Mainstem Big Rivers in the Mississippi Alluvial Valley (MAV)

INTRODUCTION 4

References 8
Tables and Figures 9
DREDGING 10

DESIRED LANDSCAPE ENDPOINT: MAINTAIN CURRENT RIVER MILES 18

LANDSCAPE ATTRIBUTE: AMOUNT 18
Data Sources and Processing Methods: 18
Summary of Findings: 18
Future Directions and Limitations: 19
Tables and Figures: 19
Links to Available Geospatial Data Outputs 21

DESIRED LANDSCAPE ENDPOINT: LINEAR CONNECTEDNESS 22

LANDSCAPE ATTRIBUTE: CONFIGURATION 22
Data Sources and Processing Methods: 22
Summary of Findings: 22
Future Directions and Limitations: 22
References 23
Tables and Figures: 24
Links to Available Geospatial Data Outputs 27

DESIRED LANDSCAPE ENDPOINT: MAINTAIN A DIVERSITY OF HABITAT TYPES – SAND BARS 28

LANDSCAPE ATTRIBUTE: AMOUNT 28
Data Sources and Processing Methods: 28
Summary of Findings: 28
Future Directions and Limitations: 28
References 28
Tables and Figures: 29
Links to Available Geospatial Data Outputs 31

DESIRED LANDSCAPE ENDPOINT: MAINTAIN A DIVERSITY OF HABITAT TYPES – DEEP WATER REFUGIA* ON FLOODPLAIN 32

LANDSCAPE ATTRIBUTE: AMOUNT 32
Data Sources and Processing Methods: 32
Summary of Findings: 33
Future Directions and Limitations: 33
References 33
Tables and Figures: 34
Links to Available Geospatial Data Outputs 36

DESIRED LANDSCAPE ENDPOINT: MAINTAIN A DIVERSITY OF HABITAT TYPES – INTERMITTENTLY INUNDATED FLOODPLAIN 37

LANDSCAPE ATTRIBUTE: AMOUNT 37
Data Sources and Processing Methods: 37
Summary of Findings: 37

Future Directions and Limitations: *38*
References *38*
Tables and Figures: *39*

DESIRED LANDSCAPE ENDPOINT: SECONDARY CHANNELS **41**

LANDSCAPE ATTRIBUTE: AMOUNT 41
Data Sources and Processing Methods: *41*
Summary of Findings: *42*
Future Directions and Limitations: *42*
References *43*
Tables and Figures: *45*
Links to Available Geospatial Data Outputs *48*

DESIRED LANDSCAPE ENDPOINT: NATURAL SINUOSITY **49**

LANDSCAPE ATTRIBUTE: CONFIGURATION 49
Data Sources and Processing Methods: *49*
Summary of Findings: *50*
Future Directions and Limitations *50*
References: *50*
Tables and Figures: *51*

DEVELOPMENT OF A DATA PRODUCT TO CHARACTERIZE CONNECTIVITY BETWEEN MAINSTEM BIG RIVER SYSTEMS AND THE ADJACENT FLOODPLAIN **54**

Defining a Connectivity Data Layer: *54*
Application of connectedness to thermal conditions: *55*
Future Directions and Limitations: *55*
References *55*
Links to Available Geospatial Data Outputs *61*

DESIRED LANDSCAPE ENDPOINT: MAINTAIN CONNECTIVITY AMONG A DIVERSITY OF HABITAT TYPES – DEEP WATER REFUGIA* ON FLOODPLAIN **62**

LANDSCAPE ATTRIBUTE: CONDITION 62
Data Sources and Processing Methods: *62*
Summary of Findings: *63*
Future Directions and Limitations: *63*
References *64*
Tables and Figures: *65*

DESIRED LANDSCAPE ENDPOINT: MAINTAIN CONNECTIVITY AMONG A DIVERSITY OF HABITAT TYPES – INTERMITTENTLY INUNDATED FLOODPLAIN **70**

LANDSCAPE ATTRIBUTE: CONDITION 70
Data Sources and Processing Methods: *70*
Summary of Findings: *70*
Future Directions and Limitations: *71*
References *71*
Tables and Figures: *72*
Links to Available Geospatial Data Outputs *75*

DESIRED LANDSCAPE ENDPOINT: VEGETATION ON INTERMITTENTLY INUNDATED FLOODPLAIN **76**

LANDSCAPE ATTRIBUTE: CONDITION 76
Data Sources and Processing Methods: *76*
Summary of Findings: *76*
Future Directions and Limitations: *76*

Tables and Figures: *77*

Introduction

Mainstem big rivers were selected by the Gulf Coastal Plains and Ozarks (GCPO) Adaptation Science Management Team (ASMT) as a priority habitat system within the Mississippi Alluvial Valley subgeography. Mainstem big rivers are dominant feature on the GCPO landscape - eight of the largest ten rivers in the lower United States by discharge terminate in the GCPO (Kammerer 1990, Table 1, Figure 1). The goal of this document is to use geospatial data and analysis to determine the amount, configuration and condition of key habitat features of the mainstem big rivers of the GCPO.

The desired ecological state for priority habitat systems should characterize the least impacted condition – systems in this condition should be targets for maintenance/protection and the goal of restoration activities in degraded systems. In the GCPO Integrated Science Agenda (ISA), a general description of the desired ecological state is: “large river systems and their associated floodplains have water quality and adequate seasonal high and low flows with a frequency and duration sufficient to ensure connectedness across the diversity of habitat types”. Ward et al. (1999) describes floodplain rivers as “disturbance-dominated ecosystems characterized by high levels of habitat diversity and biota adapted to exploit the spatio-temporal heterogeneity.”

Throughout the world, however, many people live and work along large river systems and rely on them to provide a myriad of services including commerce and navigation. In order to reliably support these services, people require the river to provide a level of stability and this has led to significant physical and hydrologic alteration of many mainstem big rivers. The Mississippi Alluvial Plain ecoregion, for example, describes the historical extent of the Mississippi River floodplain – a vast area that was subject to overbank flooding during times of high runoff from the expansive Mississippi River drainage area. In an effort to provide some level of stability and protection from periodic overbank flooding, anthropogenic alteration along the Mississippi River began early. The first levee was constructed in 1717 and by 1735 levees already extended along both banks of the Mississippi River from 30 miles above New Orleans to 12 miles below. In the aftermath of the devastating 1927 flood along the Mississippi River, the Mississippi River and Tributaries (MR&T) project, was authorized through the Flood Control Act of 1928. This project laid out a comprehensive river management program that authorized a wide variety of structural alterations: 1) levees to reduce the risk of flooding, 2) floodways to allow passage of excess flows in extreme flooding conditions, 3) channel improvement and stabilization, and 4) tributary basin improvements including dams and reservoirs, pumping plants, auxiliary channels and pumping stations. Federal protection levees are found on all mainstem big rivers within the MAV and also along the Red and Missouri Rivers (Figure 2). Other structural alterations including impoundments and channel alteration are also prevalent on many mainstem big rivers outside of those directly associated with the MR&T project. Each of these alterations can impact the function of mainstem big rivers and one objective of this assessment is to provide more detail to identify the location and degree of habitat alteration.

Many mainstem big rivers are also part of the national navigation network (Figure 3) and impacts to big rivers can occur through infrastructure and maintenance required to support commercial navigation. Examination of recent waterborne commerce statistics (2013) however, reveals a continuum of commercial activity throughout the network (Figure 4). High traffic statistics are reported for many mainstem big rivers – indicating the critical importance of navigation along that river in supporting societal needs. However, other rivers including the Alabama, White, Ouachita, Tallahatchie, Pearl, Apalachicola and possibly the lower Missouri are part of the national waterway network but currently experience very low or no commercial navigation. In a recent USACE report, the Institute for Water Resources identified strategies for modernization of US ports and inland waterways due to the impending widening of the Panama

Canal. The report outlines the fiscal challenges that must be addressed to support modernization and continued maintenance of the existing inland waterway. The analysis of condition and connectivity presented in this ecological assessment may assist in the ongoing conversation to strategically define the best function for all mainstem big rivers in the GCPO.

In addition to long-term structural changes, dredging to maintain minimum channel depths can also have a more localized impact on aquatic organisms that locally inhabit the mainstem big rivers (see dredging discussion).

GCPO Integrated Science Agenda (ISA) and Mainstem Big Rivers Ecological Assessment

The desired landscape endpoints listed in the ISA for mainstem big rivers are only qualitatively described.

> **MISSISSIPPI ALLUVIAL VALLEY**
> **Freshwater Aquatic: Mainstem "Big River" Systems** (Source: G. Constant, pers. communication)
>
> *General description of desired ecological state: Large river systems and their associated floodplains have water quality and adequate seasonal high and low flows with a frequency and duration sufficient to ensure connectedness across the diversity of habitat types*
>
> Amount: Maintain current river miles
>
> Configuration: Maintain a diversity of habitat types and connectivity among them
> - Main channel
> - Secondary channels
> - Off channel deep water refugia that is seasonally persistent
> - Seasonally-inundated floodplains
>
> Condition: Quality
> - DO – seasonally appropriate
> - Temperature – below critical threshold
>
> Quantity
> - Adequate seasonal high and low flows with frequency and duration sufficient to ensure connectedness across habitat types and ability for priority species to meet life history requirements

In the literature, habitat diversity (Gore and Shields 1989) and interaction with the floodplain (Junk et al. 1989, Bayley 1989) are widely recognized as important drivers of large river ecosystem function. This assessment therefore focused on providing various measures of habitat diversity including in-channel and floodplain features. In addition to the habitat features described in the ISA, abundance of sandbars, channel sinuosity, and floodplain vegetative cover type were also included as measures of large river habitat diversity.

In the current assessment the following metrics were not explicitly addressed: DO, temperature and main channel flow volumes. Mainstem DO levels are typically adequate in the mainstem of large river systems although oxygen levels can and do become critical in summer months within large river impoundments. Off channel open water systems are subject to low dissolved oxygen levels in summer months, but oxygen levels may be directly related to connectivity with the main channel. The chapter "off water channel open water - connectivity" may represent a surrogate for dissolved oxygen. Similarly, analysis presented in this assessment also relates temperature with the degree of connectivity with the main channel. Further research may be done to outline a more explicit relationship between connectivity and these two landscape endpoints. Information directly related to adequate seasonal high and low flows is also not presented, but we do present the degree of interaction with the floodplain and this may be seen as an indication of the desired result of ensuring "connectedness across habitat types". Conversely, the presence of dams has the potential to impair natural flows and this measure was added to the analysis.

An ongoing GCPO project led by the Southeast Aquatic Resources Partnership (SARP) seeks to further refine the desired landscape and species endpoints for all the aquatic systems using available literature and expert opinion. Once more specific landscape endpoints are identified, the geospatial information presented in this assessment may be combined to identify the distribution of mainstem big river habitats in the desired ecological state.

For the purposes of the current assessment the definition of "mainstem big rivers" includes categories of "large" and "great" by mean annual flow as defined by SARP (Figure 1, see also chapter 1). This includes the extent of rivers in the GCPO having a mean annual flow rate of greater than 6,000 cubic feet per second (cfs). Rivers in this category are characterized by a wide variety of natural and anthropogenic factors that influence their current condition. High flow is the most obvious defining factor that shapes natural conditions and because mainstem big rivers are associated with high mean annual discharge from a large drainage basin, change in flow rates tend to more dampened compared with lower order streams and rivers. Species adapted to these large rivers have evolved to adapt to opportunities and challenges afforded by high flow rates. Significant habitat features of large rivers in the GCPO include: 1) the main channel corridor with swift current, 2) secondary channels or chutes that offer a high connectivity with the mainstem river, but lower flow velocity, 3) mid-channel islands or point bars, and well-connected floodplain habitats including 4) off channel permanent water (oxbows, bayous and sloughs) and 5) intermittently inundated vegetation. The amount and condition of each of these habitat types will be quantified in the assessment. Human and natural factors have altered the distribution and condition of these habitats in large river systems within the GCPO. A visual comparison of the distribution and extent of these habitats characterized using two different data sources can be found in Figure 5 and Figure 6.

Within the GCPO, many of the mainstem big rivers are part of the Mississippi River drainage, but it also includes rivers from a variety of drainage basins including the South Atlantic Gulf drainages and Texas Gulf drainages. Because of physical barriers to dispersal between drainage basins, the species endpoints are likely to vary within a subgeography across basins. On the other hand, the landscape variables described here are intended to relate to targets for physical habitat condition and are more likely to be shared in common across subgeographies.

Data Sources and Limitations

Throughout this analysis, the medium resolution NHD plus v2 was used for direct and indirect estimates of selected landscape endpoints. These data were relied upon because they provide complete publicly available coverage throughout the GCPO geography. The data are, however, only as good as the USGS topographic data sheets upon which they are based. Inaccuracies arise due to a variety of factors including actual change in stream configuration since the data were created or overgeneralization due to the scale (1:100,000) at which the data were created. Inaccuracies may also be the result of inconsistency in flowline delineation between topographic data sheets or misinterpretation of flow pathways, particularly in areas having low relief and abundant barriers to flow.

A draft version of floodplain inundation frequency (IF, Allen *in review*) was also used extensively for assessment of mainstem big river habitat quantity and quality. This product is based on multiple observations of actual inundation extent including open water and flooded vegetation using Landsat imagery from 1983-2011 during leaf-off conditions (Dec-Mar). IF has been demonstrated to accurately characterize floodplain inundation under a variety of typical seasonal flooding scenarios. Some of the most important limitations of the inundation frequency mosaic are the following:

1) The IF mosaic is limited by the 30m pixel resolution of Landsat. There are some places where small but significant barriers to flow are not accurately captured using this moderate resolution sensor. Similarly, narrow channels will also not be accurately characterized.

2) The composite image approach assumes that significant alteration to hydrology have not occurred in the 1983-2011 timespan. This is not accurate for locations such as the lower Arkansas River and some secondary channels on the main Mississippi River.

3) The floodplain inundation data used in this analysis also have some inherent limitations primarily based on the ability of the optical sensor to determine the extent of inundation. Inundated locations that also have dense, understory vegetation that persists throughout December through March will not be accurately characterized using this approach.

4) This analysis assumes that the IF mosaic accurately characterizes the full range of inundation conditions for all areas. In some locations, the observations based on Landsat may under or overestimate floodplain inundation extent and frequency. Analysis of flow seasonality shows that this assumption is reasonable for much of the GCPO geography but IF will not accurately capture flooding extent for locations in the far west and northwest of the GCPO where seasonal highs occur in June - well after the temporal window used for the IF analysis.

5) Similarly, the analysis assumes that the landscape scale mosaic of IF represents an even distribution of inundation conditions across multiple Landsat scenes. This assumption is certainly violated in many instances because adjacent Landsat scenes rely on different sets of input imagery. To reduce errors associated with this assumption, we typically restricted the floodplain analysis to a broad range of inundation conditions (e.g. wet in <10%, 10-90%, and >90% of images).

The inundation frequency mosaic was also used in a subsequent analysis to determine the level of connectivity between mainstem big river systems and their adjacent floodplains. In addition to the limitations described above, areas with very narrow channels may underestimate actual connectivity. Similarly, movement was not allowed over dry areas. Very narrow (<30m) but significant barriers to flow or passage may not be well represented and may overestimate actual connectivity.

Throughout this assessment, many landscape endpoints are summarized by HUC12 to assist in detecting patterns within and across subgeographies. HUC12 watersheds that are directly influenced by mainstem big river systems were chosen based on proximity to the river and results from floodplain inundation frequency. USGS HUC12 boundaries were drawn based on the immediate contributing watershed. In unmanaged river systems, these delineations are usually guided by natural barriers to flow caused by variation in topography. For mainstem big rivers however, these boundaries frequently coincide with the presence of a federal protection levee. In this assessment therefore, current floodplain extent may already be confined to a much more restricted area compared with natural conditions. For example, Baker et al. (1991) reports that the current extent of the lower Mississippi River floodplain is only approximately 10% of the floodplain extent under natural high water flooding. Future versions of this assessment may wish to consider whether it is worthwhile evaluating potential expansion of the assessment beyond the confines of the current floodplain dictated by levee alignment. In the MR&T project, designated USACE floodways are not included in the current analysis because they are typically disconnected from the mainstem Mississippi river and are not intentionally reconnected except during an exceptional flood such as occurred most recently in spring 2011.

Results in the following chapters focus on the MAV but, where available, landscape level data and more limited results for the entire GCPO are also presented to provide the reader with a broader landscape level perspective.

References

Allen Y.C. *in review*. Landscape scale assessment of floodplain inundation frequency using Landsat imagery. River Research and Applications.

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Gore, J. A., and F. D. Shields Jr. 1995. Can Large Rivers Be Restored? BioScience 45:142–152.

Ward, J.V., K. Tockner, and F. Schiemer. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regulated Rivers: Research & Management 15:125–139.

Tables and Figures

Table 1. Streamflow characteristics for large and great rivers in the continental United States*. Shaded boxes indicate large rivers that are located in the GCPO geography.

Rank	River	State	Average Discharge at mouth (1,000 cfs)	Drainage Area (1,000 mi^2)	Length from source to mouth (miles)
1	Mississippi	Louisiana	593	1,150	2,340
2	Ohio	Illinois	281	203	1,310
3	Columbia	Oregon	265	258	1,249
4	Missouri	Missouri	76	529	2,540
5	Tennessee	Kentucky	68	41	886
6	Mobile	Alabama	67	45	774
7	Atchafalaya	Louisiana	58	95	1,420
8	Snake	Washington	57	108	1,040
9	Red	Louisiana	56	93	1,290
10	Arkansas	Arkansas	41	161	1,469

* adapted from Kammerer 1990

DREDGING

Currently, channel modification has increased in-channel sediment transportation and thereby greatly reduced the need for dredging throughout most of the inland waterway system. Most dredging operations occur in locations where flow velocity declines due to reduced discharge or tidal interaction, allowing sedimentation. Dredging activities can occur at any time, but are most likely to occur during the low water season and may have the greatest impact on migratory species using large rivers mouths during summer and fall.

Based on dredging statistics reported by the US Army Corp of Engineers (USACE) Navigation Data Center for 2000-2014, the New Orleans and Galveston USACE districts rank first and second, respectively, in the reported total estimate of material dredged within the United States (Table 2). Most intensive dredging activities within these two districts are associated with locations near the mouth of large rivers, intracoastal waterways and ship channels near the Gulf where large river flow velocity declines, allowing sedimentation. In the New Orleans district, dredging activities are highest along the Mississippi River downstream of New Orleans, at the mouth of the Atchafalaya River and in the Calcasieu ship channel. For the Galveston office, most dredging occurs in the Houston-Galveston Navigation Channel, the Sabine-Neches Waterway and in the Corpus Christi Ship Channel.

Table 2. Estimated quantity (thousands of tons) of material dredged based on statistics reported by the US Army Corps of Engineers (USACE) Navigation Data center. Note that USACE District offices with a * indicates values that are summed for both contract and district owned vessel statistics. District offices highlighted in blue are located within the GCPO LCC geography.

