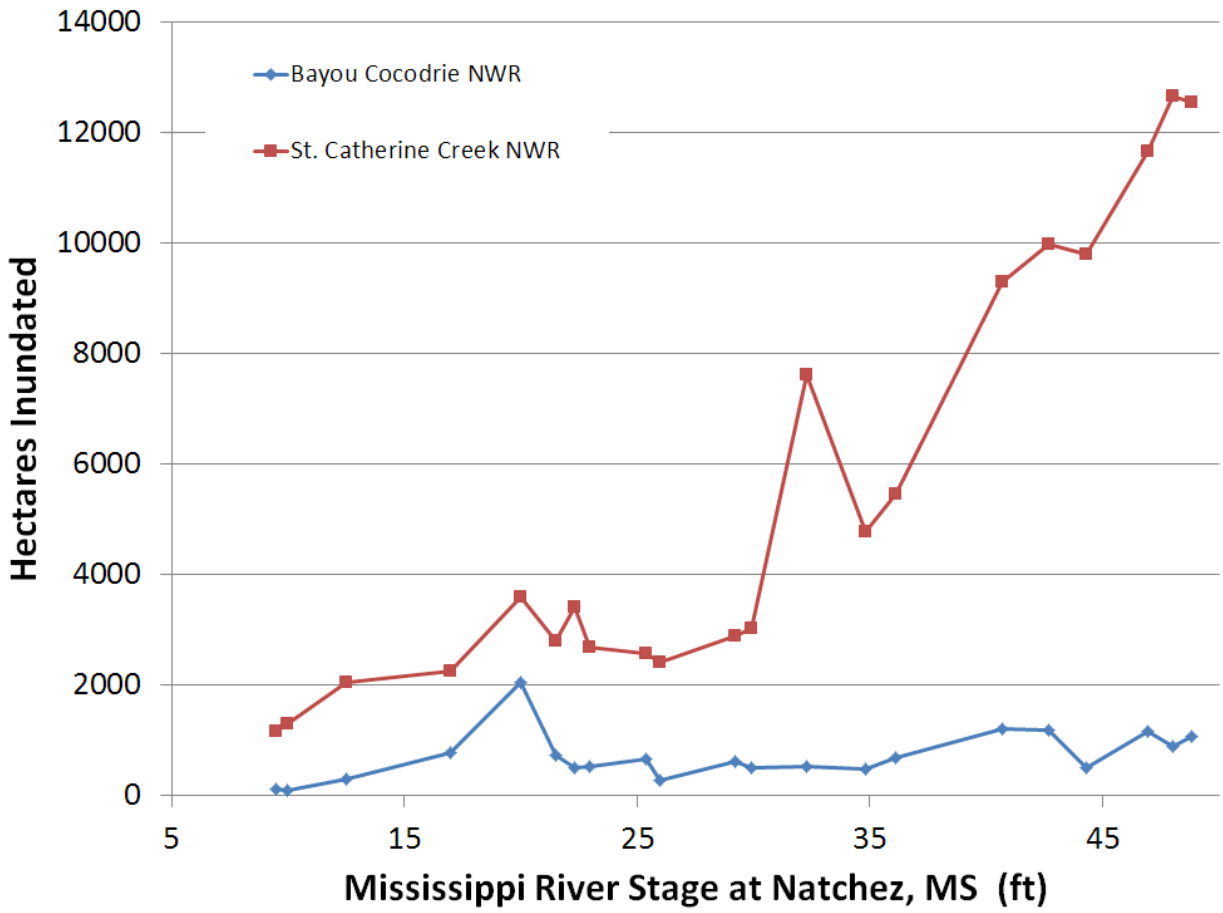


Figure 7. Area of inundation in two National Wildlife Refuges (NWR) based on Landsat imagery. The St. Catherine Creek NWR is subject to direct inundation from the Mississippi river. The Bayou Cocodrie NWR lies outside of the influence of the Mississippi river.

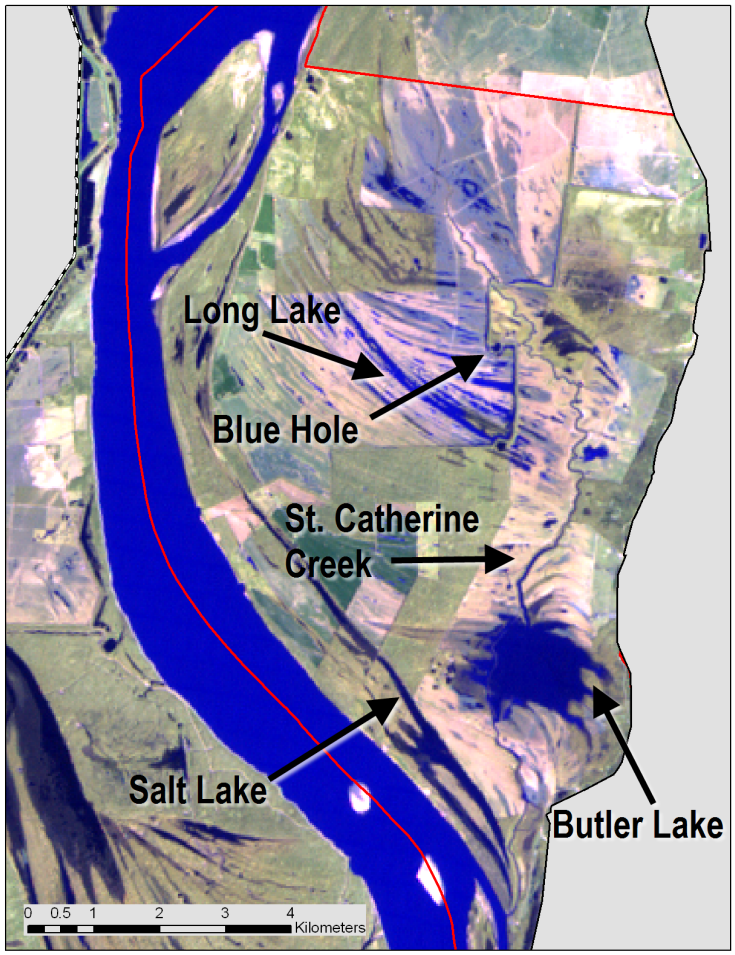


Figure 8. Landsat Image captured 7 March 1988. Natchez river stage was 30 feet

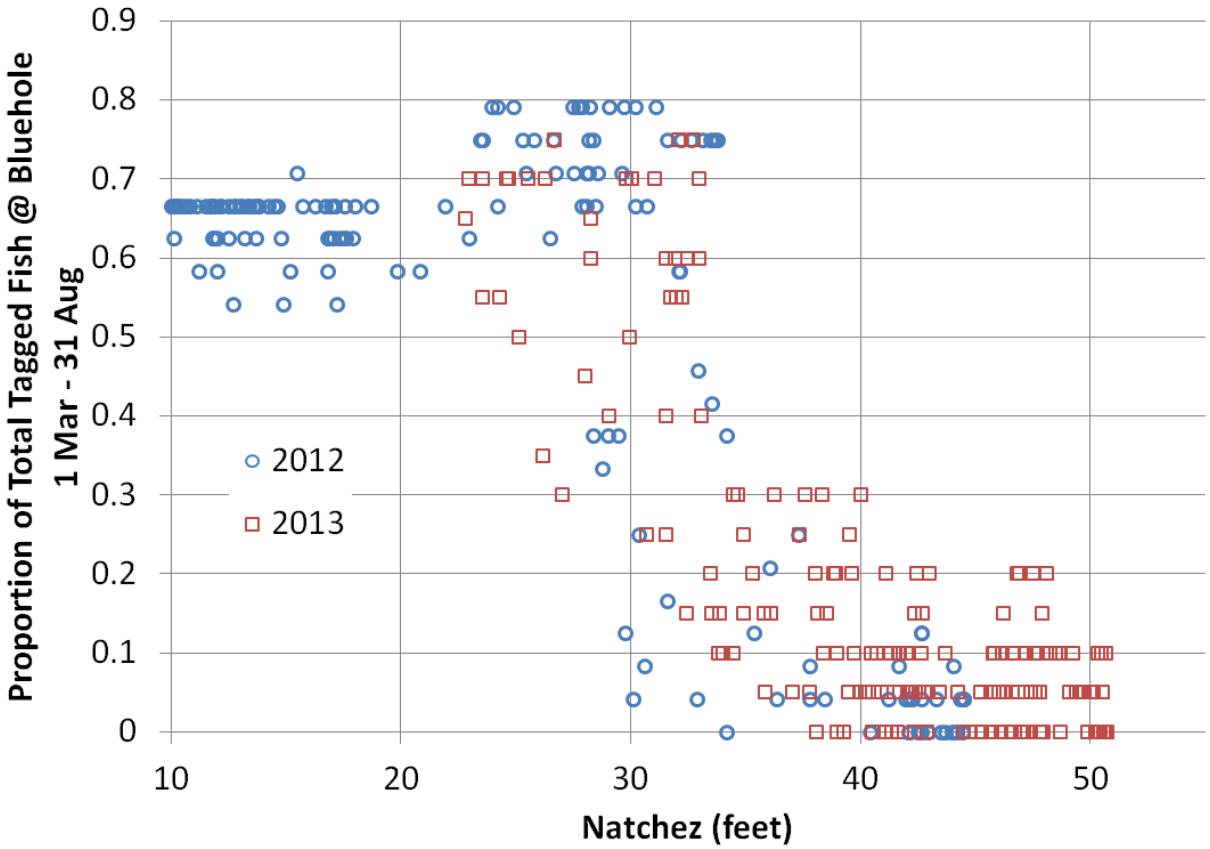


Figure 9. Occupancy of alligator gar at the Bluehole from 1 Mar – 31 Aug during 2012 and 2013.