	Year															
USACE District	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
NEW ORLEANS*	303	772	744	686	573	614	463	664	858	585	786	434	737	227	361	8808
GALVESTON	398	457	345	340	157	119	228	133	180	121	290	251	242	137	196	3592
PORTLAND*	135	140	130	101	111	128	151	215	87	149	157	136	141	114	129	2024
WILMINGTON*	192	230	219	119	132	82	121	103	75	98	93	70	90	66	81	1772
VICKSBURG*	89	157	74	160	94	64	77	111	168	61	73	57	55	57	59	1356
PHILADELPHIA*	99	83	101	85	113	95	73	55	56	133	143	117	34	7	147	1342
MOBILE	126	128	133	131	89	80	0	0	0	84	217	115	59	120	45	1328
PORTLAND	114	106	100	77	83	89	82	90	29	80	73	81	86	91	82	1263
MEMPHIS*	154	152	109	68	72	100	83	70	57	123	0	86	147	0	0	1222
SAVANNAH	75	91	208	18	70	80	75	20	0	188	20	80	50	90	89	1153
JACKSONVILLE	69	72	141	30	54	150	56	51	53	59	85	60	53	169	50	1151
NEW YORK	22	88	43	56	43	12	3	5	61	31	50	63	25	184	40	726
CHARLESTON	17	0	113	36	38	77	34	69	47	45	38	19	65	38	36	672
NORFOLK	23	10	30	54	59	24	21	35	12	27	62	116	37	22	64	596
BALTIMORE	97	83	70	20	26	30	35	9	55	27	11	45	21	3	26	559
ST. LOUIS*	3	8	45	53	48	45	74	42	17	0	28	29	0	0	0	391
LOS ANGELES	60	58	88	7	36	7	21	3	10	31	15	5	11	15	8	374
ALASKA	1	8	0	14	9	19	21	21	24	53	34	31	11	11	11	268
SAN FRANCISCO	6	20	17	3	54	3	18	50	4	12	15	19	7	8	12	247
BUFFALO	17	15	11	7	14	11	11	9	18	20	22	13	14	17	16	214
PHILADELPHIA	23	32	13	5	16	14	16	15	13	21	17	5	8	7	2	208
ST. PAUL*	10	9	27	21	7	25	8	10	15	23	7	16	15	5	0	199
SEATTLE	3	12	21	24	17	0	0	3	10	4	3	13	77	5	3	194
DETROIT	11	11	12	7	9	9	9	11	18	20	10	11	8	14	17	177
LOUISVILLE	10	10	10	10	10	10	10	10	10	10	20	20	20	0	0	160
NEW ENGLAND	4	1	5	65	0	0	7	2	4	2	0	1	1	0	0	92
LITTLE ROCK	8	0	17	0	0	0	0	17	0	0	0	0	0	0	0	42
CHICAGO	4	3	0	0	0	0	0	4	4	4	1	3	3	6	0	31
HUNTINGTON	1	0	2	3	3	2	2	2	1	2	2	0	3	3	4	29
SACRAMENTO	0	0	0	2	5	2	6	0	0	0	2	0	3	0	0	21
ROCK ISLAND	0	0	0	0	0	0	0	0	0	0	0	9	5	5	0	19
TULSA	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	5
PITTSBURGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
HONOLULU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

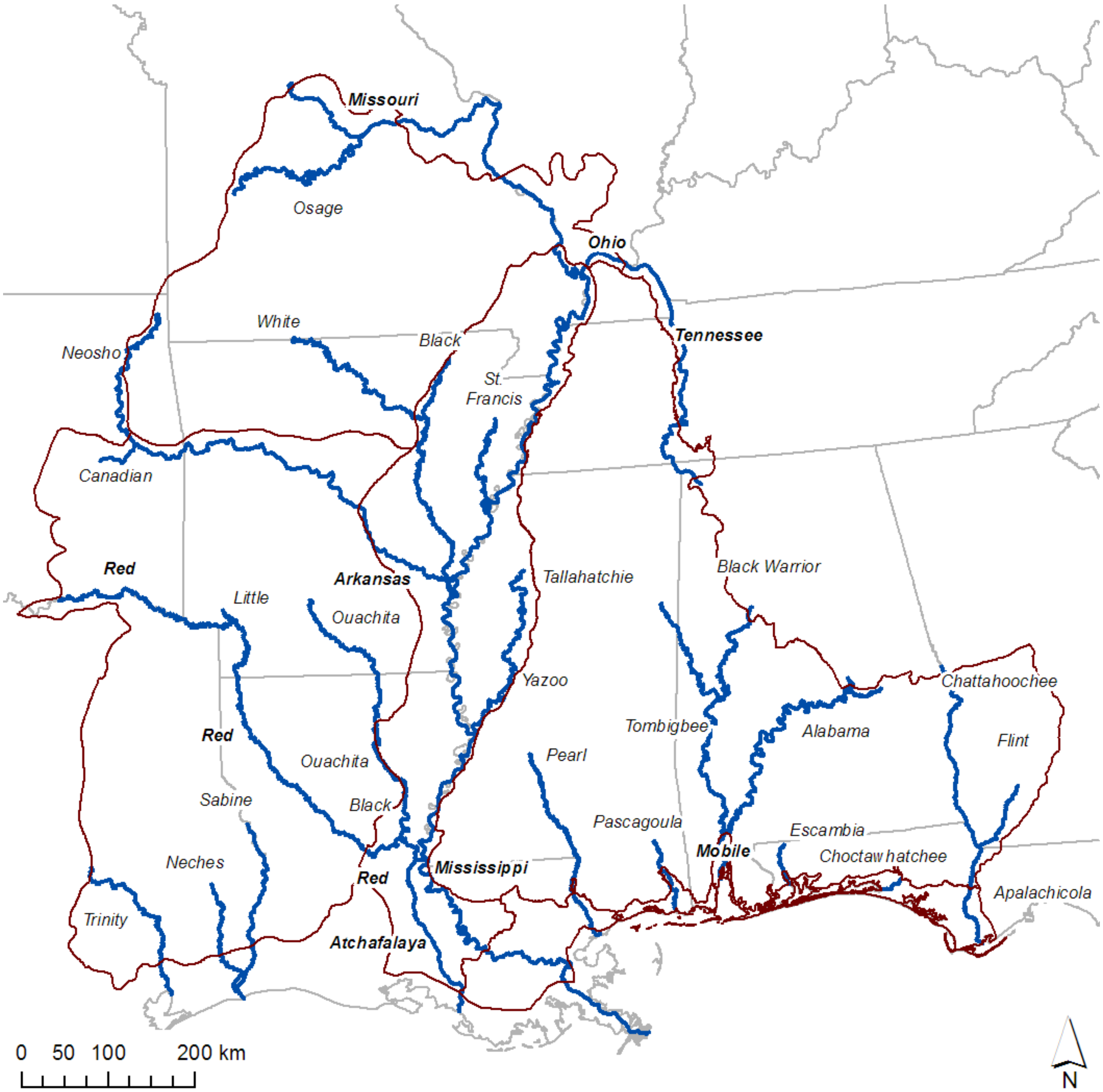

Figure 1. Configuration of mainstem big rivers within the GCPO (blue lines). Dark red outlines show the subgeographies of the GCPO. Names of major rivers referenced in Table 1 are shown in bold.

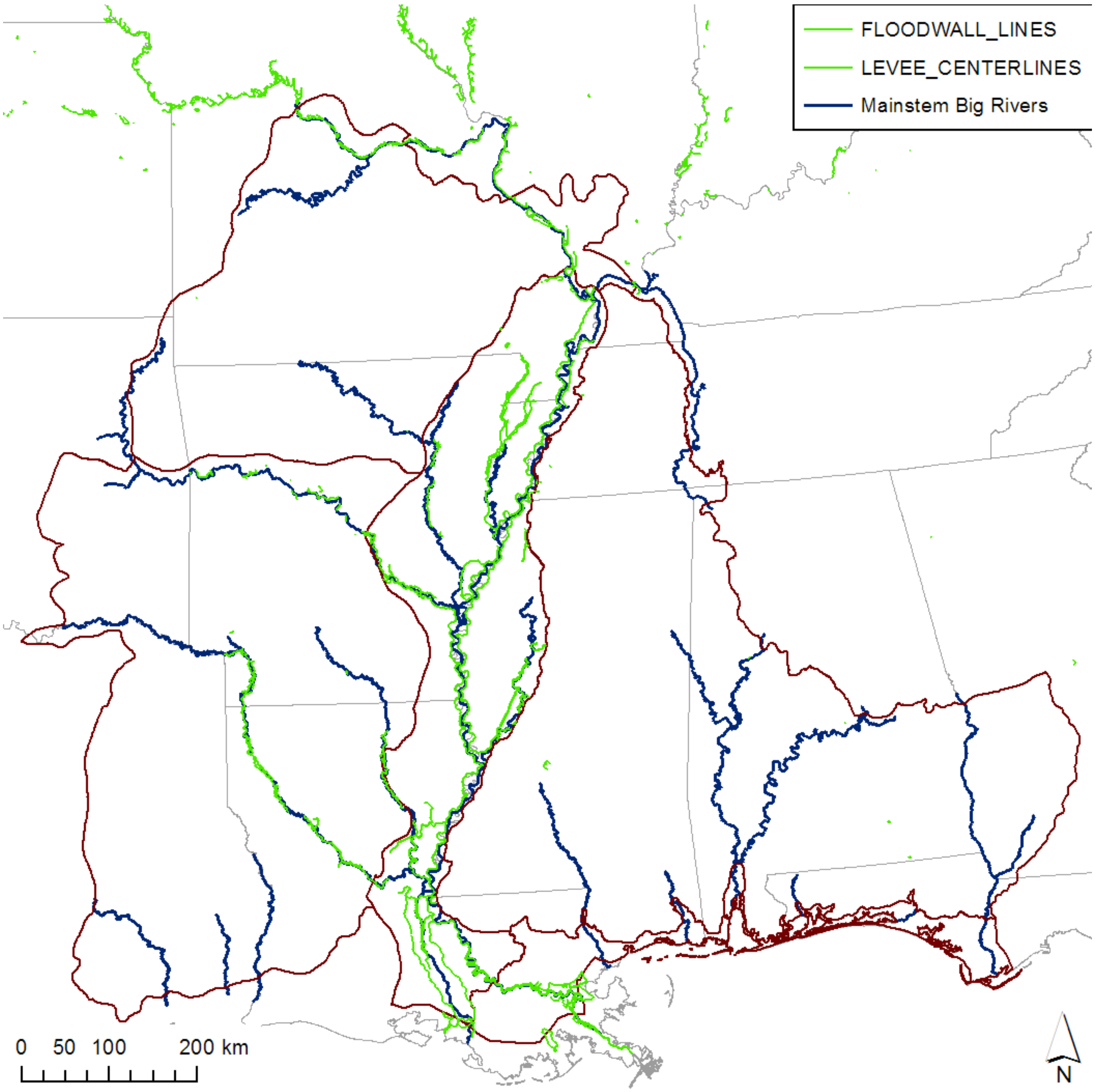

Figure 2. Distribution of mainstem big rivers (blue lines) and federal protection levees (green) within the GCPO LCC. Dark red outlines show the subgeographies of the GCPO.

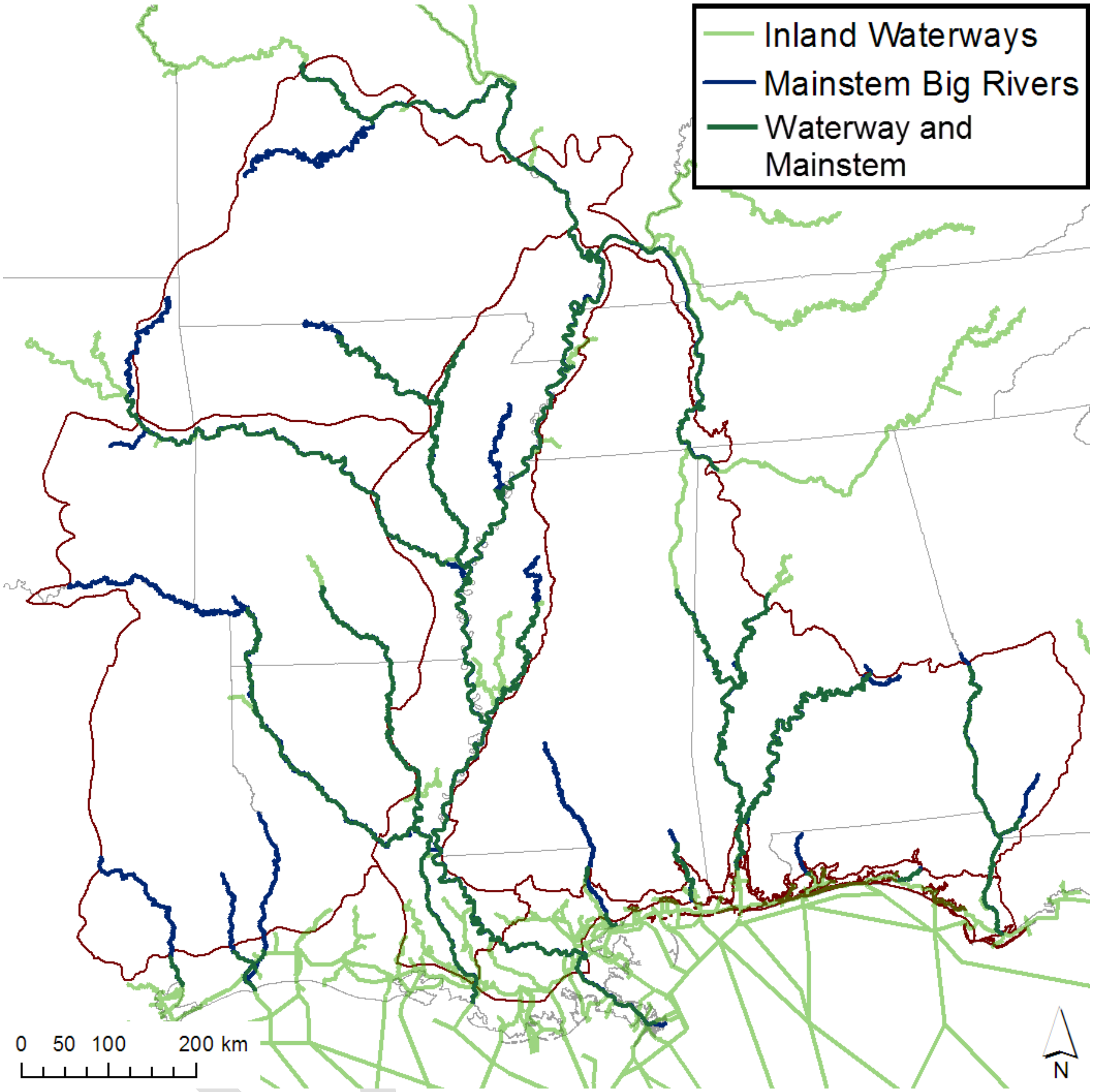

Figure 3. Comparison of the distribution of the inland waterway network of the United States (light green) and the mainstem big rivers broadly defined habitat of the GCPO (dark blue). Locations where the waterway network and mainstem big rivers coincide is shown as dark green.

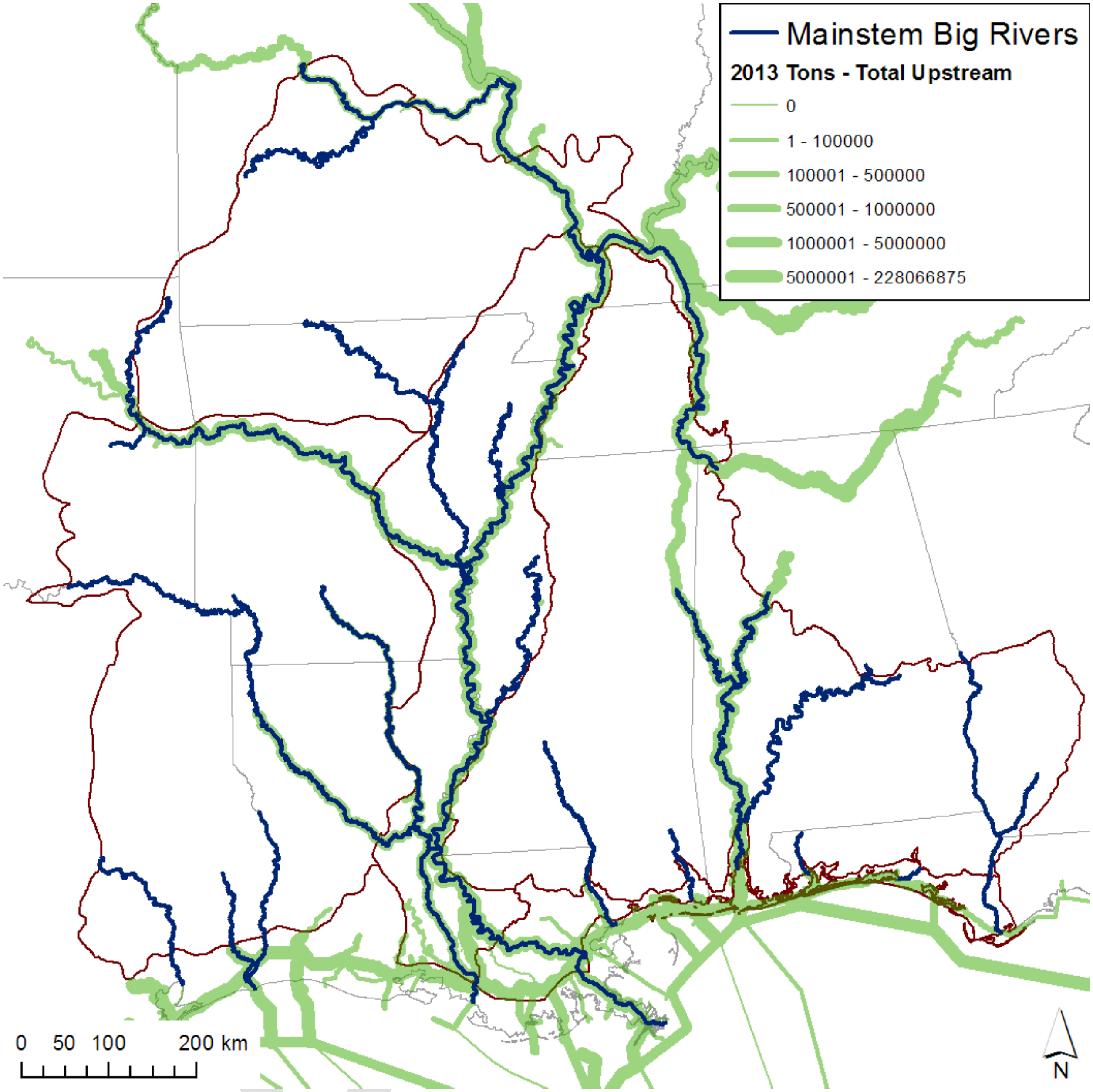

Figure 4. Total upstream tons of cargo in 2013 within the national waterway network of the United States (light green, bottom layer). The distribution of mainstem big rivers within the GCPO is displayed on top. Mainstem big rivers having little or no waterborne commerce are highlighted by blue lines that are associated with no or very thin green lines.

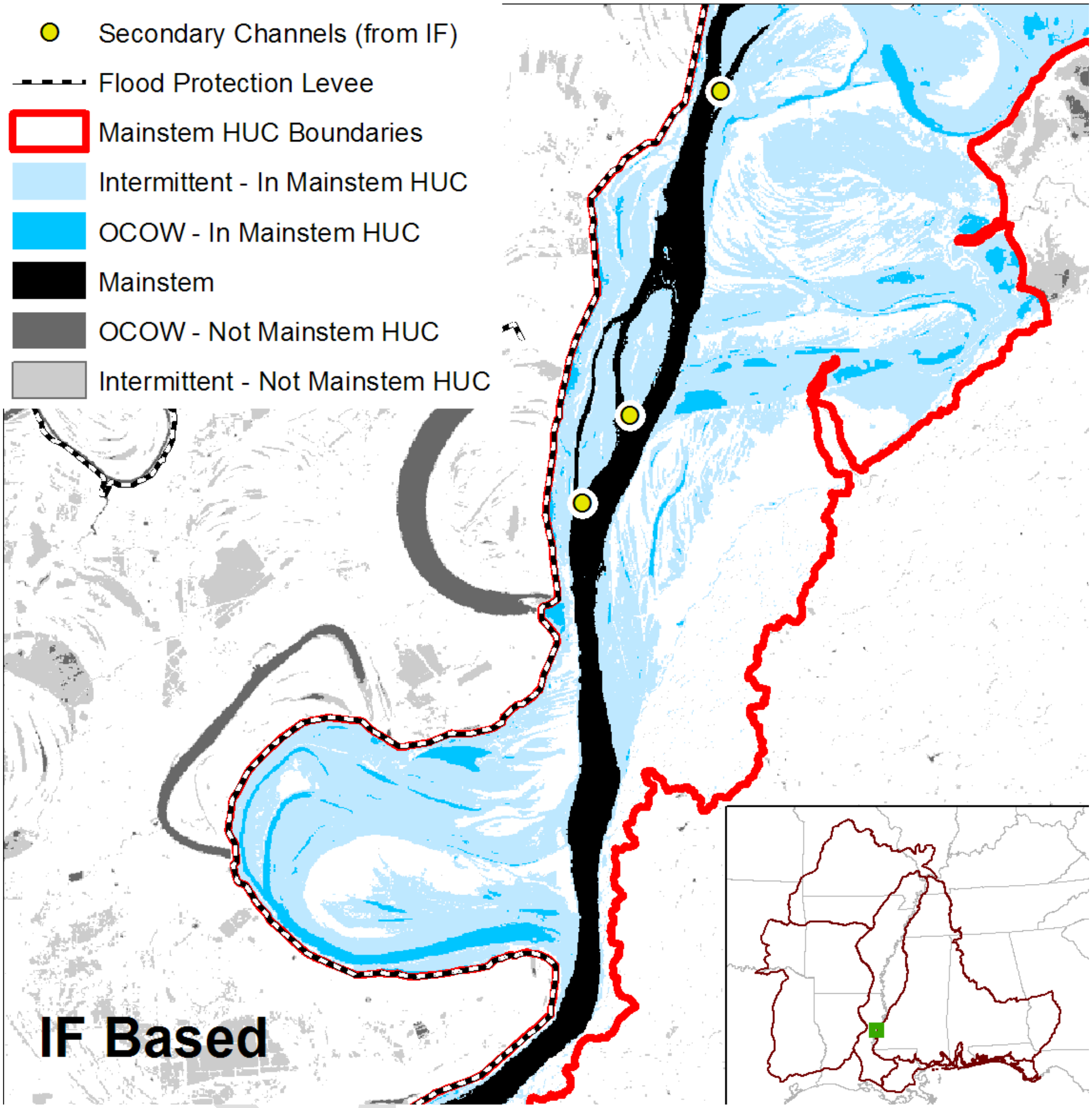

Figure 5. Distribution and extent habitats referred to in this document based on inundation frequency data. "Intermittent" refers to locations that are subject to intermittent flooding based on inundation frequency (IF). "OCOW" indicates off channel open water. Secondary channel locations were estimated using IF source information only. Note the coincidence of HUC12 boundaries (red outline) and levee location (dashed line) on the western edge of the of the mainstem big river floodplain. The eastern edge of the floodplain is confined only by elevation and not a levee.