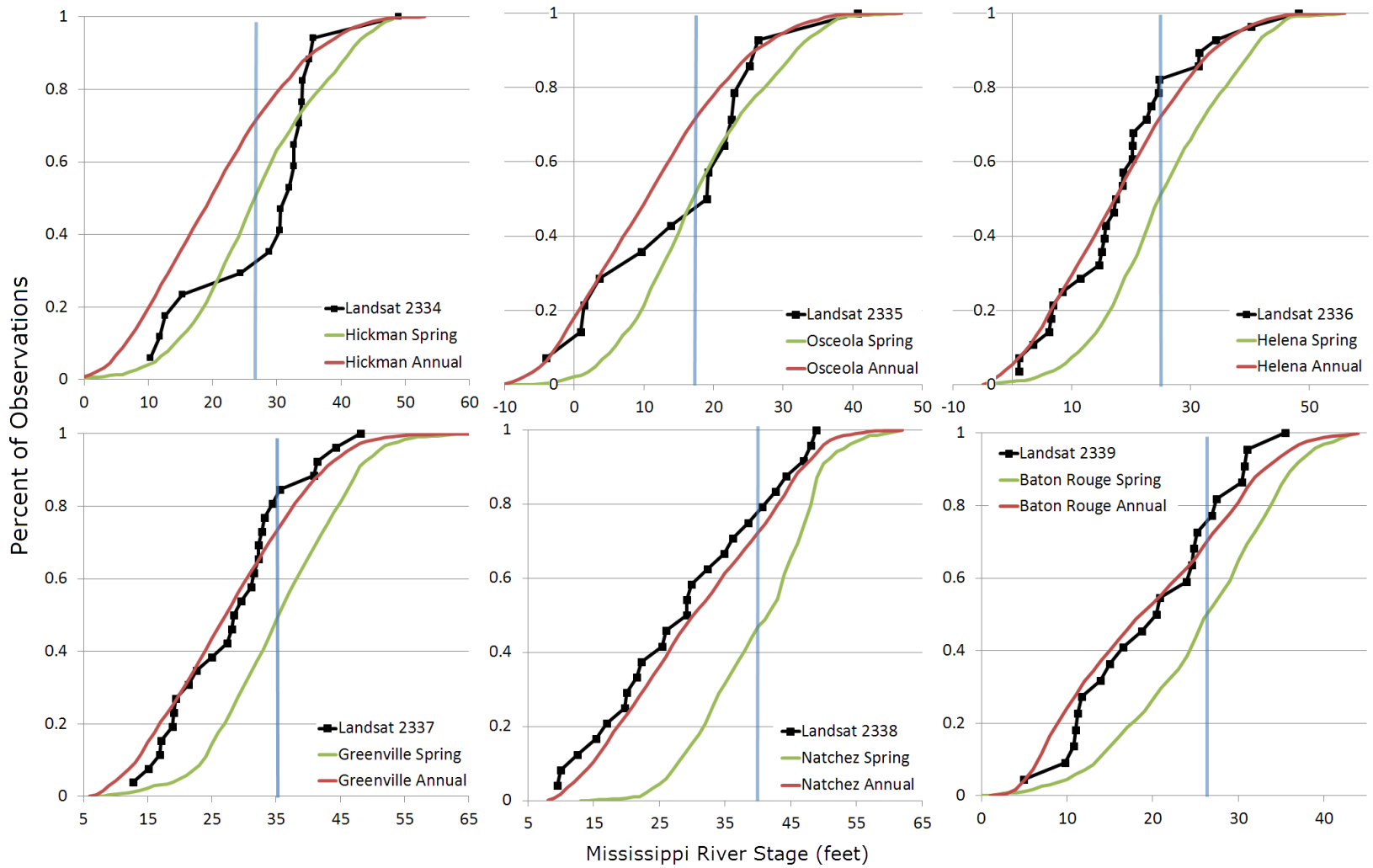


Figure 10. Demonstration of how to relate relative inundation frequency to long term gaging station information. Each panel represents a single Landsat scene along the lower Mississippi River corridor. Black lines show the cumulative distribution of gage heights on Landsat imagery dates. Red lines show the annual cumulative distribution of all gage heights at key gaging stations from 1983-2012. Green lines show the cumulative distribution of gage heights at key gaging stations during spring spawning months. The blue lines indicate the river stage which is achieved 50% of the time during spring spawning months for alligator gar.