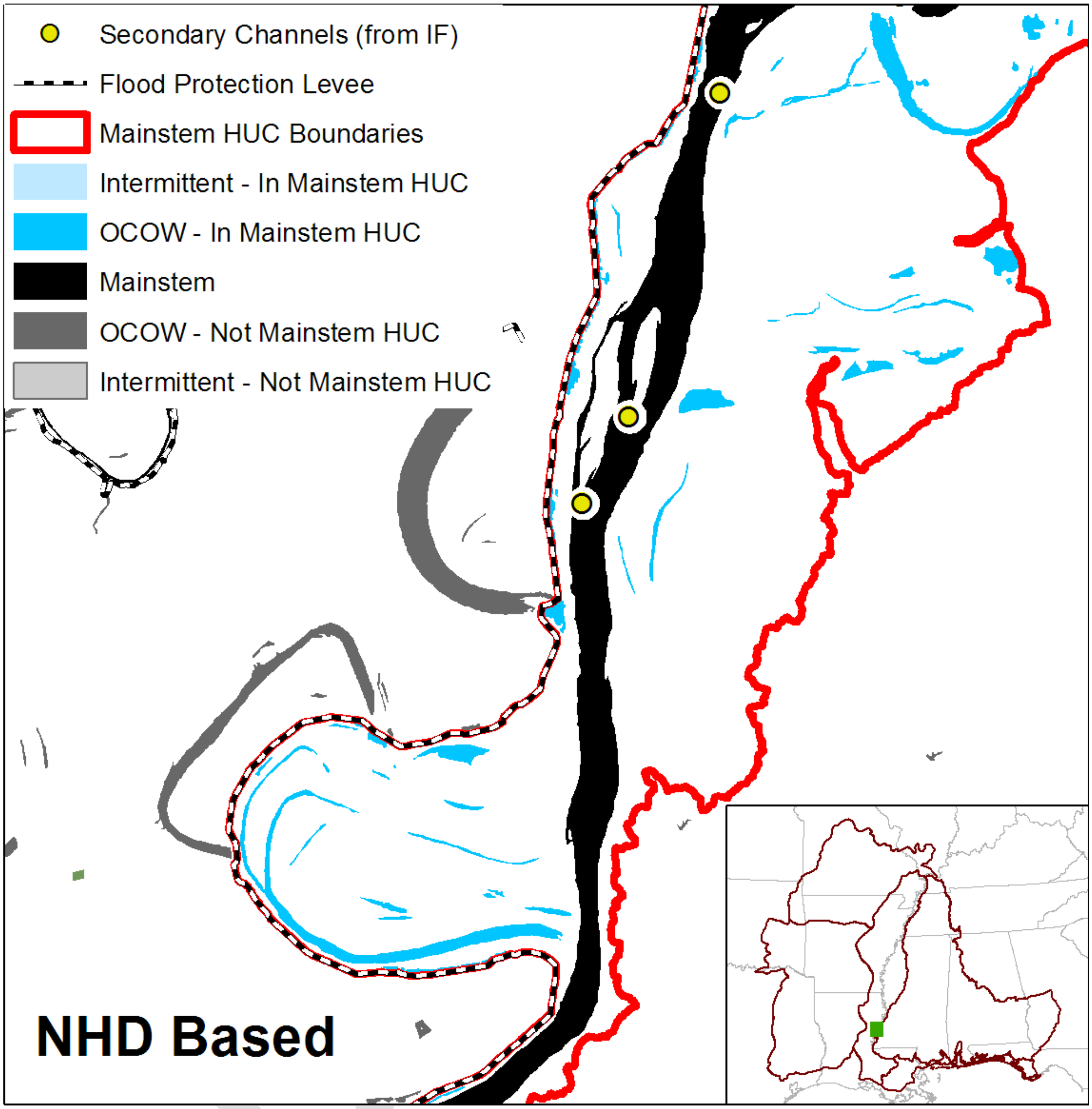

Figure 6. Distribution and extent habitats referred to in this document based on data from the National Hydrographic Dataset (NHD). Note that "Intermittent" is not available from NHD data. "OCOW" indicates off channel open water. Secondary channel locations were estimated using IF source information only. Note the coincidence of HUC12 boundaries (red outline) and levee location (dashed line) on the western edge of the of the mainstem big river floodplain. The eastern edge of the floodplain is confined only by elevation and not a levee.

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: **Mainstem Big River Systems**

Desired Landscape Endpoint: Maintain current river miles

Landscape Attribute: Amount

Data Sources and Processing Methods:

We used NHD Plus v2 flowlines to define the location of rivers in the GCPO. Mainstem big rivers were defined as having mean annual flow rates of greater than 6,000 cfs based on NHDPlus v2 (Q0001A>6000). This threshold was chosen to align with river classification thresholds including categories of, "large" and "great" rivers established by SARP. To preserve continuity, reported total river miles in the MAV include flowline segments of the Mississippi, Ouachita and Arkansas Rivers that lie along the boundary of adjacent subgeographies. The boundaries of the GCPO were not drawn with respect to large river watersheds, so the course of several mainstem big rivers including the Neosho, Osage, Missouri and Tennessee transit in and out of the GCPO.

Eight of the largest ten rivers in the lower United States terminate in the GCPO (Kammerer 1990), but their headwaters – including sections having mean annual flow greater than 6000 cfs - lie in other LCCs. These include the Tennessee, Ohio, Upper Mississippi, Missouri, Trinity, Black Warrior, Alabama, and Flint rivers. For this assessment, the most upstream boundary of mainstem big rivers in the GCPO was defined as the point when either: 1) mean annual flow fell below 6000 cfs or 2) the upstream flowpath no longer intersected the GCPO. The downstream extent was defined by the confluence with another river or terminus at the Gulf of Mexico.

Summary of Findings:

Mainstem big river systems within the MAV (Figure 7; Table 3) include the Mississippi from Cape Giradeau, MO to Donaldsonville, LA; the Atchafalaya from the confluence with the Mississippi to Morgan City, LA; the Red from just below Alexandria, LA to the confluence with the Atchafalaya; the Ouachita and Black rivers from West Monroe, LA to the confluence with the Red; the Yazoo and Tallahatchie rivers from near Charleston, MS to the confluence with the Mississippi; the Arkansas from Little Rock, AR to the confluence with the Mississippi, the White from the confluence with the Black river to the confluence with the Mississippi; the Black river from Pocahontas, AR to the confluence with the White river; the St. Francis River from Marked Tree, AR to the confluence with the Mississippi. The total kilometers of mainstem big rivers in the MAV is 3,444 km (0.033 km/sq km).

It is important at a minimum to maintain current river miles. Large rivers throughout the United States have been subject to channel straightening (reducing overall river miles). This channel improvement is done to reduce travel time and also to increase flow velocity and downstream sediment transport thus reducing the need for dredging to maintain navigability. This increase in flow can reduce the diversity of in channel habitats available for spawning. Channel alteration could also potentially alter the interaction of the mainstem river with it's adjacent floodplain.

A qualitative comparison of current channel configuration with historical data sources for the lower Mississippi River, however, indicates that the planar configuration of the main channel has not changed greatly since 1942.

Future Directions and Limitations:

The lack of updates to NHD data will limit the ability of these data to detect changes in amount of available mainstem channel. Changes to channel configuration on the Red River, for example, are part of improvements made in conjunction with the MR&T project. Many of these changes were completed in the early 1980s but are not reflected in the NHD data. Likewise, inaccuracies in the NHD data limit the application of these results to any system. On the Pearl River, for example, NHD data routes flow primarily through a very narrow and sinuous channel on the eastern edge of the basin. It is unclear which channel in the basin conveys the most flow, but is certainly not the one shown by the NHD. It is unclear what the potential solutions there might be to these limitations short of the USGS making it a priority to have more frequent review and updating of NHD data.

Tables and Figures:

Table 3. Amount of mainstem big rivers within the GCPO LCC by subgeography. Estimates are based on NHDPlus v2 using specific selection criteria and definitions described in the text.

Geographic extent	**Mainstem Big Rivers**
	km
East Gulf Coastal Plain	2,647
Gulf Coast	730
Mississippi Alluvial Valley	**3,444**
Ozark Highlands	1,533
West Gulf Coastal Plain	2,519
Gulf Coastal Plains and Ozarks (full extent)	10,875

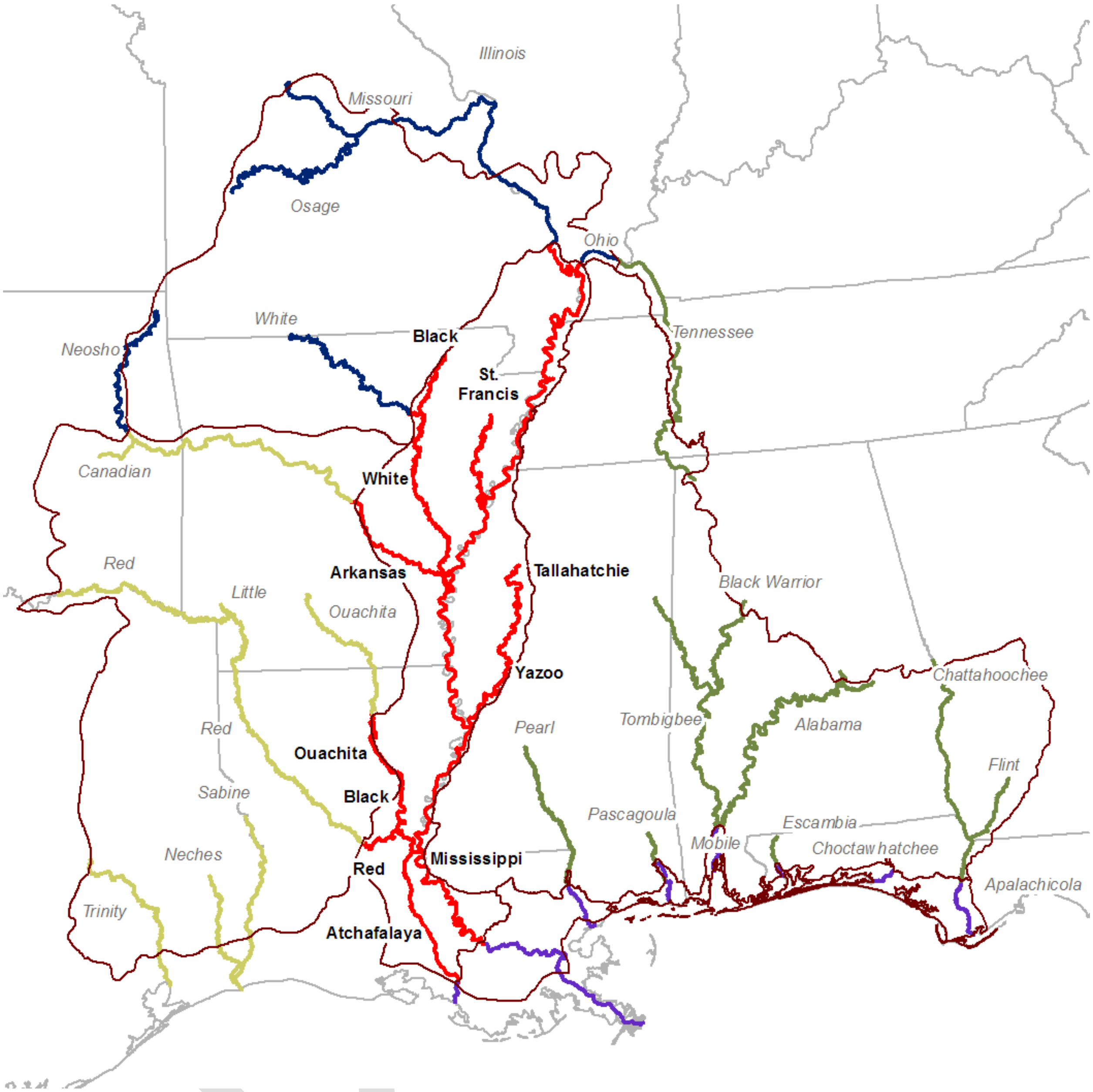

Figure 7. Distribution of mainstem big rivers within the GCPO LCC. Extent of mainstem big rivers considered in Table 3 are indicated by subgeography. Names of mainstem big rivers in the MAV are indicated in bold. Names of mainstem big rivers in the remaining subgeographies are indicated in italics.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers (based on NHDPlus v2)
  - GCPO geography (vector – line)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: **Mainstem Big River Systems**

Desired Landscape Endpoint: Linear Connectedness

Landscape Attribute: Configuration

The presence of dams along mainstem big rivers impact ecosystem function by: 1) forming a physical barrier to movement and dispersal, 2) altering the natural flow regime with respect to timing, magnitude, and rate of change, 3) altering sediment dispersal, and 4) altering depth. The absence of dams may be an indicator of natural flows.

Data Sources and Processing Methods:

The 2012 National Anthropogenic Barriers Database (NABD) was used to evaluate the presence of barriers along mainstem big river systems. The NABD represents an improved version of the National Inventory of Dams (NID) that is linked to NHDPlus flowlines. The accuracy of the data are improved in this dataset, but there are still many inaccuracies and duplicate values. The NABD was intersected with selected HUCs that are influenced by mainstem big river systems in the GCPO. From these, selected barriers were identified that interrupt flow for mainstem big rivers only. Dams were also summarized by storage capacity since larger dams may be more likely to have a greater impact overall impact to ecosystem function.

Summary of Findings:

The location of dams that interrupt flow along mainstem big rivers within the GCPO is reported in Figure 8. The number of dams along mainstem big river systems in the GCPO is reported in Table 4. Within both the MAV and the GCPO the Arkansas River had the largest number of mainstem dams (15 unique locations) and the presence of dams along the Arkansas begins at its confluence with the mainstem Mississippi. With the exception of one dam at the mouth of the Ouachita River, other mainstem big rivers in the MAV lack dams that interrupt the main channel. Upstream inputs to all of these rivers however have significant main channel dams (Figure 9). There are no dams along the mainstem big river portions of the Pearl, Pascagoula, Escambia, Choctawhatchee, Yazoo, St. Francis, Black, Missouri and Lower Mississippi Rivers within the GCPO geography. All of these rivers have impoundments further upstream in segments outside of the GCPO or along portions of the river where mean annual flow rates fall below the threshold used here for mainstem big rivers.

Future Directions and Limitations:

The accuracy of the dam inventory reported here is only as good as the accuracy of the NABD. The inventory of smaller dams or weirs is questionable. Examination of the locations of these data compared with current aerial photography reveals many instances of errors of omission (dam location is not present in the inventory) or commission (reported dam location that is not present in reality). The degree of inaccuracy is currently not possible to evaluate since there is no reference of “truth”. Even for some of the larger mainstem river dams there are duplicates and inaccuracies in locations. For instance, lock and dam #1 on the Red River is not reported in the NABD even though it was completed in 1994. An update or re-evaluation over the NABD is needed for this region.

Currently, several projects provide a more comprehensive assessment of dam and stream crossing locations including: the TNC Chesapeake Fish Passage Prioritization, the North Carolina Barrier Prioritization Tool, the Tennessee Cumberland Fish Barrier Inventory and the Southeast Aquatic Connectivity Assessment Project. Recently, the USFWS Region 4 funded SARP to expand Fish Barrier Inventory to the entire region, so a future reevaluation of these data will provide improve the current assessment.

It is clear that the presence of dams on large rivers will impact opportunities for dispersal and that the presence of upstream dams will commonly decrease peak discharge and increase low flows. Other impacts to flow, channel morphology and sediment distribution will differ greatly depending on dam location and operation, local environmental conditions, and substrate composition (Brandt 2000).

Climate change may increase pressures on large rivers for water supply particularly in western extent of the GCPO. Sun et al. (2013) report that water supply pressure in the southeastern US will be highest in the summer when higher temperatures will increase evapotranspiration and decrease available streamflow.

References

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Sun, Ge; Caldwell, Peter V.; McNulty, Steven G.; Georgakakos, Aris P.; Arumugam, Sankar; Cruise, James; McNider, Richard T.; Terando, Adam; Conrads, Paul A.; Feldt, John; Misra, Vasu; Romolo, Luigi; Rasmussen, Todd C.; Marion, Daniel A. 2013. Impacts of Climate Change and Variability on Water Resources in the Southeast USA. NCA Southeast Technical Report 204-234.

Tables and Figures:

Table 4. Linear connectedness – number of dams that interrupt flow or fish passage along mainstem big rivers and dams located within Large River HUCs that do not interrupt flow or fish passage along the mainstem.

Mainstem Big River	Dams Intersecting Mainstem	Dams in Large River HUCS - Off Mainstem
Arkansas	15	31
Chatahoochee	8	13
Alabama	7*	19
Tombigbee	6	20
Red	5**	14
Ouachita/Black	3	2
White	4	14
Neosho	4	6
Black Warrior	3	34
Tennessee	2	11
Trinity	2	30
Osage	2	14
Canadian	1	0
Neches	1	3
Sabine	1	2
Little	1	2
Pearl	0	27
Pascagoula	0	3
Escambia	0	8
Choctawatchee	0	2
Apalachicola	0	1
Flint	0	0

Yazoo	0	18
Lower Mississippi	0	19
Middle Mississippi	0	19
Missouri	0	39
Mobile	0	7
St. Francis	0	1

*including 4 on the Tallapoosa and Coosa rivers

** only four reported in NABD

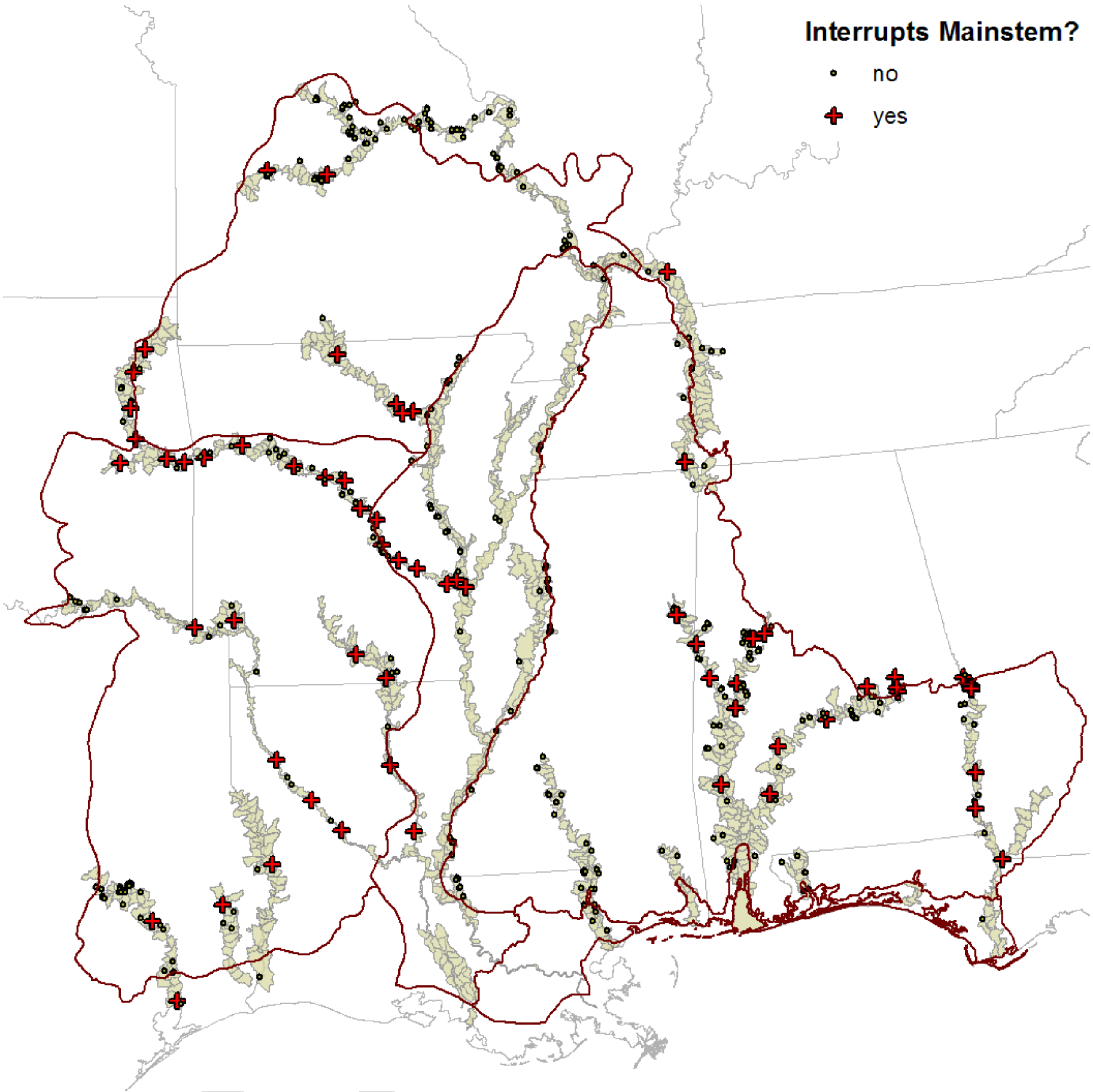

Figure 8. Location of dams along mainstem big rivers that interrupt or obstruct flow based on the 2012 National Anthropogenic Barriers Dataset (NABD) are highlighted by red crosses. Other barriers that lie within the HUCs affected by mainstem big rivers but do not obstruct mainstem flow are indicated by small yellow dots.

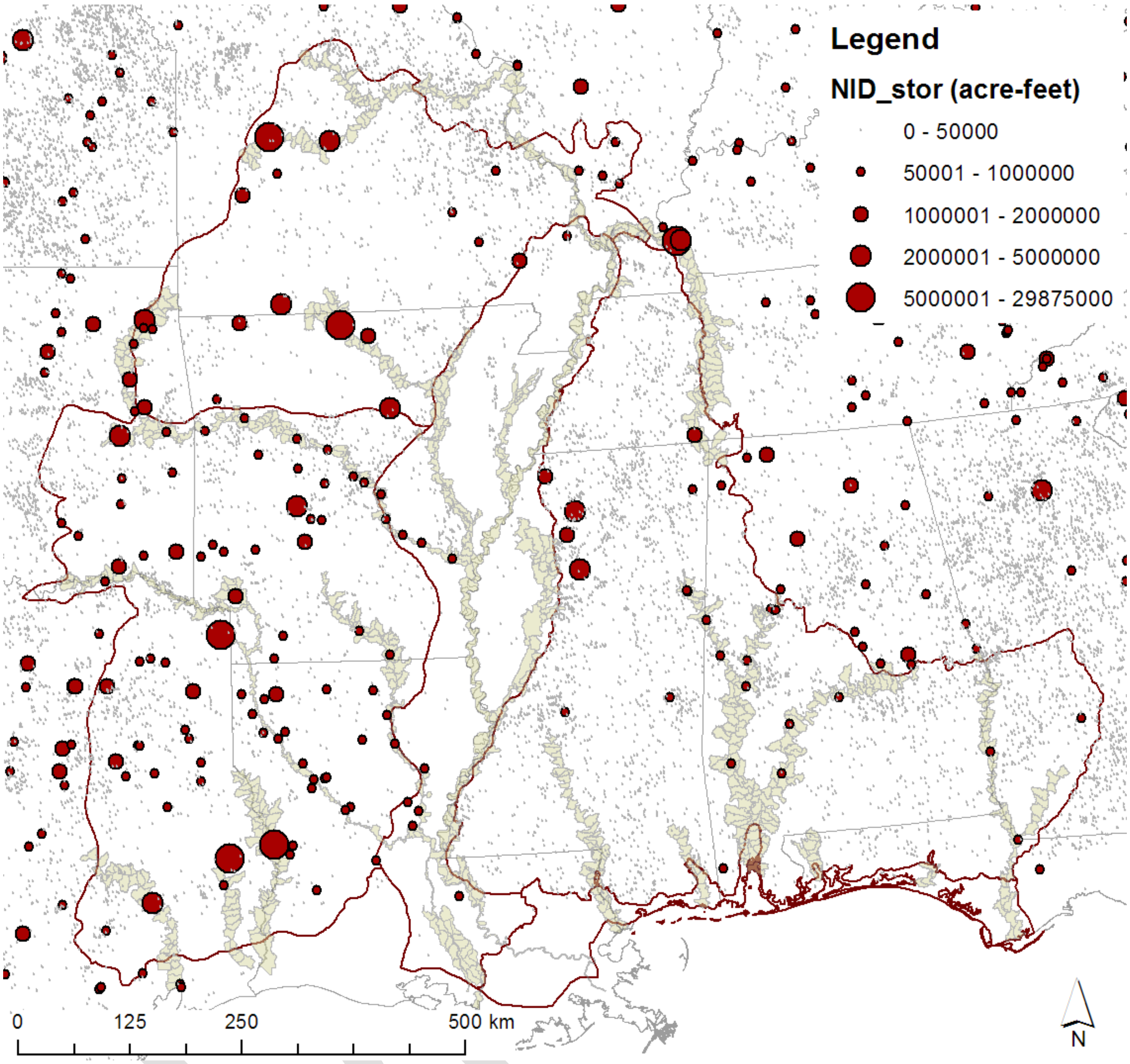

Figure 9. Location of dams by storage volume (acre-feet) based on the 2012 National Anthropogenic Barriers Dataset (NABD).

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – Linear Connectedness
    - GCPO geography (vector – point)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Maintain a diversity of habitat types – sand bars

Landscape Attribute: Amount

This analysis considers one aspect of the floodplain: the presence of exposed bare substrate (sand bars) suitable for use by birds and turtles as well as for spawning by riverine fishes *"Sandbars have sparse, intermittent or no herbaceous plant cover, and are distinguished from islands by their absence of persistent woody vegetation*" (Tracy-Smith et al. 2012).

Data Sources and Processing Methods:

We combined two data sources to estimate the amount of sand bars within the mainstem big rivers floodplains of the GCPO. The "barren" category within NLCD 2011 was combined with locations having intermittent inundation (10-90% inundation frequency). The "barren" category alone included locations having some vegetation. The "intermittent inundation" criterion was added to more carefully restrict sand bar delineation to locations having mostly clear sand.

The total area of sand bars as defined above was summarized within each HUC12 using "tabulate area" in ArcGIS. Results are shown in Figure 10. Results were also summarized by subgeography (Table 5).

Summary of Findings:

An example of the classification results along with original aerial photography and NLCD "barren" classification is shown in Figure 11. The highest area of sand bars occurs along the lower Mississippi River corridor and especially from River Mile 232 (north of Baton Rouge, LA) to 710 (just south of Memphis, TN). High areas of sand bars also occur along the upper reaches of the Red River from approximately the Louisiana-Arkansas state line to just downstream of the Denison Dam at Lake Texoma.

Future Directions and Limitations:

Landsat imagery selected for input to the NLCD classification is not chosen with respect to water levels and the amount of exposed sand bars can vary greatly with water level. The classification is therefore best seen as a rough estimate of available sand bars within the floodplains of mainstem big river systems. A better evaluation might use late summer/fall Landsat imagery captured under conditions of low water and maximum vegetation to more accurately assess the current extent of sand bars.

Limitations for the base IF dataset are outlined in the chapter "Intermittent Inundation – amount).

References

Tracy-Smith, E., D. L. Galat, and R. B. Jacobson. 2012. Effects of Flow Dynamics on the Aquatic-Terrestrial Transition Zone (ATTZ) of Lower Missouri River Sandbars with Implications for Selected Biota. River Research and Applications 28:793–813.

Tables and Figures:

Table 5. Area of sand bars within HUC12 boundaries of mainstem big rivers by subgeographies within the GCPO.

Subgeography	Sand Bar Area (km^2)
East Gulf Coastal Plain	11.5
Gulf Coast	3.8
Mississippi Alluvial Valley	**59.0**
Ozark Highlands	6.8
West Gulf Coastal Plain	35.9

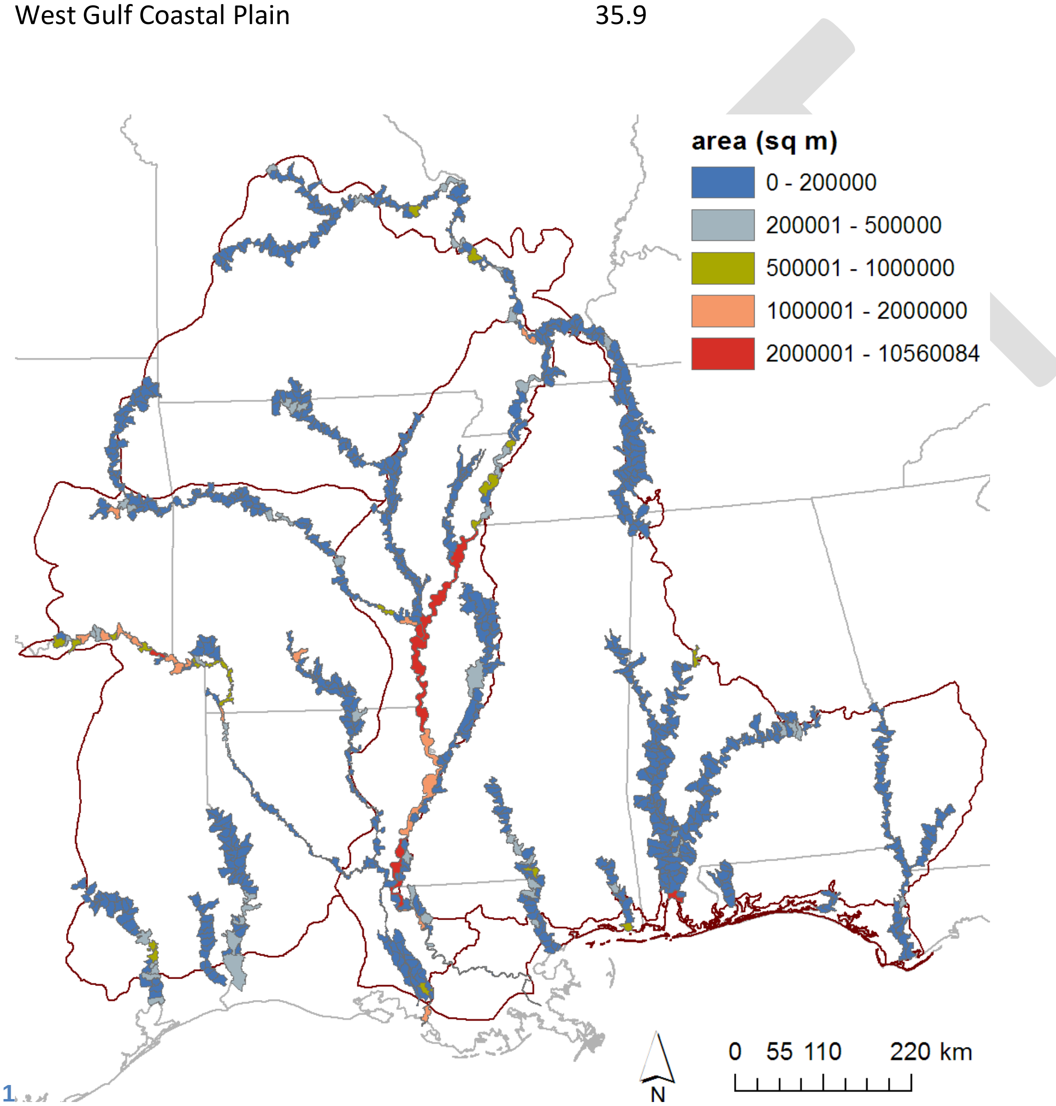

Figure 10. Area of sand bars within the floodplain of mainstem big river systems of the GCPO.

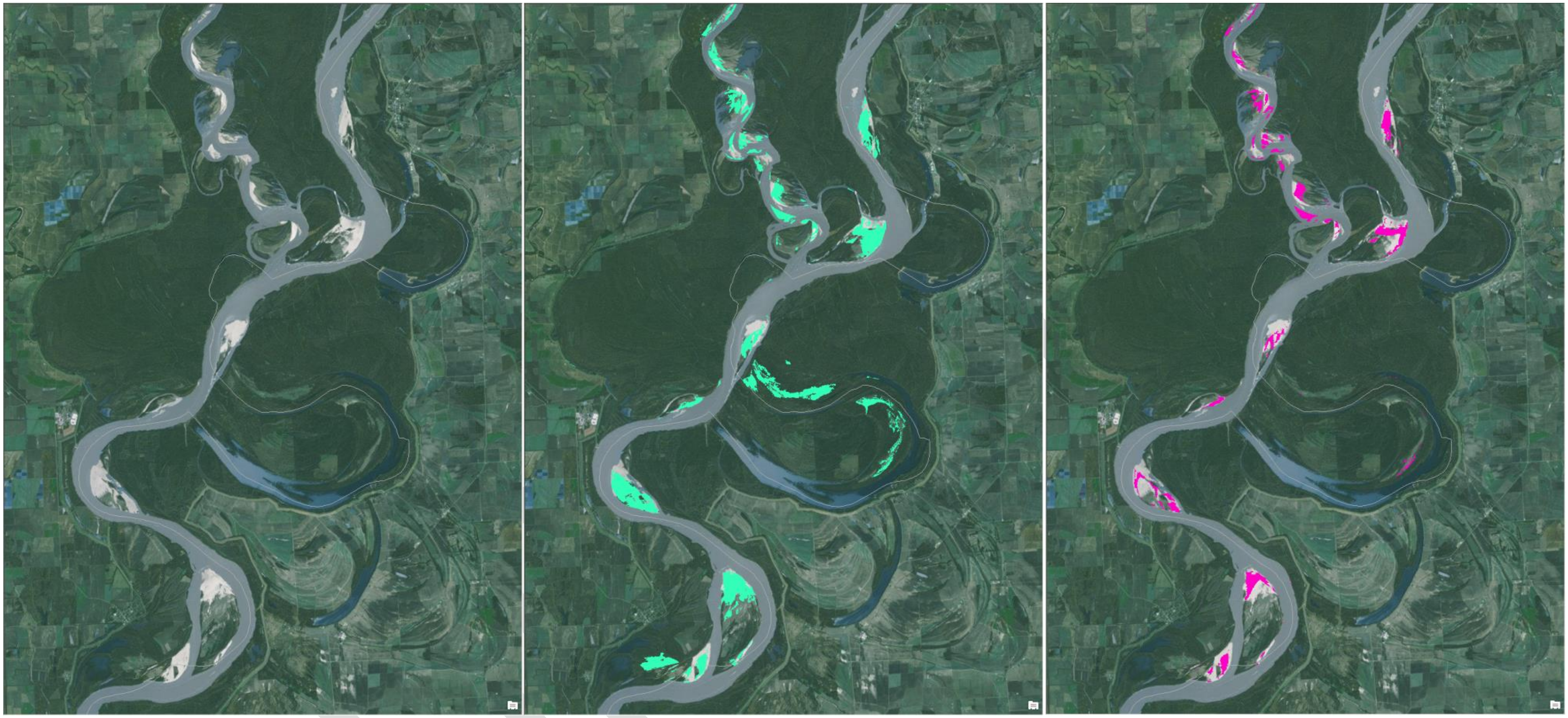

Figure 11. Demonstration of sand bar classification. Image on the left shows aerial photography with sand bars at the time of image acquisition displayed as white areas along the main Mississippi River channel. Middle figure shows the same aerial photography overlaid with the NLCD "barren" classification in green. Right figure shows the same aerial photography overlaid with the sand bar classification representing the intersection between NLCD barren and 10-90% inundation from the current assessment shown in pink.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – sand bars
    - GCPO geography (raster)
    - GCPO geography (vector – polygon)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Maintain a diversity of habitat types – deep water refugia* on floodplain

Landscape Attribute: Amount

This analysis considers one aspect of the floodplain: the presence of **deep water refugia** on the floodplain. Ward and Stanford (1995) refer to these habitats as paleopotamon and plesiopotamon depending on the degree of connectedness with the mainstem. Floodplain dependent aquatic species frequently take advantage of off channel deep water refugia, particularly within the GCPO where the timing and frequency of inundation is more predictable compared with large river floodplains in more arid climates (Winemiller et al. 2000, King et al. 2003). Alligator gar have been reported using off channel open water habitats within the St. Catherine Creek NWR (Allen et al. 2014). These are persistently inundated lentic habitats that are not directly connected with the main channel but may be connected during higher water events. They may offer elevated primary productivity because of lower turbidity. Conditions during the cooler months may be more moderate compared with the main river channel leading to increased growth rates. In the summer however, isolated floodplain lakes may be subject to extreme thermal conditions and anoxia.

* For the current analysis, bathymetric data was not available to determine whether the waterbody is deep or shallow. Any open water body within the mainstem big river floodplain was included in this analysis so this may represent an overestimate of "deep water refugia". For that reason, we refer to this endpoint instead as "off channel open water".

Data Sources and Processing Methods:

We compared two data sources to estimate the amount of off channel open water along mainstem big rivers: 1) the draft version of GCPO relative floodplain inundation frequency mosaic (IF) developed by Allen (in review) and 2) NHDPlus v2

Using the IF, off channel open water was described by locations that have >90% inundation frequency. A shapefile was created from raster locations satisfying that criterion using ArcGIS Conversion Tools > From Raster > Raster to Polygon. Polygons having an area of one pixel or less were removed. The remaining polygon data were edited along the coastal boundary to exclude waterbodies associated with coastal estuaries. Waterbodies that intersected the mainstem big rivers flowlines were excluded as these are associated with the mainstem river channel or with a reservoir along the mainstem. The remaining polygons represent permanently open water habitats such as oxbow or floodplain lakes that lie within the mainstem big rivers floodplain. Area within each HUC12 was summarized using "tabulate area" in ArcGIS.

Using the NHDPlus v2 off channel open water was described by waterbody areas having the attribute "LakePond". Along the lower Mississippi River corridor, several mid-channel vegetated islands were misclassified as "LakePond" and those polygons were removed from the analysis. Waterbodies that intersected the mainstem big rivers flowlines were also excluded as these are typically associated reservoirs along the mainstem. The remaining polygons represent permanently open water habitats that lie within the mainstem big rivers floodplain. Examples of off channel open water evaluated using each methodology can be found in Figure 5 and Figure

6. Area of off channel open water within each HUC12 was summarized using “tabulate area” in ArcGIS (Figure 12). Tables and Figures:

Table 6 summarizes the area of off channel open water by subgeography within the GCPO.

Summary of Findings:

A qualitative comparison of the IF and NHD based analyses show similar results (Figure 1). The highest area of off channel open water tended to occur in mainstem big river floodplains within the MAV subgeography. The highest area of off channel open water along the lower Mississippi River corridor occurred between river miles 710 at the Tennessee/Mississippi state border and 305 at the Louisiana/Mississippi state border. Although the Tennessee and Missouri Rivers rank 4th and 5th in the nation for average annual discharge (see intro), there are very few off channel open water areas along the floodplain of these rivers within the GCPO study area compared with other mainstem big rivers. There are also very few off channel open water habitats along the middle Mississippi River between the confluences with the Ohio and Missouri Rivers. Similarly, most other mainstem big rivers have relatively low areas of off channel open water in the uppermost reaches and greater areas of off channel open water near the mouth of those rivers at the Gulf of Mexico.

Future Directions and Limitations:

The results show good comparability of the NHD and IF based approaches to determining the area of off channel open water habitats. This result is important in confirming the potential utility of IF in addressing more complex questions of connectivity of floodplain habitats with mainstem big river systems. Limitations for the IF dataset are outlined in introduction chapter.

References

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Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research & Management 11:105–119

Winemiller, K. O., S. Tarim, D. Shormann, and J. B. Cotner. 2000. Fish Assemblage Structure in Relation to Environmental Variation among Brazos River Oxbow Lakes. Transactions of the American Fisheries Society 129:451–468.

Tables and Figures:

Table 6. Total area of off-channel open water habitat that does not directly intersect mainstem big rivers in the GCPO **.

	Area (km^2)	
SubGeography	**IF based**	**NHD based**
East Gulf Coastal Plain	152	122
Gulf Coast	74	49
Mississippi Alluvial Valley	**714**	**629**
Ozark Highlands	35	37
West Gulf Coastal Plain	193	172

**** Note that this analysis is based upon the areas of off channel open water that lie within the mainstem big rivers HUCs *and* within the boundaries of the GCPO. It does not include areas of off channel open water that are part of the mainstem big rivers floodplains that lie outside of the GCPO boundaries.**

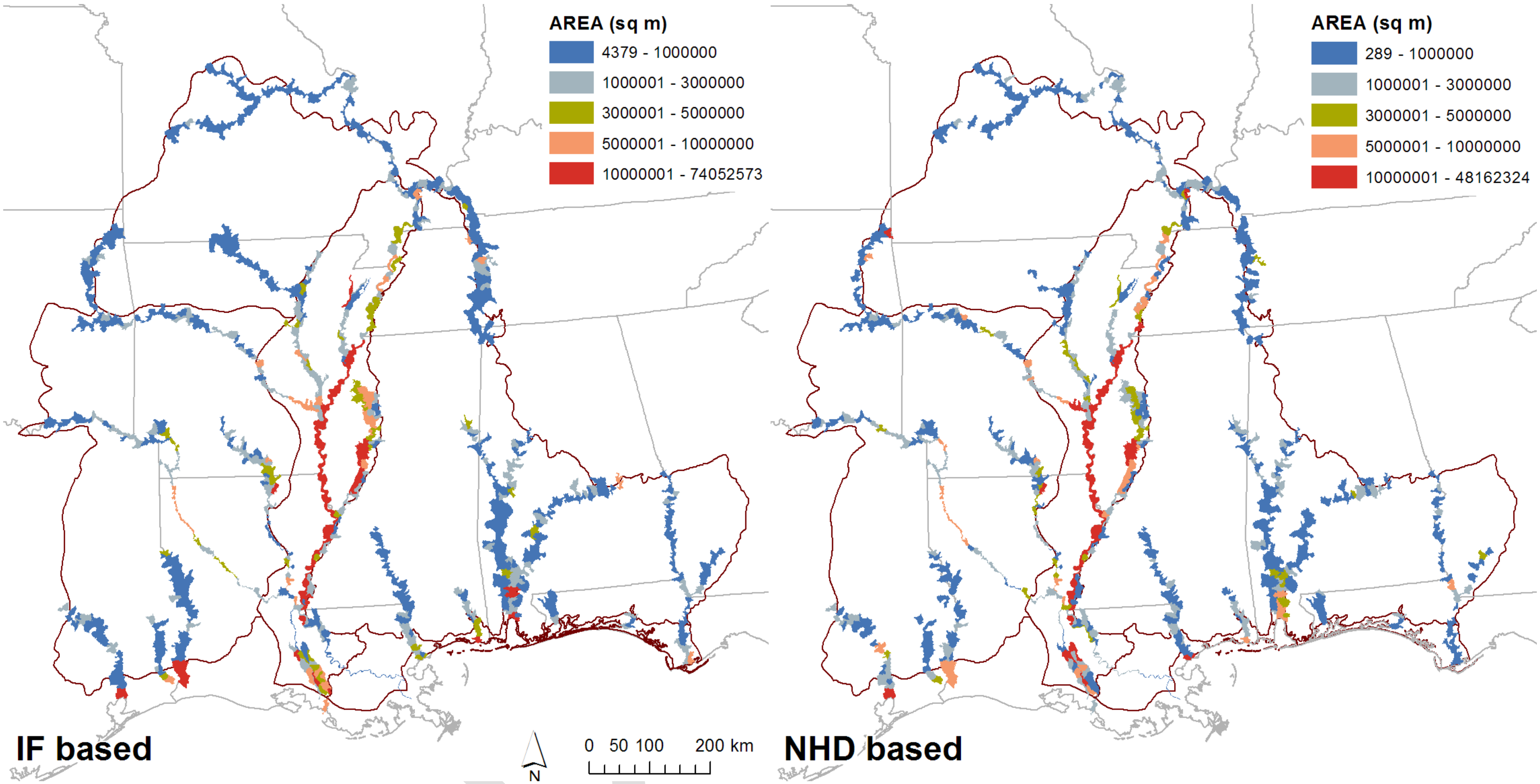

Figure 12. Area of off channel open water within the floodplain of mainstem big river systems within the GCPO. "IF based" analysis uses inundation frequency to determine area. "NHD based" uses lake/pond waterbody area from NHDPlus v2. Note that reservoirs along the main river channel are excluded from the analysis.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – deep water refugia – amount
  - GCPO geography (raster)
  - GCPO geography (vector – polygon)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Maintain a diversity of habitat types – intermittently inundated floodplain

Landscape Attribute: Amount

The floodplain is an integral part of large river ecosystems (Junk et al., 1989; Bayley, 1995; Opperman et al., 2010) and the timing, extent, duration and frequency of floodplain inundation greatly affects the quality of fish and wildlife habitat and the supply of important ecosystem goods and services. Floodplain dependent aquatic species frequently take advantage of seasonally inundated floodplains for spawning and nursery habitat where there is elevated primary productivity, more moderate environmental conditions and the physical structure of vegetation that offers refuge from predation and increased growth rates. This analysis considers one aspect of the floodplain: areas of intermittent inundation. Seasonal high flows should also allow for interaction of the mainstem with the adjacent floodplain so this assessment of intermittent inundation also evaluates the condition of high flows.