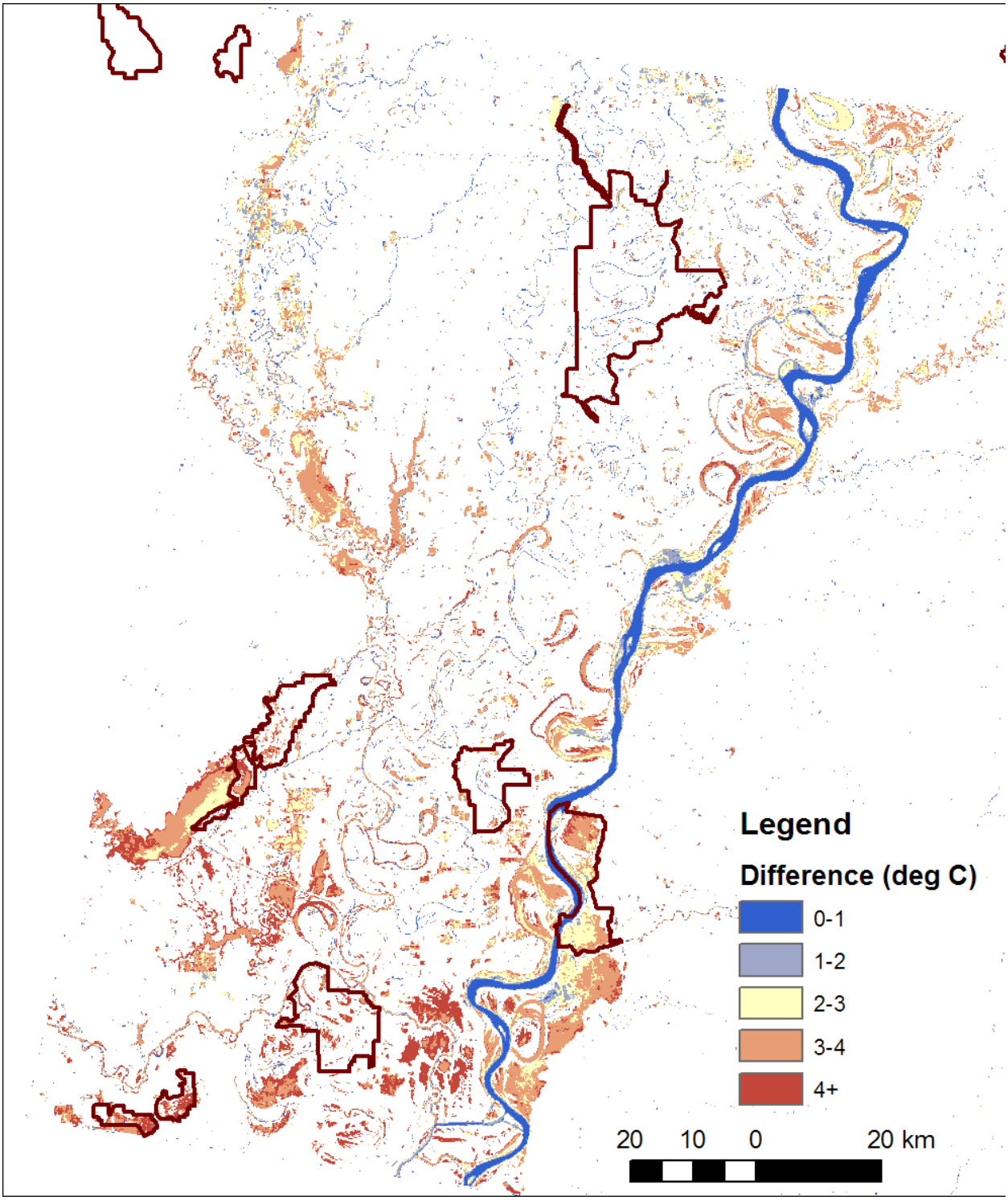


Figure 11. Average thermal difference of wetted areas from river temperature based on Landsat thermal imagery from 1985-2010. National wildlife refuge analysis boundaries are shown in red.