Data Sources and Processing Methods:

We used a draft version of GCPO relative floodplain inundation frequency mosaic developed by Allen (in review) as a basis for estimating intermittently inundated floodplain associated with mainstem big rivers in the MAV. This product is based on multiple observations of inundation extent including open water and flooded vegetation using Landsat imagery from 1983-2011 during leaf-off conditions (Dec-Mar). For this assessment, "intermittently inundated floodplain" was described by locations that have inundation frequency of 10-90%. Areas of "permanent inundation" (> 90% inundation frequency) that also lie on the floodplain are excluded from this analysis. These areas are quantified in another chapter (deep water refugia – amount).

Intermittently inundated areas were converted to polygons using Conversion Tools > From Raster > Raster to Polygon. Polygons have an area of one pixel or less were removed. The remaining polygons were then intersected with mainstem big rivers HUCs using the "intersect" function in ArcGIS. The amount of intermittently inundated floodplain was summarized by HUC12 (Figure 13). Total area having intermittent inundation (10-90%) in each HUC was normalized by dividing by the total area (square kilometers) of each HUC. The total area of intermittent inundation by GCPO subgeography that is associated with mainstem big river floodplains is shown in Table 7.

Summary of Findings:

The MAV subgeography shows the highest total amount of intermittently flooded area in the GCPO (Table 7, Figure 13). Significant mainstem big river floodplains in the MAV include the Atchafalaya, White and parts of the Mississippi River basins. The largest areas of intermittent flooding on the lower Mississippi River lie between the confluence with the Yazoo river at Vicksburg, MS and St. Francisville, LA - a section of approximately 284 km (177 river miles). Floodplain area for most large rivers outside the MAV all tend to be lower with notable exceptions of large river floodplains just prior to entering the Gulf of Mexico. Intermittent inundation along the Missouri River is likely to be significantly underestimated using IF data because typical high water on that river does not occur until May-July which is outside of the temporal window of Landsat observations used to compile the IF data.

At a minimum, large river floodplain extent should not be reduced and conservation action in the GCPO should at least defend existing floodplain extent, function and connectivity. Because the floodplain is such an important component of large river systems and many large river floodplains have been converted to agricultural production, conservation action should ideally focus on increasing available floodplain extent where practicable. This is a challenging proposal for conservation because barriers to full floodplain connectivity may be levees that provide flood protection or support other major infrastructure. One recent example of successfully increasing floodplain availability however is a TNC project at Mollicy Farms located on the Ouachita River below the Felsenthal dam. For this area, the IF dataset showed a high frequency of inundation even before the restoration project was underway. The IF dataset may therefore be highly useful in identifying areas that provide marginal returns for agricultural production but hold great potential to provide important ecosystem services if reconnected to a mainstem big river system.

Future Directions and Limitations:

As for many things, the output is only as good as the input. Please refer to the introduction chapter for a description of the IF dataset and its limitations.

References

Bayley PB. 1995. Understanding Large River: Floodplain Ecosystems. *BioScience* **45**:153–158.

Junk, W.L., Bayley, P.B., and Sparks, R.E. 1989. The flood pulse concept in river–floodplain systems. In Proceedings of the International Large River Symposium. Edited by D.P. Dodge. Can. Spec. Publ. Fish. Aquat. Sci. No. 106. pp. 110–127.

Opperman JJ, Luster R, McKenney BA, Roberts M, Meadows AW. 2010. Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. JAWRA Journal of the American Water Resources Association **46**:211–226.

Tables and Figures:

Table 7. Total area of intermittent inundation associated with mainstem big rivers by subgeography in the GCPO **.

SubGeography	**Area (km^2)**
East Gulf Coastal Plain	1,876
Gulf Coast	1001
Mississippi Alluvial Valley	**8,311**
Ozark Highlands	602
West Gulf Coastal Plain	2,075

** Note that this analysis is based upon the area of intermittent inundation that lies within the mainstem big rivers HUCs ***and*** within the boundaries of the GCPO. It does not include areas of intermittent inundation that are part of the mainstem big rivers floodplains that lie outside of the GCPO boundaries.

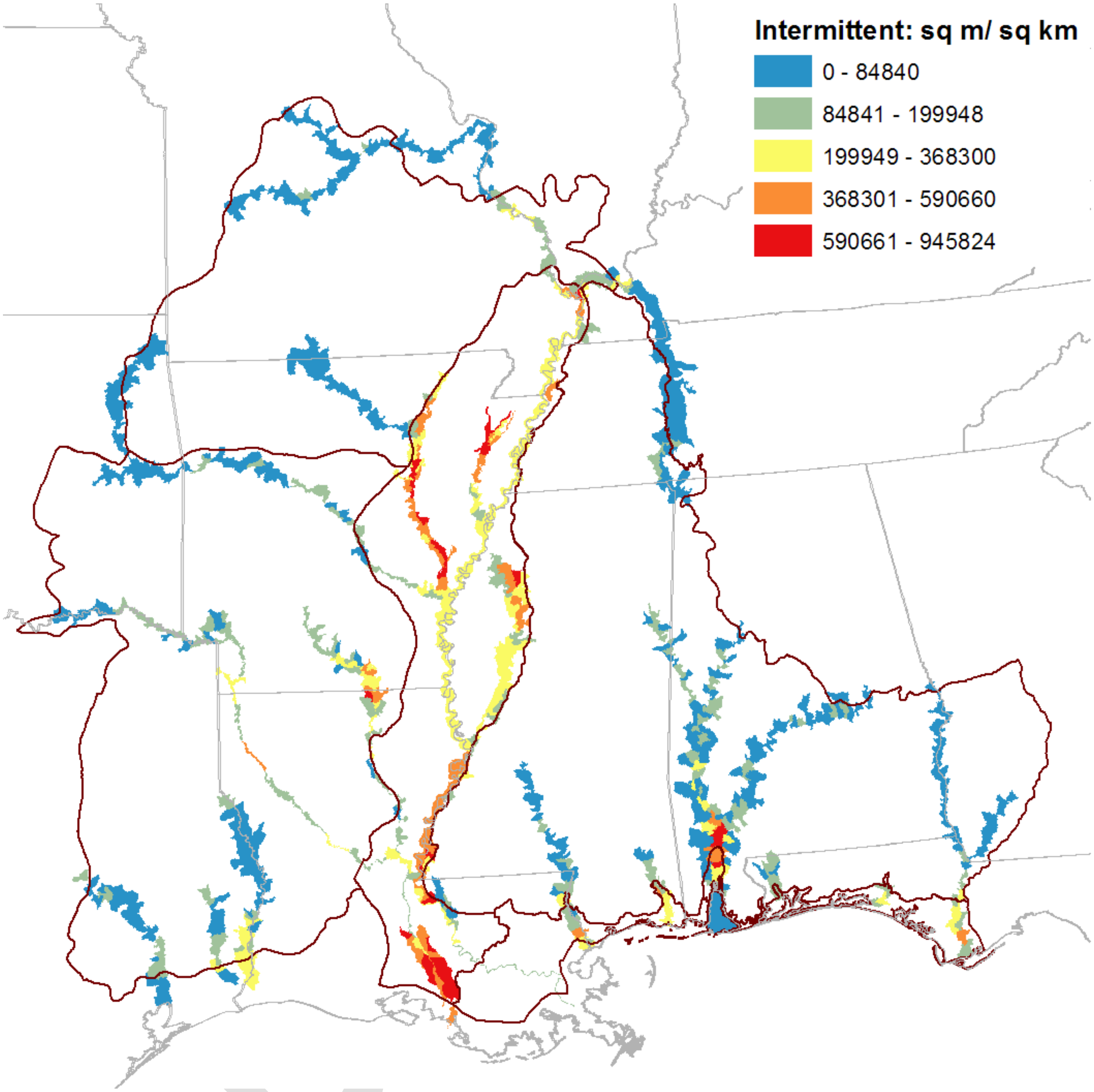

Figure 13. Amount of intermittent inundation (10-90%) normalized by the total area for mainstem big river HUCs.

<u>Links to Available Geospatial Data Outputs</u>

- Mainstem Big Rivers – Lateral Connectedness
  - GCPO geography (raster)
  - GCPO geography (vector – polygon)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Secondary Channels

Landscape Attribute: Amount

Secondary channels or chutes are separated from the main channel by an island or sand bar. The diversity of flow and substrate conditions and high hydrologic connectivity to the main river channel provides habitat for a wide variety of organisms in large rivers throughout the world (Baker et al. 1991, Simons et al. 2001, Ellis et al. 2004, Sallam and El-Barbary 2004). The distribution, dynamics and ecological value of secondary channels on lower Mississippi River have been studied extensively by the US Army Corps of Engineers (Baker et al. 1987, Cobb and Clark 1980, Cobb and Magoun 1985, Lowery et al. 1987, Payne et al. 1989, Pennington and Coleman 1988, Guntren et al. 2012). Chutes tend to form in higher energy settings where point bars may be cut through at higher flows (Fryirs and Brierley 2012). Meander cutoffs tend to occur in lower energy environments.

Killgore et al. 2012 provided a comprehensive analysis of the distribution and condition (habitat quality) of secondary channels within the lower Mississippi River. They assigned a habitat quality metric to each secondary channel. In addition, they also provided an economic feasibility score for channel restoration or improvement. For the lower Mississippi River, the Killgore et al. findings should provide the foundation for secondary channel condition assessment and restoration priority. Much of the analysis presented here focuses on methodology and options to design a comprehensive landscape scale evaluation of secondary channel distribution throughout the GCPO.

Data Sources and Processing Methods:

In addition to the Killgore et al. analysis, Guntren et al. (in review) conducted an extensive and detailed spatial and temporal assessment of secondary channels in the lower Mississippi River using hydrographic survey data. That assessment includes not only details of presence/absence but also spatial extent and volume. We compared locations from this baseline assessment to the GCPO inundation frequency (IF) assessment to determine visual cues for secondary channel presence. Guntren et al. found 172 unique observations of secondary channels based on all data from 1989-2004. Using the IF assessment (based on Landsat observations from 1983-2011), 144 unique secondary channels could be identified or 84% of channels identified by Guntren et al.. Based on this result, we used IF to identify the distribution and abundance of secondary channels in other mainstem big rivers throughout the GCPO.

The following visual cues and methods were used to identify secondary channels using IF:

- Channels had to have some level of connectivity with the main channel at both the top and bottom of the channel. This criterion excludes tributaries and meander cutoffs that have been primarily disconnected from the mainstem river through natural processes or closures engineered to improve channel flow. This condition was confirmed using aerial photography since the footprint of some intentional closures were too small to discern at the Landsat scale.
- Channels that are the result of reservoirs not quantified because they do not provide the habitat function intended in this landscape endpoint.

- Dike fields were not counted because they were typically difficult to discern at the Landsat scale.
- A point was placed at the downstream end of secondary channels. No attempt was made to quantify the depth or volume of the channel.
- The presence of secondary channels was only evaluated for the extent of mainstem big rivers within the GCPO.
- The presence of secondary channels on the lower Arkansas River was not evaluated due to massive channel shifting that occurred during the Landsat period of observation.

The abundance of secondary channels was summarized by river and also analyzed by HUC12 based on the total amount of mainstem big river length within each HUC12.

Summary of Findings:

Comparison with Guntren et al. location data shows that the IF analysis may offer a very good means for rapid screening of the distribution secondary channels throughout the GCPO. Figure 14 shows the distribution of secondary channels in mainstem big rivers based on IF. The lower Mississippi River had the greatest number of secondary channels (Table 8), but the highest density of channels (channels/river km) occurred on the Missouri River. The density of secondary channels is similar on the Arkansas, Middle and Lower Mississippi Rivers. The highest number of secondary channels along mainstem big rivers is found in the MAV (Table 9).

A comparison of mean annual flow and mean annual velocity with secondary channel location did not show an obvious relationship among mainstem big rivers in the GCPO. Measurements related to peak stream power (peak discharge and slope) may be more predictive. Secondary channels were frequently found immediately downstream of large dams (e.g. Osage and Tennessee Rivers) - a location where peak stream power may be greatest. They are also found at the mouth of many tributary rivers where added flows and increased sedimentation may combine to form a tributary confluence bar and channel complex. Conversely, secondary channels were largely absent on sections of rivers that have large overbank flooding such as the White and Mobile where river power may be reduced compared with similar rivers in a confined channel.

The analysis for the Atchafalaya River was problematic. The lower Atchafalaya River basin has numerous interconnected side channels in addition to mainstem secondary channels that offer a refuge from flow and may offer suitable habitat diversity. The definition for secondary channels in this part of the river system may need further refinement.

The analysis also does not work well for Red River where there have been many engineered channel alterations that have occurred during the period of the Landsat analysis. Currently, some locations that were previously well connected are now disconnected. For this reason, all locations of secondary channels along the Red River were compared with recent aerial photography.

Although not quantified in this analysis, the average and maximum size of secondary channels on the lower Mississippi tended to be much larger than on any other mainstem big river.

Future Directions and Limitations:

The current analysis only describes channel location but does not describe condition such as channel depth, flow velocity, flow variability or adjacent landcover contributions. Guntren et al. (2012) used a series of hydrographic surveys on the lower Mississippi River to quantify secondary channel volume. The analysis was limited in locations where hydrographic survey data was unavailable or incomplete. The current analysis provides complete spatial coverage, but does not describe volumetric data. Some more detailed crosswalk between these two datasets may reveal a means for establishing a channel condition metric based on IF.

Killgore et al. (2012) used georeferenced video captured from a helicopter at low water along the lower Mississippi River to assign an index of secondary channel habitat quality based on: abundance of gravel, number of habitats, percent of forested riparian areas and distance to the protection levee (Table 10). The use of low water video to assess exposed habitat quality is invaluable, but is at this point cost prohibitive to collect at the landscape scale. Some combination of currently available GIS layers including landcover and IF could be used to establish a partial condition metric for each channel location which may be later confirmed through aerial photography or drone collections of habitat quality. The habitat quality metric related to floodplain extent may actually be improved by using the IF dataset.

The goal of the IF dataset was to collect a range of inundation conditions. Future monitoring of secondary channel locations and condition may be possible using satellite imagery acquired under low water conditions in the fall.

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Tables and Figures:

Table 8. Abundance and density of secondary channels on mainstem big rivers throughout the GCPO based on visual interpretation of inundation frequency. The top five rivers by secondary channel density are shown in red. Rivers having no reported secondary channels are shown in blue.

River System	Length (km)	Secondary Channels	Secondary Channels / km
Alabama	500	3	0.006
Apalachicola	171	2	0.012
Arkansas	660	63	0.095
Atchafalaya	233	27	0.116
Black	208	0	0.000
Black Warrior	245	3	0.012
Canadian	59	2	0.034
Chattahoochee	274	3	0.011
Choctawhatchee	42	0	0.000
Coosa	33	1	0.030
Escambia	74	0	0.000
Flint	108	0	0.000
Little	34	0	0.000
Lower Mississippi River	1473	143	0.097
Middle Mississippi River	315	29	0.092
Missouri	347	51	0.147
Mobile	76	0	0.000
Neches	226	7	0.031
Neosho	197	3	0.015
Osage	362	13	0.036
Ouachita	507	8	0.016
Pascagoula	124	1	0.008
Pearl	432	9	0.021
Red	1007	39	0.039
Sabine	315	1	0.003
Saint Francis	243	0	0.000
Tallahatchie	125	0	0.000
Tallapoosa	73	0	0.000
Tennessee	387	7	0.018
Tombigbee	488	1	0.002
Trinity	318	0	0.000
White	754	33	0.044
Yazoo	266	0	0.000

Table 9. Abundance of secondary channels by subgeography.**

Subgeography	Secondary Channels	Percent of total number of secondary channels in GCPO
East Gulf Coastal Plain	24	5.3
Gulf Coast	2	0.4
Mississippi Alluvial Valley	**211**	**46.9**
Ozark Highlands	86	19.1
West Gulf Coastal Plain	88	19.6

**** Note that this analysis is based upon secondary channels that lie within the mainstem big rivers HUCs *and* within the boundaries of the GCPO. It does not include secondary channels that are part of the mainstem big river floodplains that lie outside of the GCPO boundaries.**

Table 10. Index of secondary channel habitat quality metrics from Kilgore et al. 2012

Metric	Metric Implications	Optimum
Abundance of gravel	Gravel represents stable habitat used by riverine fishes including endangered sturgeon, for spawning and feeding	High
Number of habitats	Greater habitat diversity corresponds to greater faunal diversity	> 4
Percent of forested riparian – landside	Trees provide shade and woody debris, filter sediment-laden water, and stabilize banks. Functions as a floodplain	> 75%
Percent of forested riparian – Island	Trees provide shade and woody debris, filter sediment-laden, water, and stabilize banks. Functions as a channel littoral zone	> 50%
Distance to levee	Greater distance to levee results in a more expansive floodplain used by a variety of fishes that move laterally for spawning, rearing, and feeding	> 4 miles

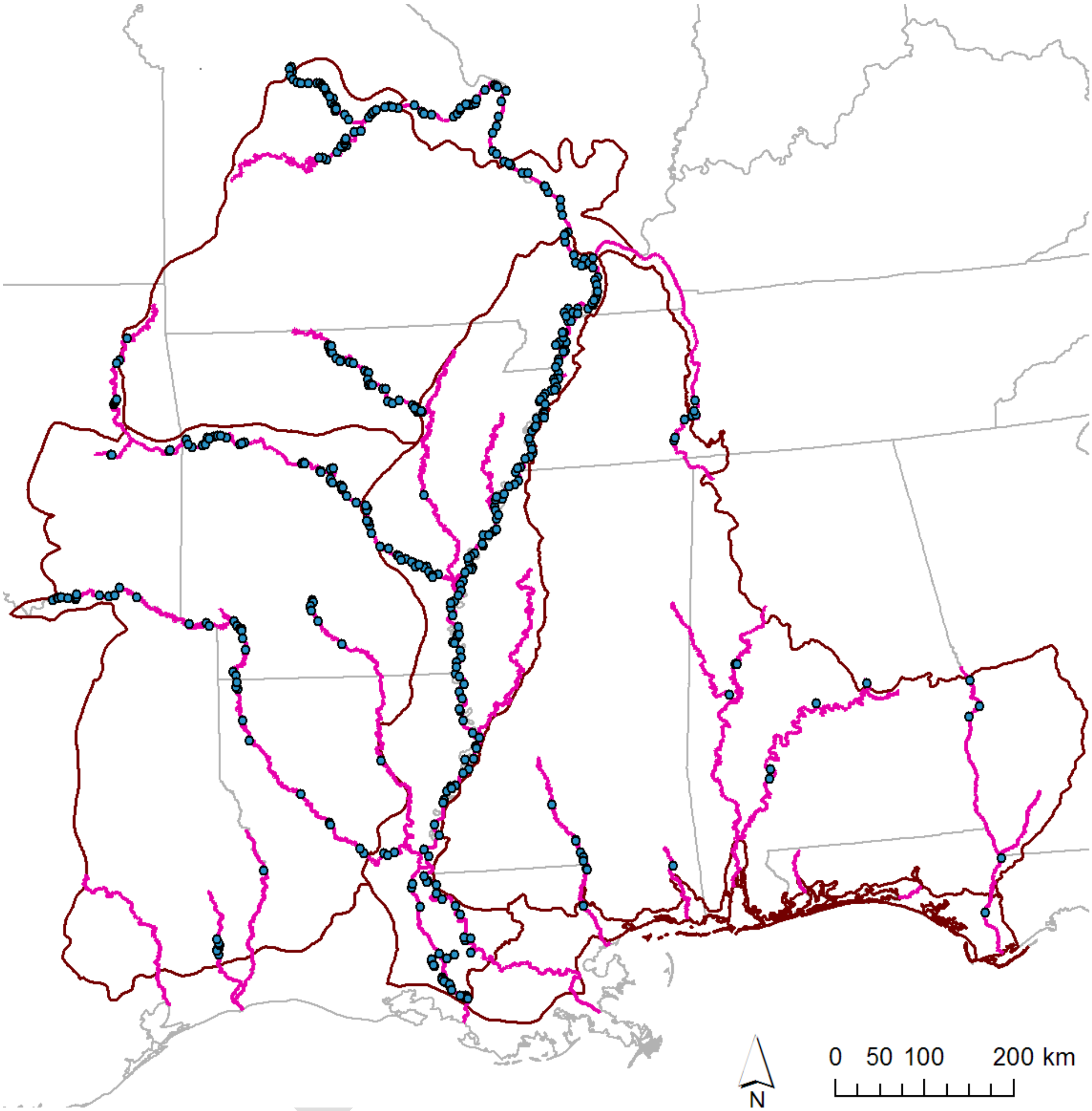

Figure 14. Distribution of secondary channels on mainstem big rivers within the GCPO based on analysis of inundation frequency.

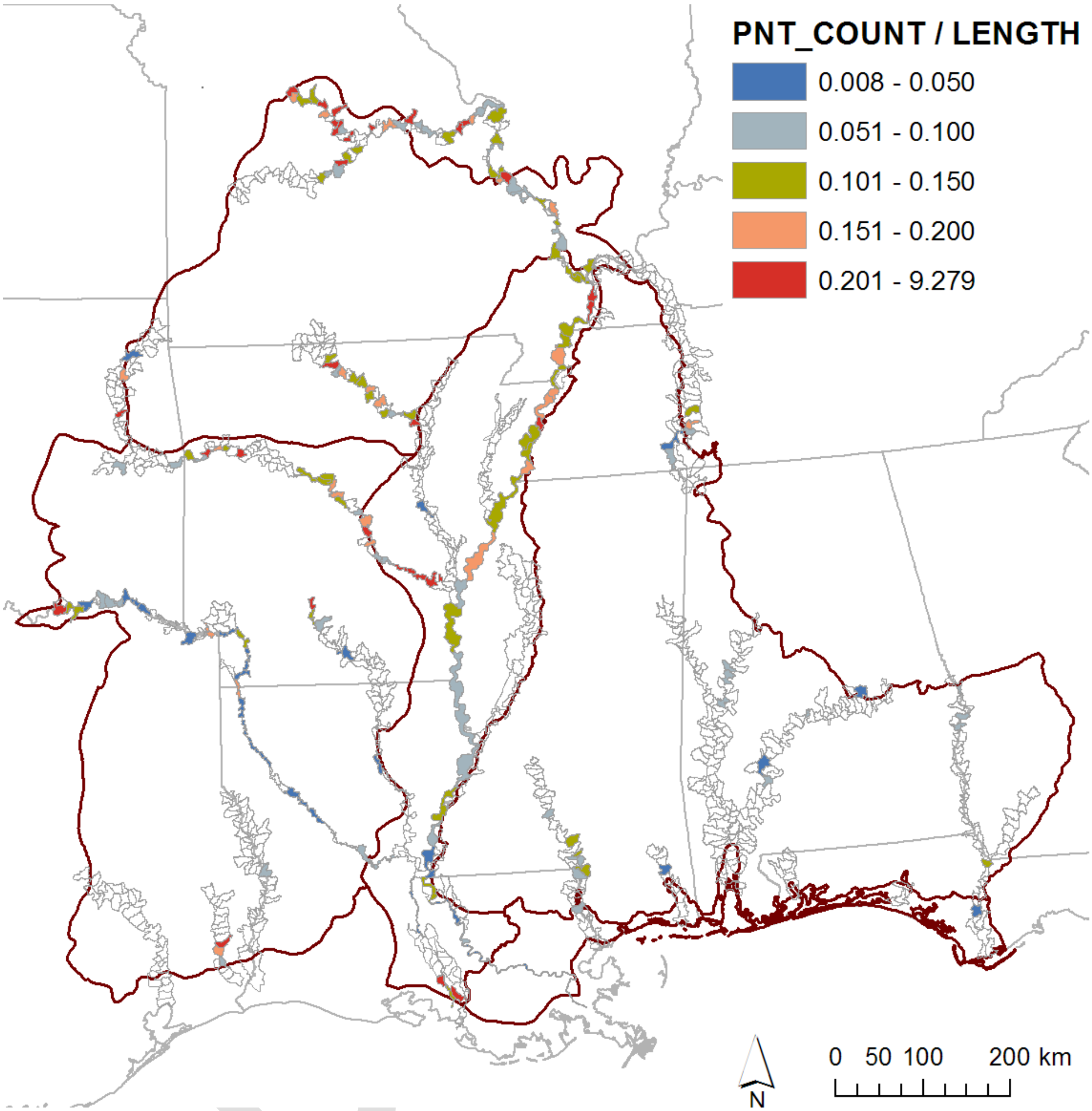

Figure 15. Abundance of secondary channels per river kilometer by HUC12 on mainstem big rivers within the GCPO based on analysis of inundation frequency.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – Secondary Channels
    - GCPO geography (vector – points)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Natural Sinuosity

Landscape Attribute: Configuration

High sinuosity may be seen as a measure of increased available habitat diversity. Large rivers and streams are frequently straightened to reduce localized flooding and increase navigability.

Data Sources and Processing Methods:

The National Hydrographic Dataset (NHDPlus v2) flowlines were used as a basis for assessing sinuosity within mainstem big rivers. Rosgen (1994) stream classification recommends that sinuosity be measured over reaches that are 20-30 times channel width. This scaling is particularly important for large river systems with large variability in river width. For this reason, we created a new segmentation of mainstem big river NHD lines – creating new segments that are 30X average river width. Sinuosity could then be more accurately calculated over these new segments.

Mainstem big river NHD segments were first dissolved to produce a smaller subset of large reaches having similar inflow and outflow points ("MBRdissolve"; n=75 segments). Reaches that fell predominantly within an open water body were deleted from this layer. To estimate average river width, we used a recently published geospatial dataset that describes river width for large rivers in North America (Allen and Pavelsky 2015; "NAR_width"). These two datasets were joined using "spatial join" in ArcGIS with "MBRdissolve" set as the target dataset and "NAR_width" set as the join layer. Average river width for each "MBRdissolve" segment was calculated using "merge rules" and river width from the "NAR_width". A distribution of river width categories is shown in Figure 16.

Each river reach ("MBRDissolve") was then divided into measured sub-segments based on 30 times average river width. To accomplish this we first selected all segments satisfying a given 100m range of river widths (e.g. 0-100, 100-200 etc.) We then split those selected segments into sub-segments using XTools conversion tool > split polylines. The length of the resulting sub-segments was equal to 30 times the maximum average width, for example 0-100m width segments were split into 30x100m = 3km sub-segments, 100-200m width segments were split into 30x200m = 6km sub-segments, etc. This created 10 separate files which were then merged into one file.

We calculated sinuosity on all sub-segments using a modified version of the ArcGIS sinuosity calculator. The modified version calculates sinuosity in the more typical sense as actual reach length divided by straight line distance. The original ArcGIS sinuosity calculator version calculates the inverse value. Mainstem big river sub-segments were classified into three sinuosity categories: "good", "intermediate" and "poor". "Good" has sinuosity values greater than 1.2; "intermediate" has values greater than or equal to 1.1 and less than 1.2, "poor" has values less than 1.1. These thresholds were chosen to represent a conservative interpretation of river condition. Rosgen (1994) reports sinuosity > 1.2 as "moderate" but still in the range for natural conditions of a river. He also reports that sinuosity values can vary by +/- 0.2 units. To simplify the presentation for this landscape endpoint, total length of stream reaches in each sinuosity category were not summarized by HUC12.

Summary of Findings:

The approach used here differs from the assessment of sinuosity for medium-low gradient streams and rivers in two ways: 1) the sinuosity metric is calculated as the inverse to improve conventional interpretability and 2) the metric is calculated using variable reach lengths depending on average measured stream width. For these reasons, direct comparison of results for these two priority habitats may not be appropriate.

In the MAV, 66% of the mainstem big river segments show sinuosity greater than 1.2. The Tallahatchie, Yazoo and Atchafalaya Rivers have a greater prevalence of reaches having sinuosity of less than 1.1. The White River has generally high sinuosity (>1.2) and most of the mainstem Mississippi River has sinuosity values greater than 1.1. By contrast, the Middle Mississippi and Missouri Rivers in the Ozark Highlands subgeography have extensive reaches of low sinuosity (<1.1). Low sinuosity is also prevalent in the Chattahoochee and Tombigbee rivers in the EGCP.

Future Directions and Limitations

The current analysis is an improvement over a simple evaluation of sinuosity using the default NHD segment lengths. It is however uncertain whether suitable sinuosity thresholds have been chosen to characterize these large rivers. The thresholds for sinuosity established here were determined based solely on fluvial geomorphic properties and do not necessarily relate to species requirements. Further determination of species-specific requirements and the applicability of these data to describing those relationships accurately should be further investigated. Natural sinuosity according to Rosgen also depends on valley entrenchment and width/depth ratios which could not be characterized in this assessment.

The analysis is limited by the temporal and spatial resolution of the NHD. There has, for example, been significant channel alteration in the Red River since the early 1980s which is not reflected in the NHD. Sinuosity values for the Red River are therefore likely to be significantly over estimated.

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Tables and Figures:

Table 11. Summary of stream reaches in each sinuosity category by subgeography in the GCPO. Note that these totals do not include river reaches that overlap with impoundments.

	Good (> 1.2)		Intermediate		Poor (< 1.1)		
Subgeography	**(km)**	**%**	**(km)**	**%**	**(km)**	**%**	**Grand Total**
East Gulf Coastal Plain	1,329	64%	429	21%	310	15%	2,068
Gulf Coast	499	87%	60	11%	15	3%	574
Mississippi Alluvial Valley	**2,175**	**66%**	**734**	**22%**	**387**	**12%**	**3,296**
Ozark Highlands	312	41%	142	19%	303	40%	757
West Gulf Coastal Plain	1,520	71%	366	17%	242	11%	2,127

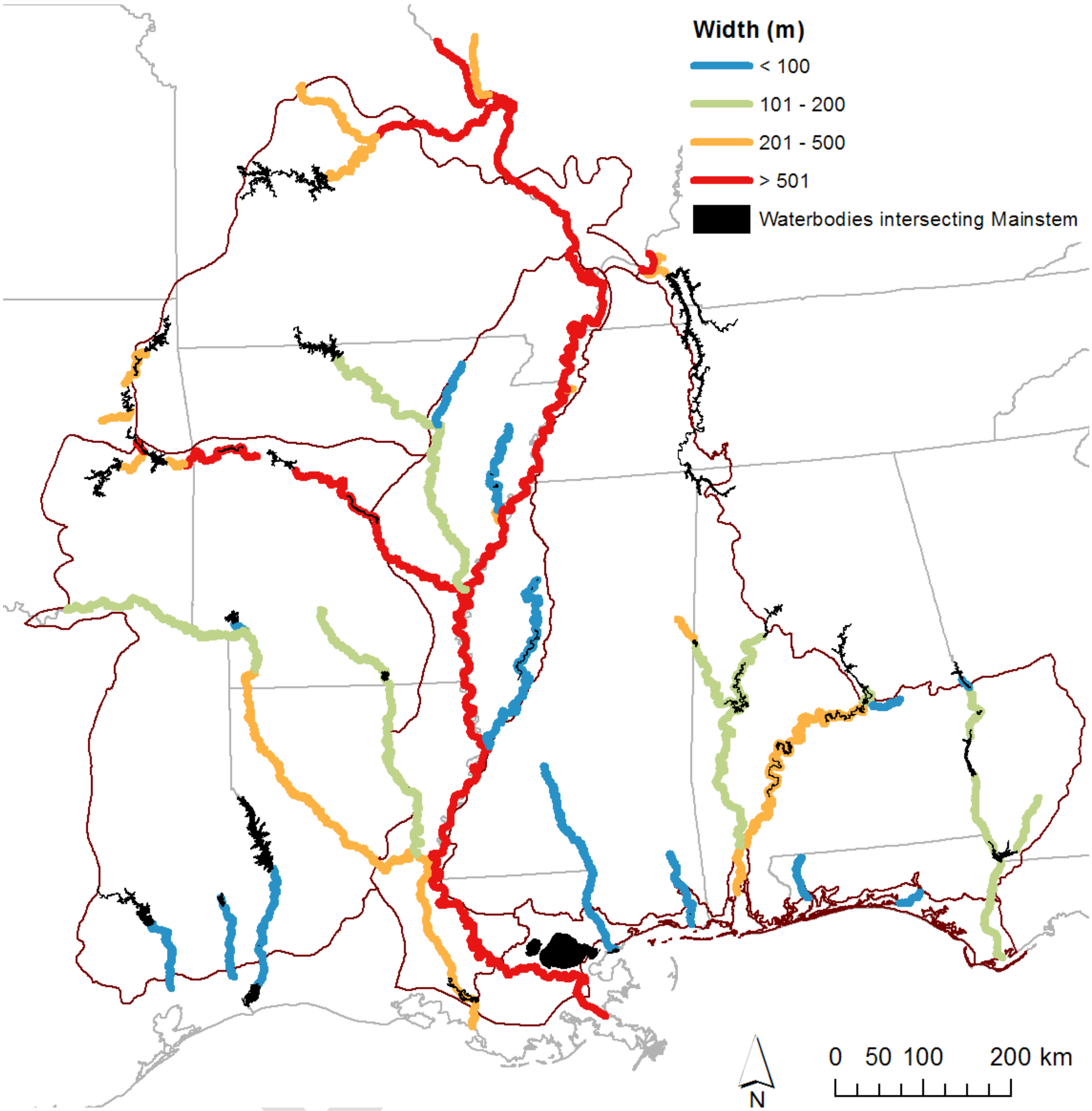

Figure 16. Distribution of average river width for mainstem big rivers within the GCPO based on the analysis detailed in the text.

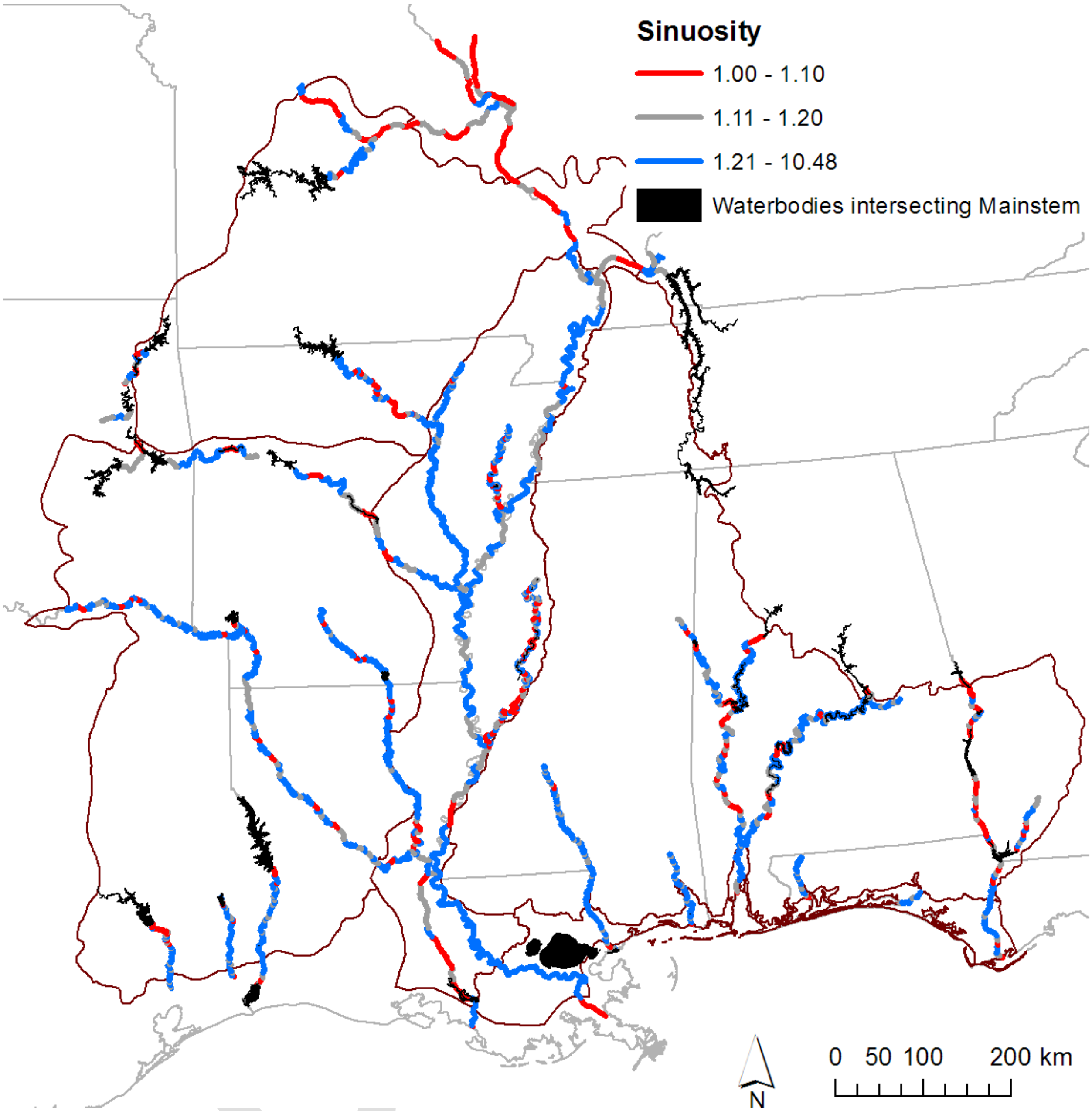

Figure 17. Distribution of sinuosity for mainstem big rivers within the GCPO based on the analysis detailed in the text. Blue lines show segments having good sinuosity based on the analysis presented in the text while red lines show segments of poor sinuosity.

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Development of a data product to characterize connectivity between mainstem big river systems and the adjacent floodplain

"Connectivity may be defined as the ease with which organisms, matter or energy traverse the ecotones between adjacent ecological units…. ecotones, connectivity and succession play major roles in structuring the spatio-temporal heterogeneity leading to the high biodiversity that characterizes floodplain rivers" (Ward et al. 1999)

The goal of this analysis is to determine a quantitative and objective data product that characterizes floodplain connectivity and, more specifically, connectivity of mainstem big rivers with any off channel floodplain location at a landscape scale.

Defining a Connectivity Data Layer: We used two input data sources: 1) the draft version of the GCPO relative floodplain inundation frequency mosaic and 2) NHD flowlines, as the basis for quantifying floodplain connectivity within mainstem river systems of the GCPO. A point file was generated from NHD flowlines for the mainstem big rivers with points dropped at 1km intervals using the XTools Pro "disperse points" function. The IF mosaic was then treated as a cost surface to determine the ease of movement from each 1 km point out onto the adjacent floodplain using the ArcGIS Spatial Analyst "Cost Distance" tool. This tool calculates the least accumulative cost distance ("distance raster") for each cell to the nearest source (1 km interval points) over the cost surface (inundation frequency). Adjacent locations have a lower cost if they are close and are more frequently inundated. Locations that are more distant and/or less frequently inundated are associated with higher cost. Values in the IF mosaic were inverted so that pixels with higher frequency of inundation have the least cost (i.e. 80% IF becomes 20 or *(1-Value) *100*). Locations that have a relative inundation frequency of less than 10% were reclassified as "NoData" pixels and movement was prevented from occurring across those pixels. This restriction reduced the error associated with movement across narrow but significant barriers to flow such as federal protection levees. Some errors were associated with very narrow barriers to flow that were not accurately captured in the inundation frequency dataset. Areas of intermittent inundation that were also associated with agriculture were included in the connectivity analysis because these locations have been shown to be important spawning areas for floodplain dependent species such as alligator gar. The output file format was floating point, but was reclassified into 11 categories (4-bit) to reduce file size. Categories were determined based on the spatial distribution of the data and experience of field-based levels of connectedness determined in St. Catherine Creek and the Atchafalaya Basin (

Table 12). The mainstem big rivers "distance raster" was then merged with the relative floodplain inundation frequency mosaic using model maker in ERDAS Imagine to identify areas which are intermittently or permanently inundated but which are primarily disconnected from mainstem big rivers. This data product serves as the basis for estimation of connectivity from mainstem big rivers to intermittently inundated and permanently inundated floodplain locations within the GCPO. Figure 18 shows an example of source points along the lower Mississippi River and connectedness categories for the adjacent floodplain.

Figure 19 shows the overall data product for the entire GCPO. Note that in some instances, the connectedness analysis shows locations that extend well beyond the HUC12 boundaries that define the areas directly within the floodplain of mainstem big rivers. This is particularly obvious for tributaries of the lower Mississippi River in western Tennessee including the Obion, Forked Deer and Hatchie Rivers. This analysis highlights the potential importance of these distant off channel locations in providing additional resources for organisms within the mainstem big river systems – particularly rivers for such as the Mississippi where much of the historical floodplain is currently unavailable. Preliminary results from the connectedness analysis were sent to selected researchers along the Mississippi River for validation with ground conditions.

Application of connectedness to thermal conditions:

Floodplain waters also offer a thermal advantage compared with mainstem river condition (Schramm et al. 1999, Allen et al. 2014). Results from the current connectivity analysis were compared with multiple Landsat observations of floodplain thermal conditions (Allen et al. 2014). The Landsat observations reported temperature for all wetted areas for a single Landsat image (path 23, row 38). This temperature was compared with river temperature in the mainstem Mississippi River for that same image. Average temperature difference from the mainstem river was calculated based on results from 23 total images. The average temperature difference was then compared with the connectivity classes for all areas of intermittent inundation (Figure 20).

These results indicate that, in the absence of detailed *in situ* reporting, connectedness categories may be a good surrogate for estimates of thermal conditions on large river floodplains.

Future Directions and Limitations:

As for many things, the output is only as good as the input. There are some places where small but significant barriers to flow are not accurately captured using the IF mosaic, so movement patterns may be unrealistic (e.g near Greenville, MS where the map shows movement through the west protection levee into Lake Chicot). It also may not be doing a good job for areas where there has been significant change/configuration (e.g. lower Arkansas river and maybe some secondary channels on the main Miss River). Also, the original NHD linework is faulty in some locations – highest MAF passing through the wrong channels or through channels where there has been significant channel alteration (especially in the lower Mississippi, lower Arkansas, and Red Rivers).

The IF data used in this analysis have some inherent limitations primarily based on the ability of the optical sensor to determine the extent of inundation. Inundated locations that also have dense, understory vegetation that persists throughout December through March will not be accurately characterized using this approach.

This analysis also assumes that the inundation frequency mosaic accurately characterizes the full range of inundation conditions for all areas. In some locations, the observations based on Landsat may under or overestimate floodplain inundation extent and frequency. A detailed analysis based on long-term gaging data would be required to reveal the accuracy for an individual local watershed.

In this analysis, connectedness is based solely on resistance provided by inundation frequency. There is strong connectivity indicated for some locations that are only connected to mainstem big rivers via routes through the Gulf of Mexico. Depending on the specific limitations of a single species, a more refined data product or analysis might include other factors that might hinder movement such as salinity and possibly also land cover.

References

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Schramm, HL, MA Eggleton, RB Minnis. 1999. Spatial Analysis of Floodplain Habitat Critical to Lower Mississippi River Fishes. Final Report submitted to US Fish and Wildlife Service and US Geological Survey. Mississippi State University.