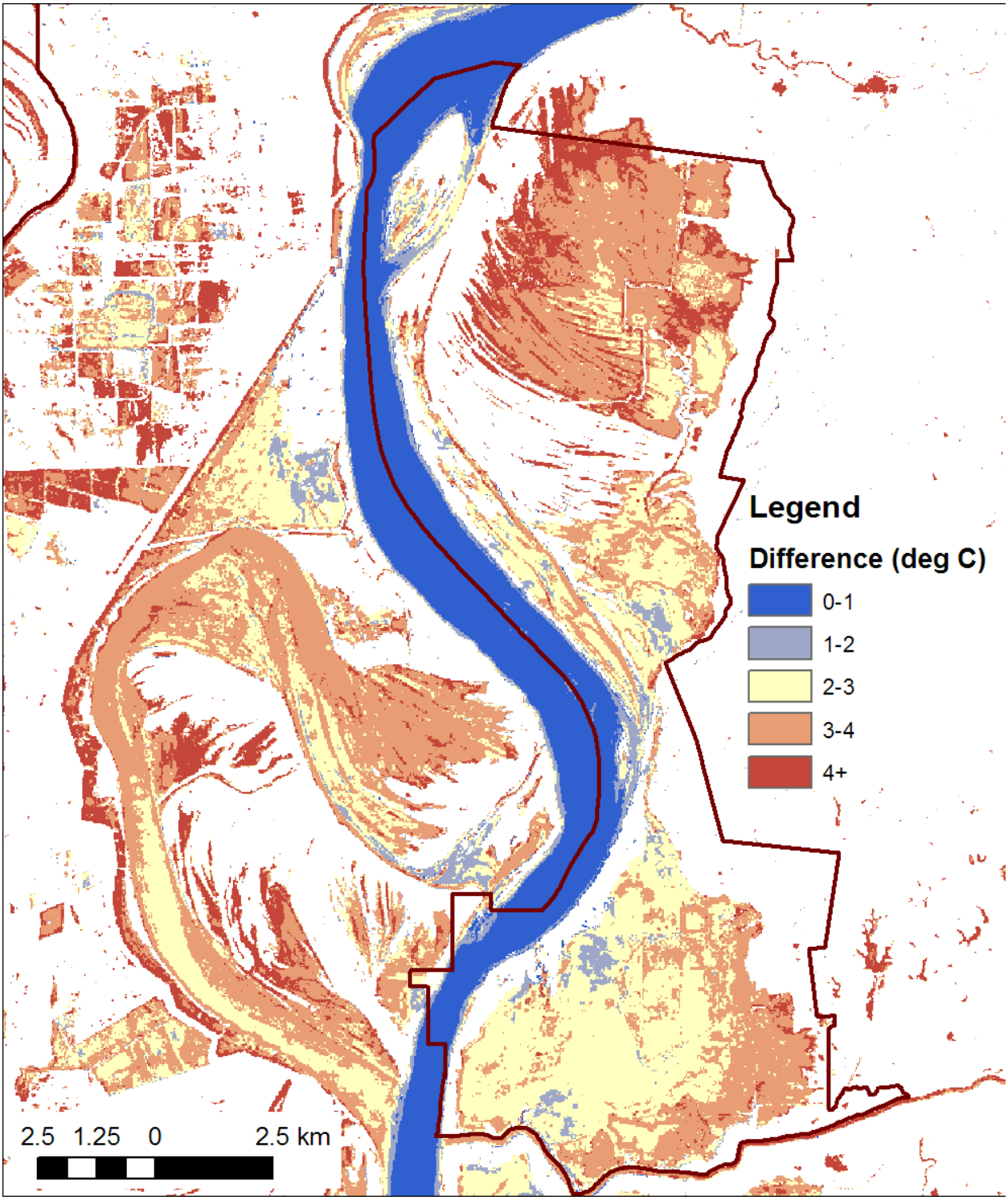


Figure 12. Average temperature difference from the mainstem Mississippi River in the St. Catherine Creek NWR based on Landsat thermal imagery (Dec-Mar only) from 1985-2010. National wildlife refuge analysis boundaries are shown in red.

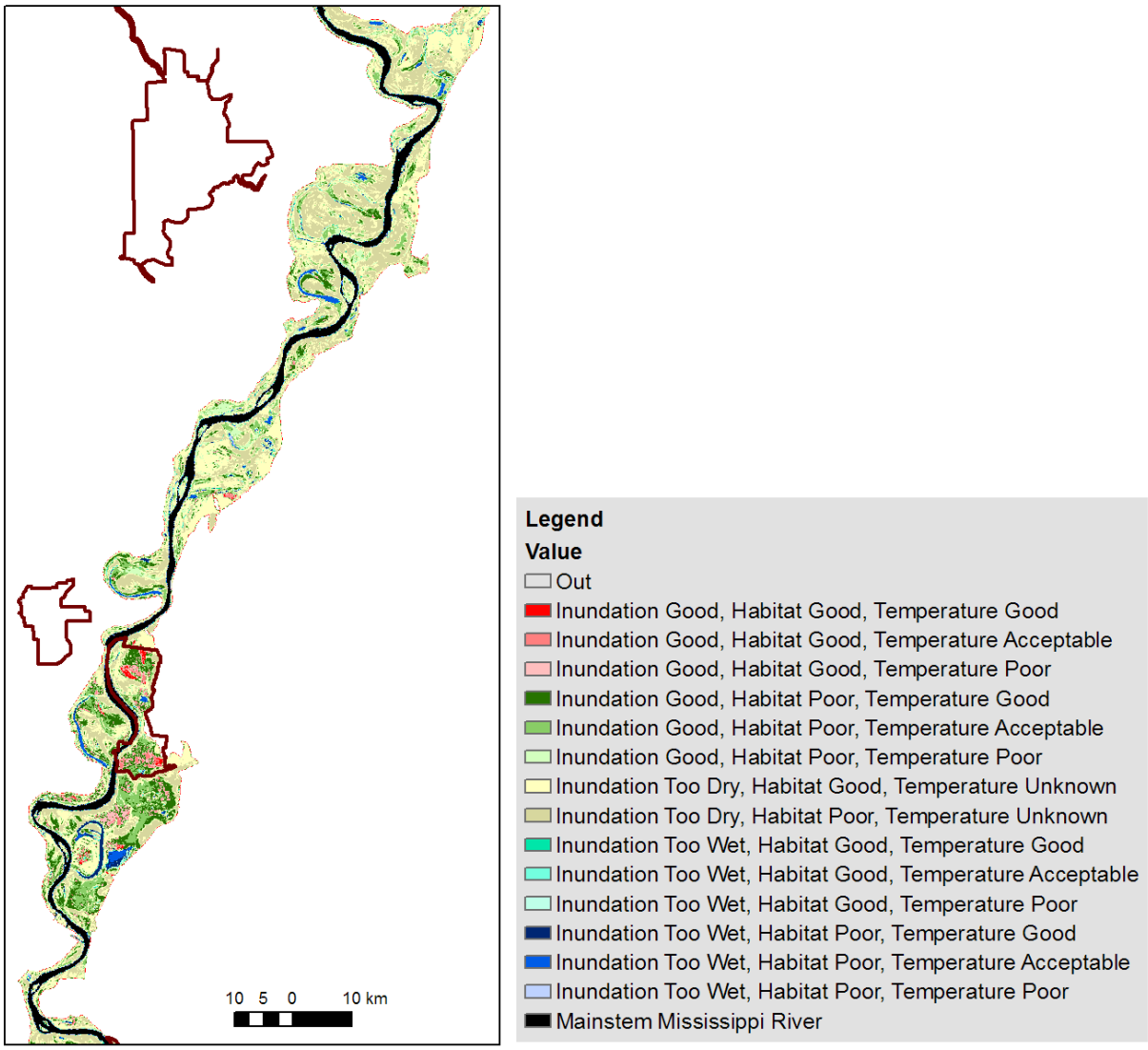
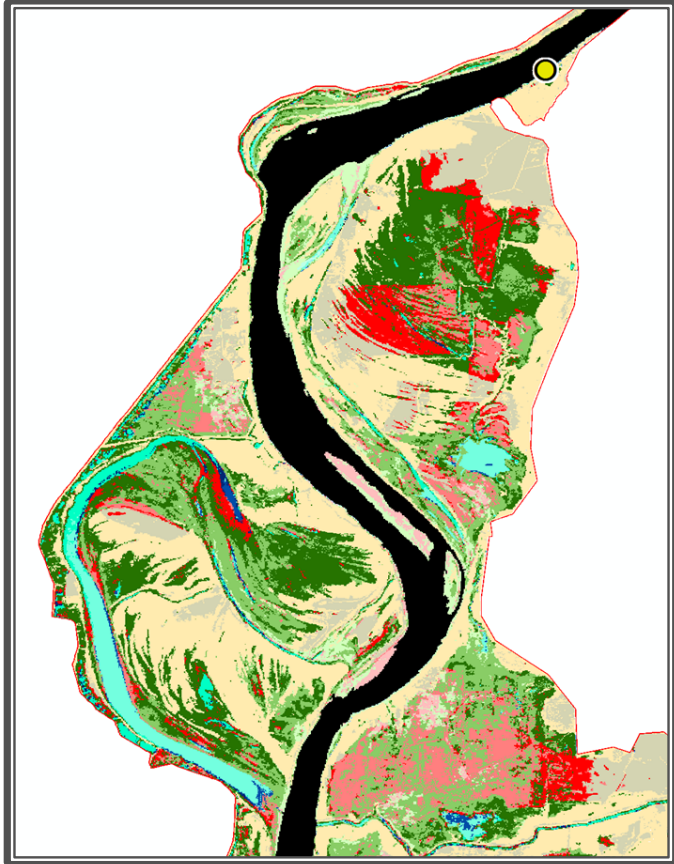


Figure 13. Landscape analysis for potentially suitable AG spawning habitat. Suitability rank is based on conditions of inundation frequency, average thermal difference from Mississippi River temperatures and physical habitat. Analysis is constrained locations that are directly influenced by the Mississippi River. National wildlife refuge analysis boundaries are shown in red.

Using remote sensing to assess alligator gar spawning habitat suitability in the Lower Mississippi River



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