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Table 12. Shows the original value of accumulated cost of movement from point locations along the mainstem big river to locations in the adjacent floodplain. These values were collapsed into the categories listed here based on the distribution of the data and field experience.

Original Cost Value	Cost Category	Connectedness
0-500	1	Strong
500-1,000	2	↓
1,000-5,000	3	
5,000-10,000	4	
10,000-20,000	5	
20,000-50,000	6	
50,000-100,000	7	
100,000-200,000	8	
200,000-300,000	9	
300,000-500,000	10	
> 500,000	11	Weak
Intermittently inundated	13	Unconnected
Permanently inundated	14	Unconnected

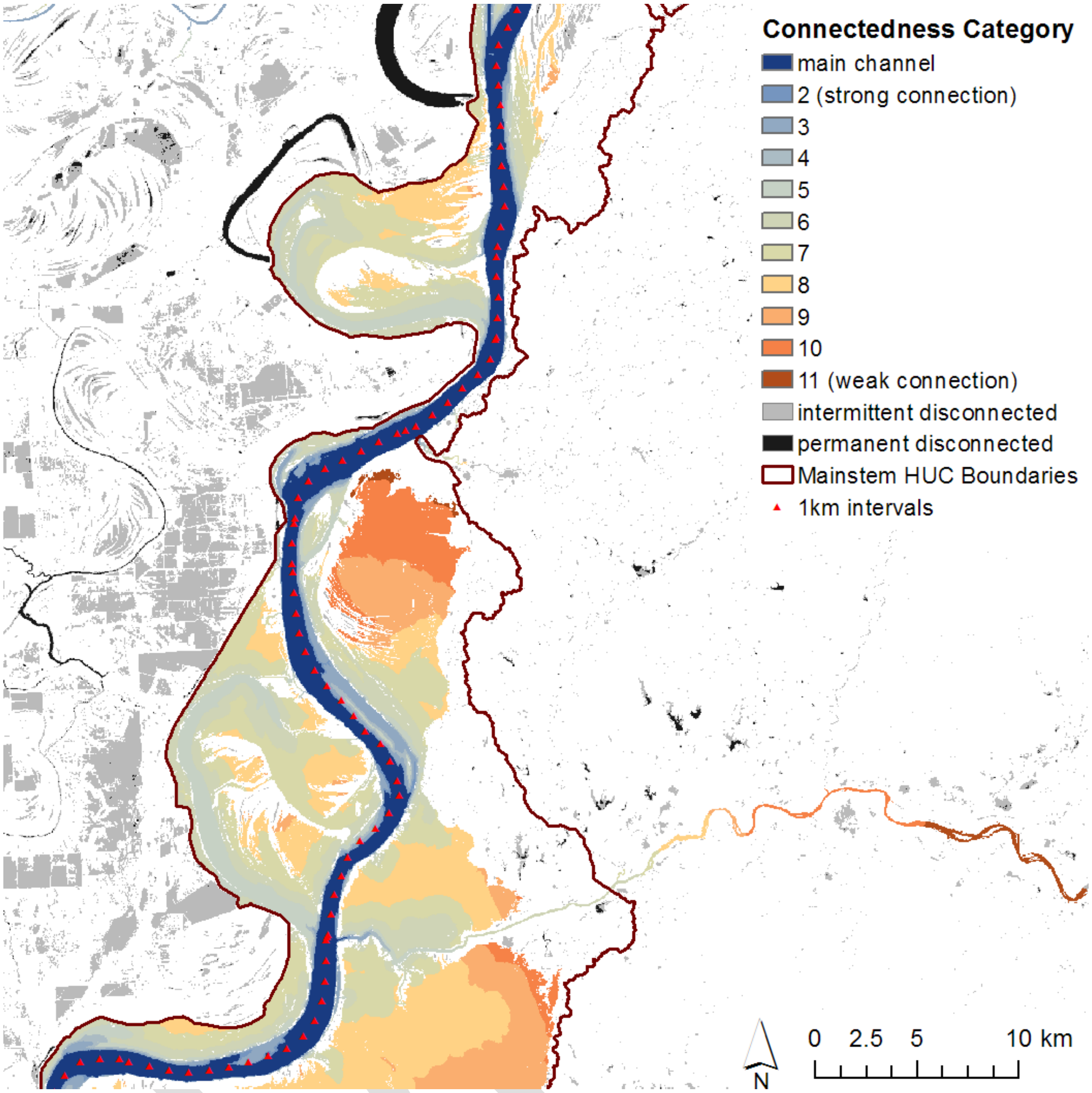

Figure 18. Example of mainstem big rivers connectedness analysis for the lower Mississippi River near the St. Catherine Creek National Wildlife Refuge. Red triangles show the location of 1km interval points (source) for the connectedness assessment. Areas having strong connectedness with the mainstem river area shown in blue. Warmer colors denote increasing remoteness from the river.

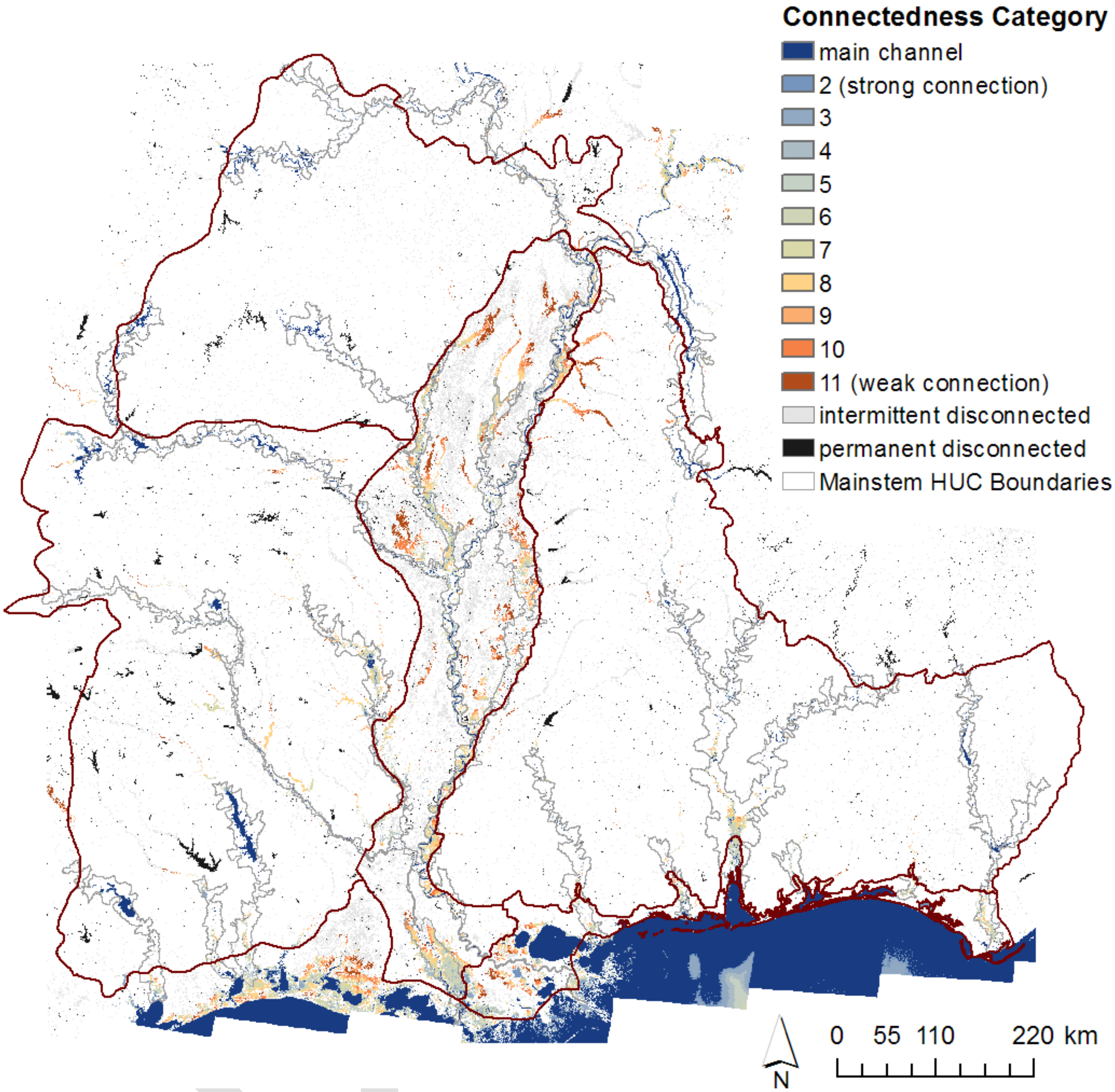

Figure 19. Mainstem big rivers connectedness analysis for the GCPO. Areas having strong connectedness with the mainstem river area shown in blue. Warmer colors denote increasing remoteness from the river.

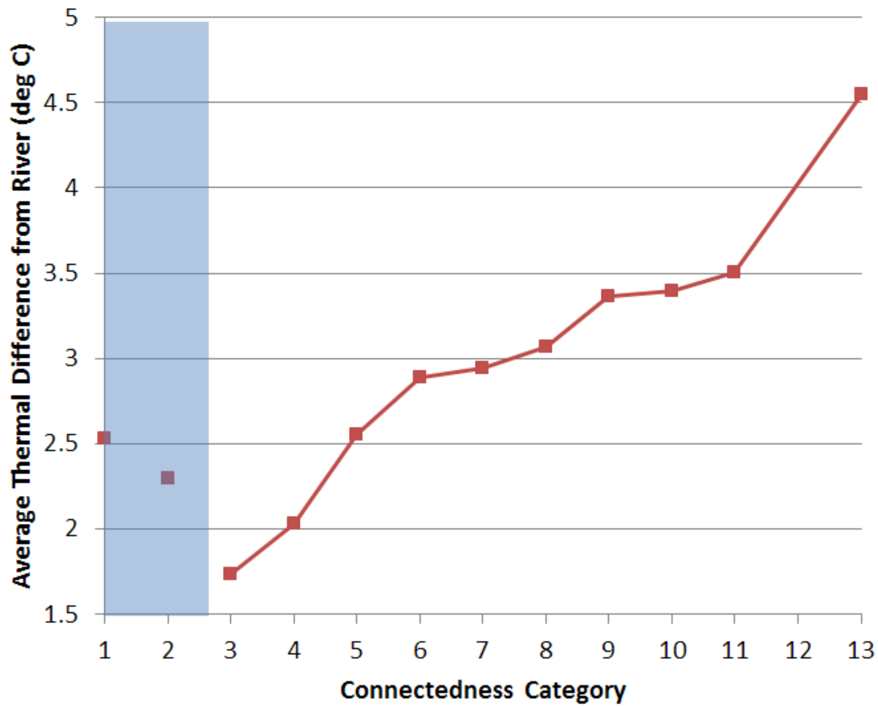

Figure 20. Average thermal difference from the mainstem Mississippi River compared with connectedness categories described in this document. Note that categories 1 and 2 occur along the boundaries of the mainstem river and not on the floodplain. Categories 3-13 lie on the adjacent floodplain and category 13 is primarily disconnected from the mainstem river.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – Lateral Connectedness
    - GCPO geography (raster)
    - GCPO geography (vector – polygon)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Maintain connectivity among a diversity of habitat types – deep water refugia* on floodplain

Landscape Attribute: Condition

This analysis considers one aspect of the floodplain: connectivity of deep water refugia on the floodplain with the mainstem big rivers. Miranda (2005) suggested that major physical changes in floodplain lakes are linked to reduced connectivity including loss of depth and area – both factors that impact the longevity of the lake. He further suggested that an intermediate level of connectivity may be most conducive to the development of lacustrine fish communities and long term stability of the lake. Allen et al. (2014) suggest variable suitability of floodplain lakes depending on connectivity and physical and chemical tolerance limits for a given species or guild. Adult alligator gar, for example, are very tolerant of hypoxia and may occupy remote floodplain water bodies to benefit from higher temperatures.

* For the current analysis, bathymetric data was not available to determine whether the waterbody is deep or shallow. Any open water body within the mainstem big river floodplain was included in this analysis so this may represent an overestimate of "deep water refugia". For that reason, we refer to this endpoint instead as "off channel open water".

<u>Data Sources and Processing Methods:</u>

We used the methodology described in the amount chapter to evaluate the location of off channel open water. Note that this definition excludes waterbodies that are *directly* connected with the mainstem river such as reservoirs and secondary channels. Because comparison of the IF and NHD based areas of off channel open water are comparable, the analysis of connectedness is restricted to analysis only based on IF. We used the connectivity data layer described here (link to description of data generation for connectivity layer) to evaluate the degree of connectedness for each off channel open water area with the main channel. Each off channel open water polygon feature was assigned a connectivity value using the ArcGIS function "Zonal Statistics as Table" where: the input feature zone is the ObjectID for each off channel open water polygon and the "majority" statistic is calculated for each polygon. "Majority" determines the value from the connectivity data layer that occurs most often within each off channel open water polygon. An example of the results of for this analysis is shown in Figure 21.

To determine the overall statistics of off channel open water connectedness for a single HUC12, we used "tabulate intersection" in ArcGIS where: the zone fields are the HUC12 boundaries, the input class features are the polygons with assigned majority attributes as described above, the class fields are the majority attributes and the sum field is the shape area. This procedure outputs a one-to-many table with a row for each HUC12 and the associated area in a single majority class. This table was brought into excel to calculate a pivot table with a single row for each HUC12 polygon and columns for the area of off channel open water in each majority class. Based on this pivot table the following statistics were calculated for each HUC12 polygon: 1) the total area of off channel open water that has any level of connectivity to the mainstem, 2) the percent of total off channel open water that is connected and 3) the area of off channel open water within each class was used to calculate an area weighted mean connectivity value for each HUC12. Note that this area weighted mean connectivity value is calculated for all off channel open water bodies including those that are primarily disconnected.

Summary of Findings:

Previous studies have primarily applied subjective categorizations of connectedness based on expert opinion and planar configuration. The current analysis uses previously unavailable information to build upon those studies and assign a more quantitative measure to the degree of connectedness.

Figure 22 shows a comparison of the total area of all off channel open water with the area of all off channel open water having some level of connectivity with mainstem big rivers. Results are comparable for mainstem big rivers within the MAV. With the exception of the Gulf Coast and the MAV, other subgeographies all report lower areas of connected off channel open water – or a higher area of disconnected off channel open water (Table 13).

The percent of total off channel open water that is connected to mainstem big rivers within the GCPO is reported in Figure 23. Most mainstem big rivers within the MAV report a high percentage of connected off channel open water. In the WGCP, a relatively high percentage off channel open water along the Red River is connected. This may be an inaccurate because there have been substantial changes in channel configuration along the Red River over the 1983-2011 time period upon which the IF dataset was based. The thalweg of the Red River has been straightened by cutting off many meanders to reduce navigation time and improve the capacity for sediment transport. High connectivity in other rivers tends to occur at the river mouth near the Gulf of Mexico.

Figure 24 reports the area weighted connectivity value for all off channel open water within mainstem big river floodplains. This metric is intended to assign a single value for each HUC12 to characterize connectivity of off channel open water habitats. Low values indicate a strong connection. Strongly connected habitats receive regular inundation from the mainstem river and may not provide the refuge value intended by this landscape endpoint. High values show the opposite extreme that most off channel open water habitats lie far off the mainstem and may be difficult for floodplain dependent organisms to reach. More moderate mean connectivity values may indicate an optimal floodplain position which provides some isolation from regular direct inundation from the mainstem river, but not so much that the waterbody is primarily isolated. Most of the HUC12 units within the MAV appear to fall in this more moderate range of connectivity. Notable exceptions occur along the Yazoo River, but some of this comes as the result of inaccuracies in HUC12 boundaries where the National Levee Database indicates that there is a federal protection levee, but the HUC12 boundary does not follow that delineation. Outside of the MAV, the upper Ouachita, as well as lower reaches of the Pearl, Pascagoula, Mobile, Tombigbee, Apalachicola and Sabine also fall in this more moderate range.

Future Directions and Limitations:

Limitations and potential improvements for the connectedness dataset and its antecedent (the IF dataset) are detailed in other chapters.

This new quantitative analysis of floodplain connectivity provides a novel data product that may be used to set conservation targets for connectivity throughout the GCPO. Future versions of the ISA may wish to incorporate more explicit landscape endpoints based on this analysis rather than based on the qualitative description currently used.

References

Allen YC, K Kimmel, GC Constant. 2014. Alligator Gar Movement and Water Quality Patterns on the St. Catherine Creek National Wildlife Refuge Floodplain. US Fish and Wildlife Service Report. Baton Rouge Fish and Wildlife Conservation Office.

Bayley PB. 1995. Understanding Large River: Floodplain Ecosystems. *BioScience* **45**:153–158.

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Ward, J. V., and J. A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. Regulated Rivers: Research & Management 11:105–119.

Tables and Figures:

Table 13. Total area of off-channel open water for with mainstem big rivers in the GCPO **.

	Area (km^2)		
SubGeography	**Total Off Channel Open Water (*IF based*)**	**Off Channel Open Water With Some Connectivity to Mainstem**	**Connected % of Total**
East Gulf Coastal Plain	152.1	92.2	61%
Gulf Coast	74.3	68.3	92%
Mississippi Alluvial Valley	**714.4**	**570.4**	**80%**
Ozark Highlands	35.2	19.0	54%
West Gulf Coastal Plain	193.1	116.8	61%

**** Note that this analysis is based upon the areas of off channel open water that lie within the mainstem big rivers HUCs *and* within the boundaries of the GCPO. It does not include areas of off channel open water that are part of the mainstem big rivers floodplains that lie outside of the GCPO boundaries. It also does not include water bodies that are directly connected with the mainstem river such as reservoirs and secondary channels.**

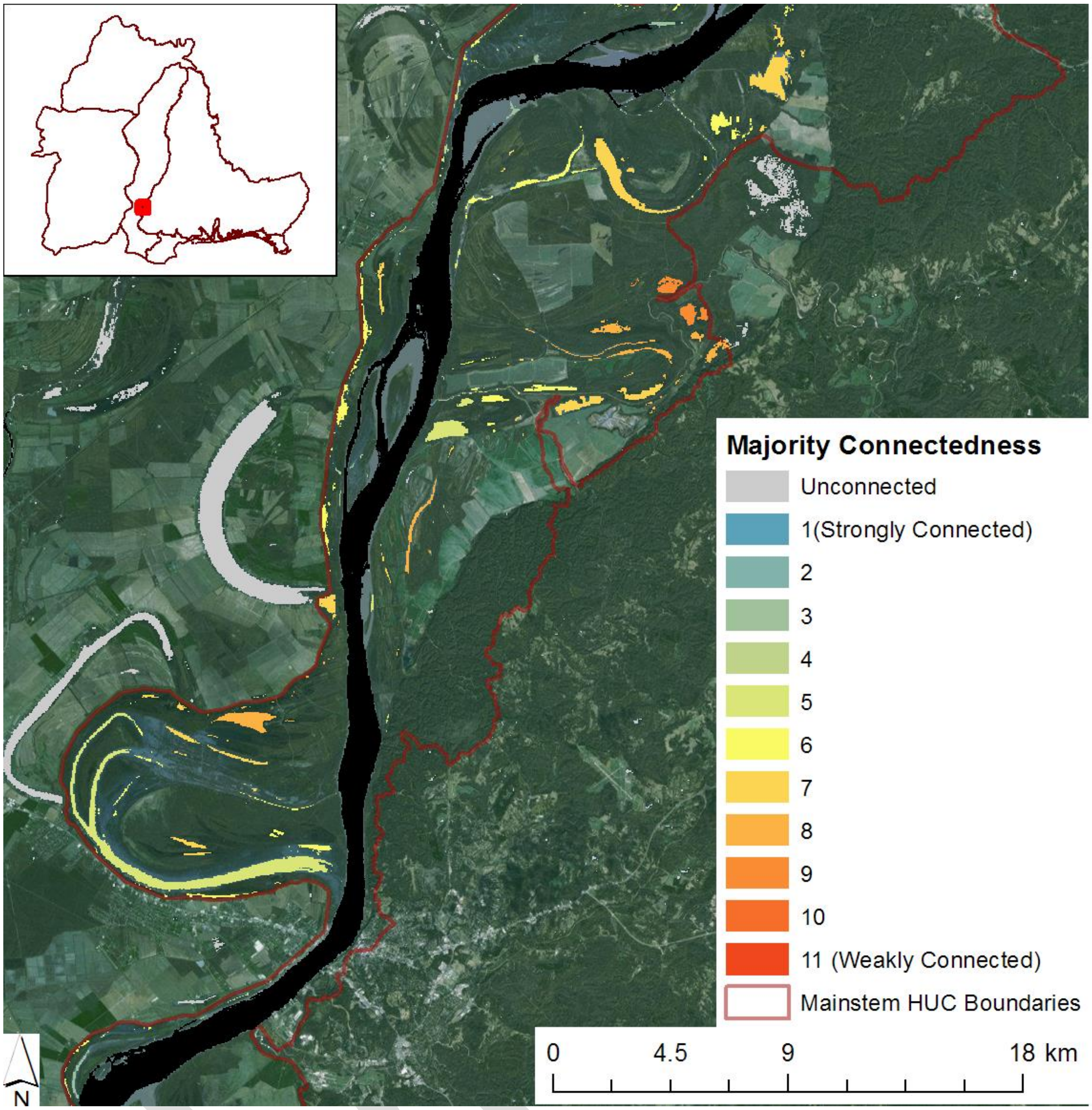

Figure 21. Example of connectedness assessment for off channel open water described in the text. Black area shows the Mississippi River.

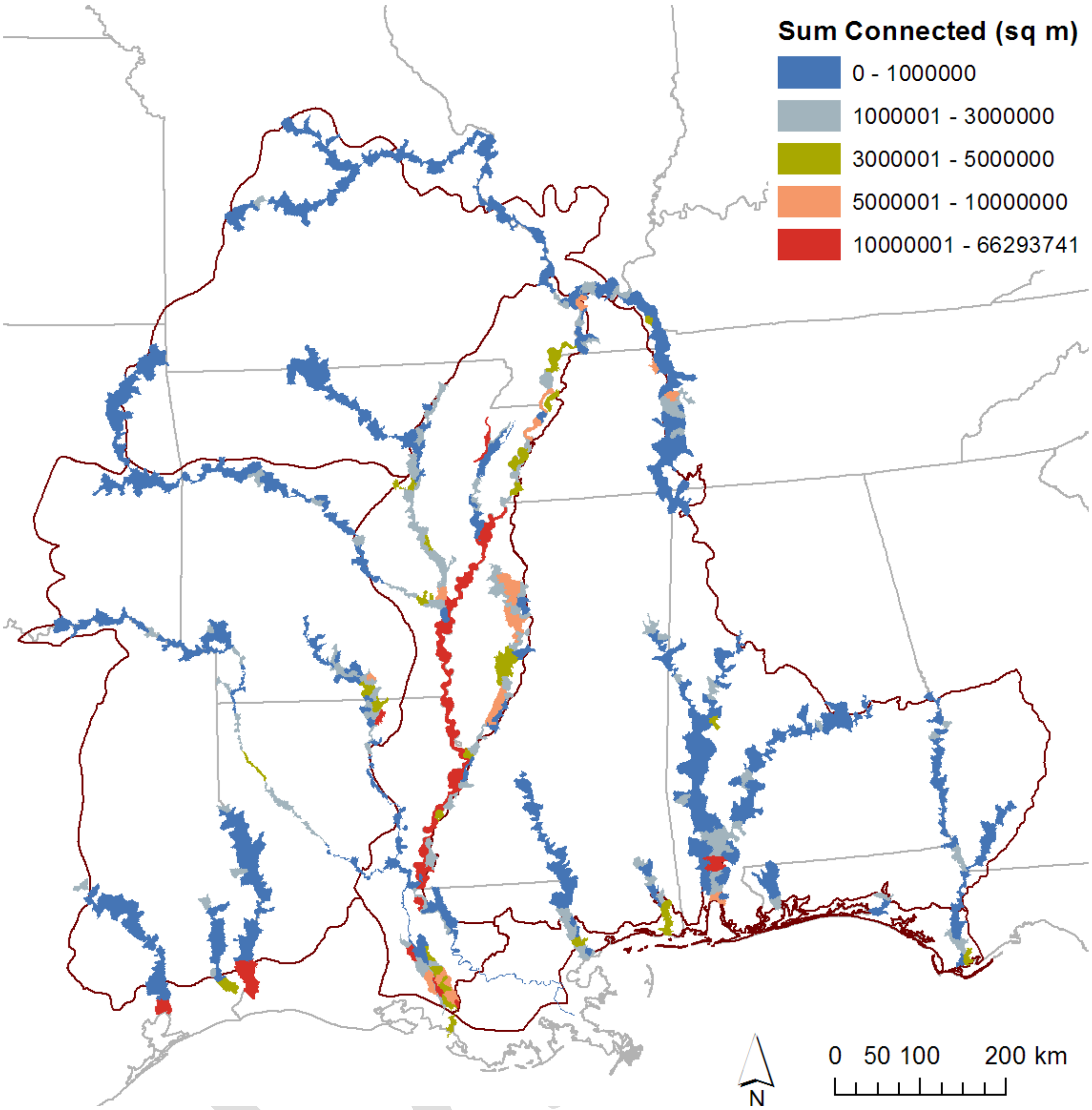

Figure 22. Area of off channel open water areas that have some degree of connectivity with mainstem big rivers within the GCPO. Note that reservoirs along the main river channel are excluded from the analysis.

Figure 27

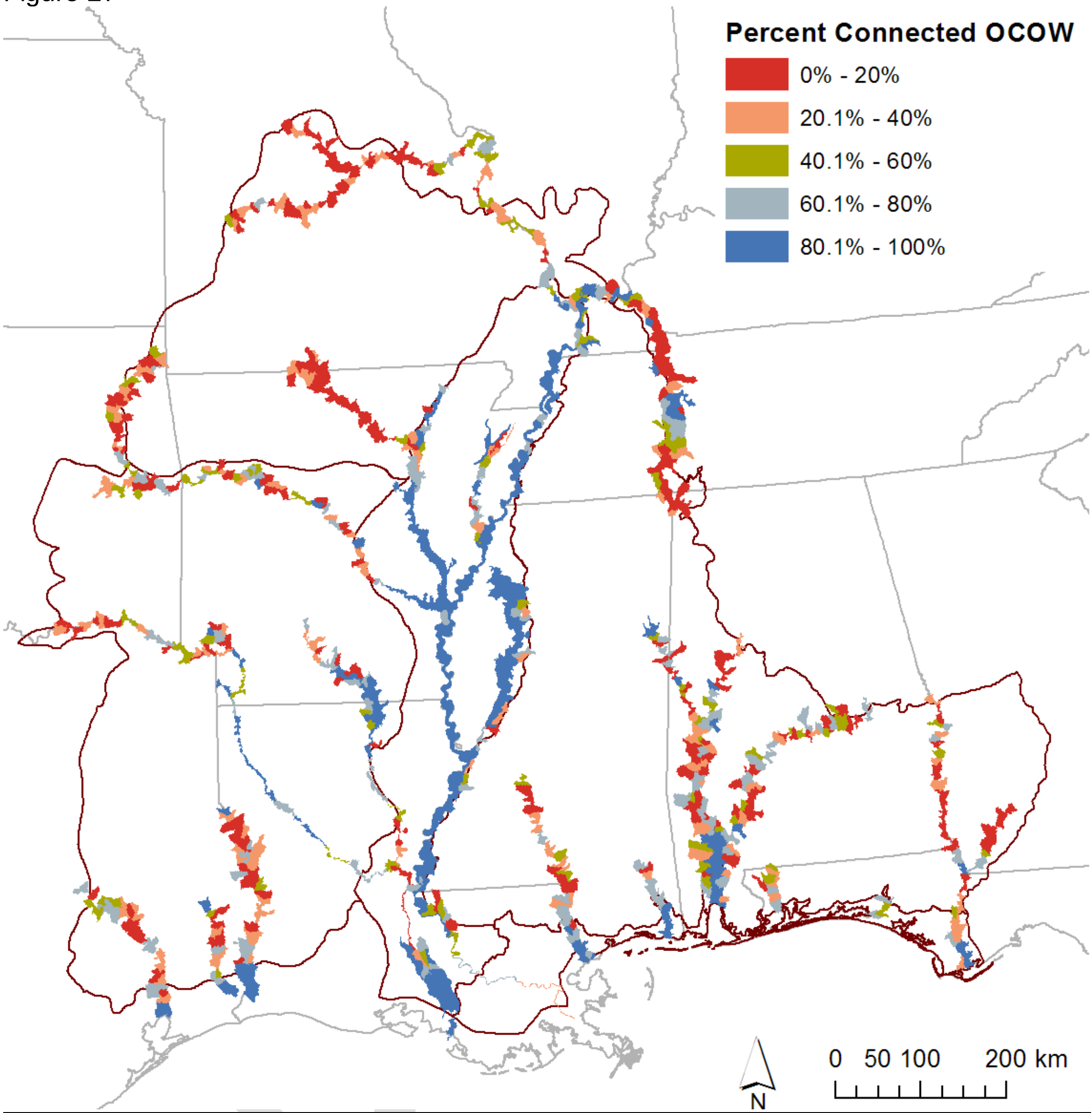

Figure 23. The percent total area of off channel open water (OCOW) that is connected to mainstem big rivers within the GCPO.

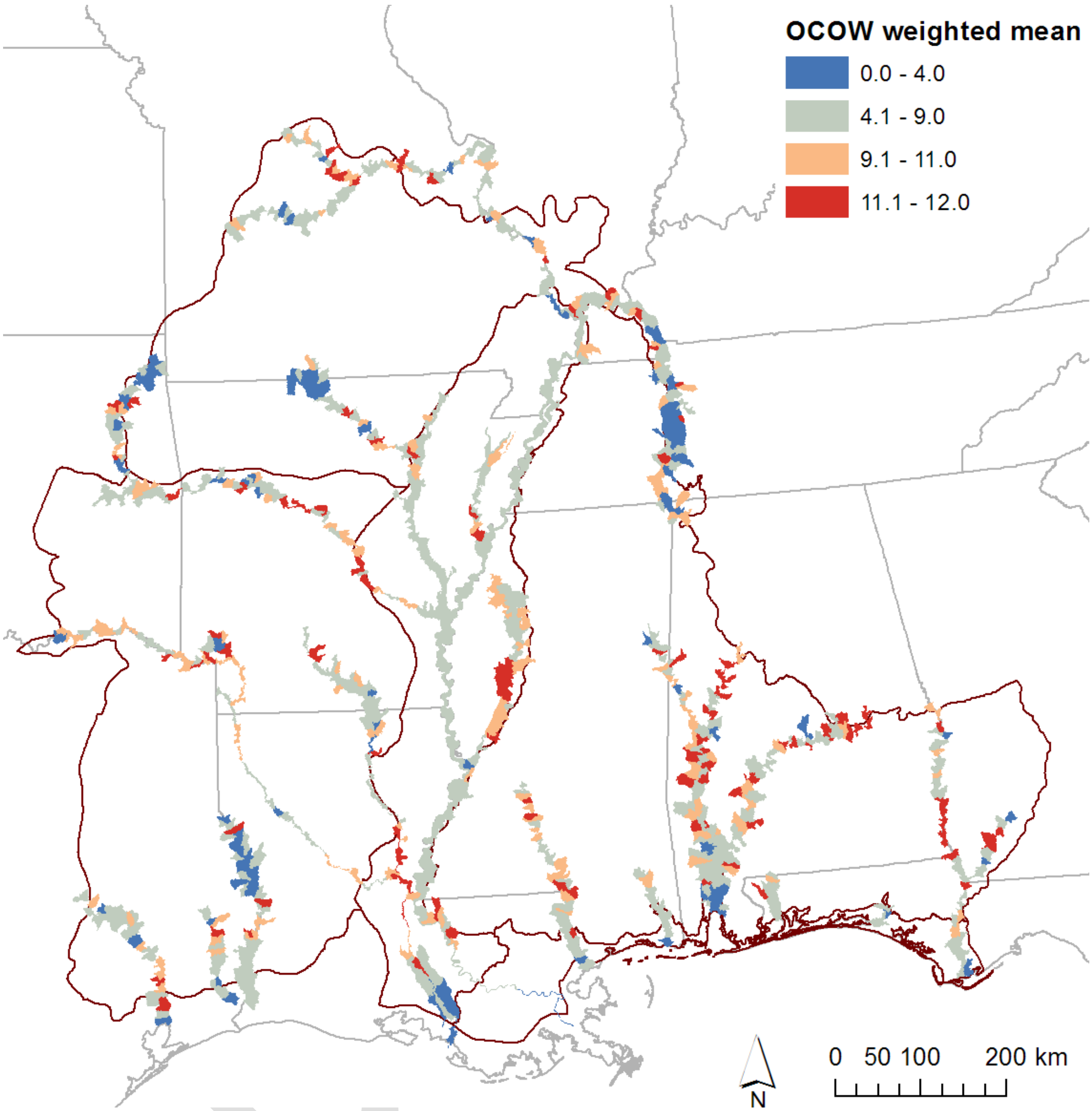

Figure 24. The area-weighted connectivity value (area weighted mean) of off channel open water bodies within the GCPO. Low values indicate strong connectivity and high values indicate weak connectivity.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – Lateral Connectedness
    - GCPO geography (raster)
    - GCPO geography (vector – polygon)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Maintain connectivity among a diversity of habitat types – intermittently inundated floodplain

Landscape Attribute: Condition

The floodplain is an integral part of large river ecosystems (Junk et al., 1989; Bayley, 1995; Opperman et al., 2010) and the timing, extent, duration and frequency of floodplain inundation greatly affects the quality of fish and wildlife habitat and the supply of important ecosystem goods and services. This analysis considers one aspect of the floodplain: connectivity of intermittently inundated areas on the floodplain of mainstem big rivers. This analysis quantifies not only the amount of intermittent inundation on mainstem big river floodplains, but also provides a measure habitat availability and accessibility from all mainstem big river systems within the GCPO. As described here these results may also be related to floodplain thermal conditions.

Data Sources and Processing Methods:

We used the IF mosaic to determine the locations of all areas of intermittent inundation (inundation frequency of 10-90%). We also used the connectivity data layer described here (link to description of data generation for connectivity layer) to evaluate the degree of connectedness with the main channel. An ERDAS imagine model was constructed to assign connectivity to each intermittently inundated pixel and these data were clipped to mainstem big river HUC12 boundaries. This new data layer forms the basis for the current analysis.

To determine the overall statistics of intermittently inundated connectedness for a single HUC12, we used “tabulate area” in ArcGIS where: the zone fields are the HUC12 boundaries, the input raster is the intermittently inundated connectivity data layer. This procedure outputs a table with a single row for each HUC12 and columns containing the area in each connectivity class within that HUC12. This table was brought into excel to calculate the following additional statistics: 1) the total area of all intermittent inundation, 2) the total area of intermittent inundation that has some level of connectivity to the mainstem, 3) the percent of intermittent inundation that is connected to the mainstem and 4) the mean connectivity value for each HUC12 weighted by the area of each connectivity class. The area weighted mean connectivity value is calculated using values from all areas of intermittent inundation – excluding those areas that are primarily disconnected.

Summary of Findings:

Previous studies have primarily applied subjective categorizations of connectedness based on expert opinion and planar configuration. The current analysis uses previously unavailable information to build upon those studies and assign a more quantitative measure to the degree of connectedness.

Figure 25 and Table 14 show a comparison of the total area of intermittent inundation with the area of all intermittent inundation having any level of connectivity with mainstem big rivers. Mainstem big rivers within the MAV have the highest amounts of intermittent inundation in the GCPO. Figure 26 shows that a large percentage (80%) of intermittent inundation is also connected to some degree with mainstem big river systems in the MAV. This is particularly true for large section of the lower Mississippi River below the confluence with the Arkansas

River, and also for the White River in Arkansas. Lower percentages of intermittent inundation are connected with mainstem big rivers in the EWGCP and OZH subgeographies.

Figure 27 reports the weighted connectivity value for areas of intermittent inundation within mainstem big river floodplains. This value is intended to assign a single value for each HUC12 to characterize connectivity for areas of intermittent inundation that maintain some degree of connectivity with the mainstem river. This value excludes areas of intermittent inundation which are primarily disconnected with the river. Such habitats do not function as intended for this landscape endpoint – they may be disconnected agriculture fields that occasionally flood or other backwater areas that are unsuitable for nursery or spawning habitat. Low connectivity values indicate a predominance of intermittent inundation which is strongly connected with the mainstem river. This characteristic is important for species which rely on intermittently inundated sandbars or other strongly connected habitat for spawning. Higher connectivity values show the opposite extreme of weak connection where most areas of intermittent inundation in that HUC lie far off the mainstem. Such areas may be suitable for species that rely on extensive protection from the direct influence of mainstem big rivers for spawning or nursery grounds. These areas may also offer a thermal advantage in the spring because of their isolation from the direct influence of cooler mainstem river temperatures. The lower Mississippi River floodplain in the vicinity of St. Catherine Creek, for example, is an important spawning location for alligator gar and the mean connectivity value for that HUC is 8.9.

Connectivity values tend to be high throughout the MAV with notable exceptions along the Arkansas, lower Ouachita and Red Rivers. The middle Mississippi River, lower Ohio, and Mobile River systems also have moderate connectedness values but the total area of intermittent inundation is lower. With the exception of the upper Ouachita and Mobile Rivers, the small areas of intermittent inundation along mainstem big river floodplains of the East and West Gulf Coastal Plains tend to be highly connected with the adjacent river.

Future Directions and Limitations:

Limitations and potential improvements for the connectedness dataset and its antecedent (the IF dataset) are detailed in other chapters.

Although this analysis addresses the status of the currently available inundated floodplain, it does not explicitly address potential habitat. Adjacent habitat that is currently disconnected but frequently inundated may offer potential for conservation action. Future versions of the landscape endpoints in the ISA might describe adjacency and patch size parameters that may be used to identify candidates for conservation.

Although this analysis provides a relative measure of the availability of intermittently inundated floodplain, it does not provide explicit links to stage-specific duration and availability. Currently such an analysis could be performed on a project-specific basis.

References

Bayley PB. 1995. Understanding Large River: Floodplain Ecosystems. *BioScience* **45**:153–158.

Junk, W.L., Bayley, P.B., and Sparks, R.E. 1989. The flood pulse concept in river–floodplain systems. In Proceedings of the International Large River Symposium. Edited by D.P. Dodge. Can. Spec. Publ. Fish. Aquat. Sci. No. 106. pp. 110–127.

Opperman JJ, Luster R, McKenney BA, Roberts M, Meadows AW. 2010. Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale1. JAWRA Journal of the American Water Resources Association **46**:211–226.

Tables and Figures:

Table 14. Area of intermittent inundation (total and connected) associated with mainstem big rivers by subgeography in the GCPO **.

	Area (km^2)		
SubGeography	**Total**	**Connected**	**Percentage**
East Gulf Coastal Plain	1,876	1,221	65%
Gulf Coast	1001	916	91%
Mississippi Alluvial Valley	**8,311**	**6,685**	**80%**
Ozark Highlands	602	329	55%
West Gulf Coastal Plain	2,075	1,452	70%

** Note that this analysis is based upon the area of intermittent inundation that lies within the mainstem big rivers HUCs ***and*** within the boundaries of the GCPO. It does not include areas of intermittent inundation that are part of the mainstem big rivers floodplains that lie outside of the GCPO boundaries.

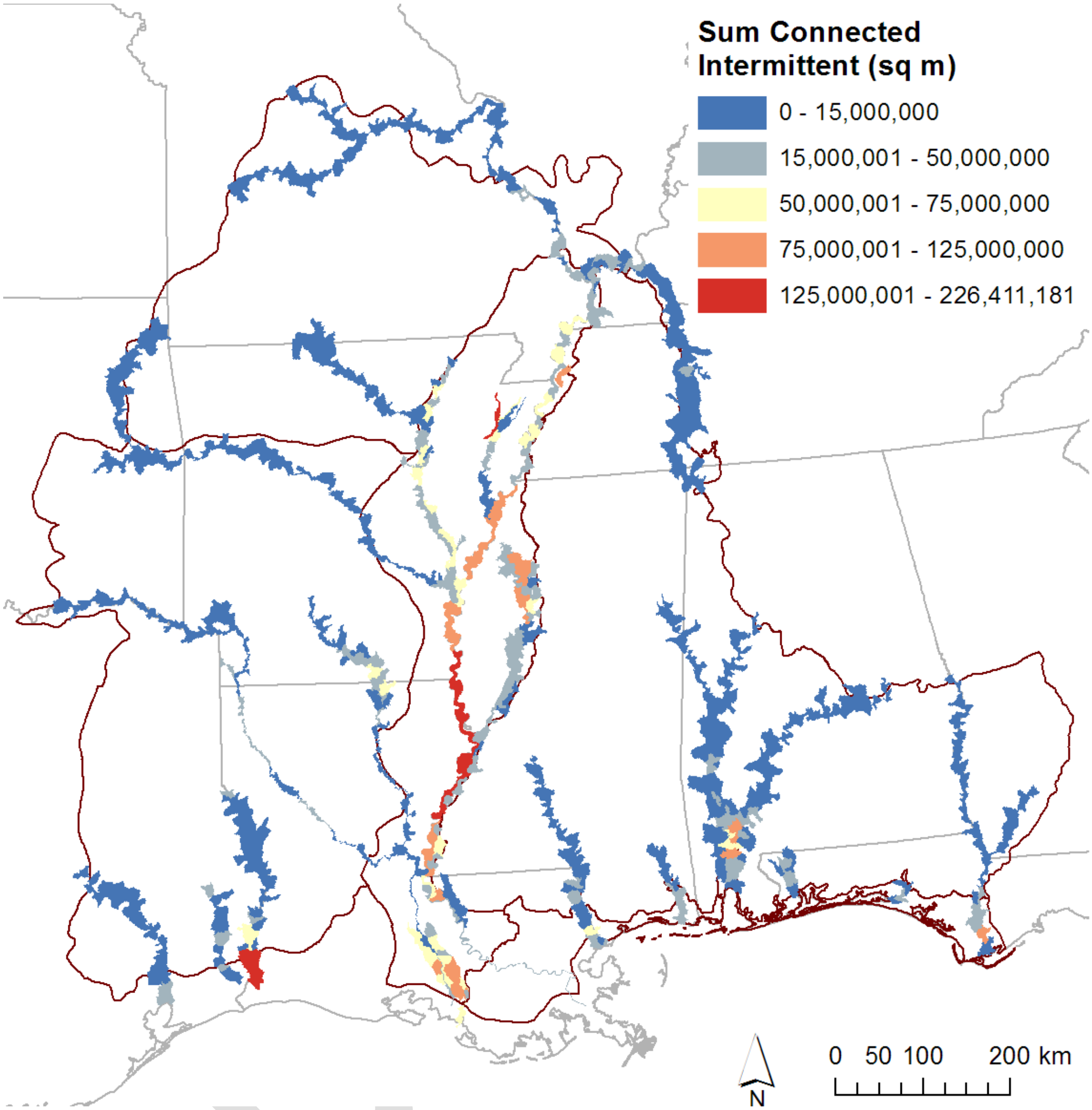

Figure 25. Areas of intermittent inundation that have some degree of connectivity with mainstem big rivers within the GCPO.

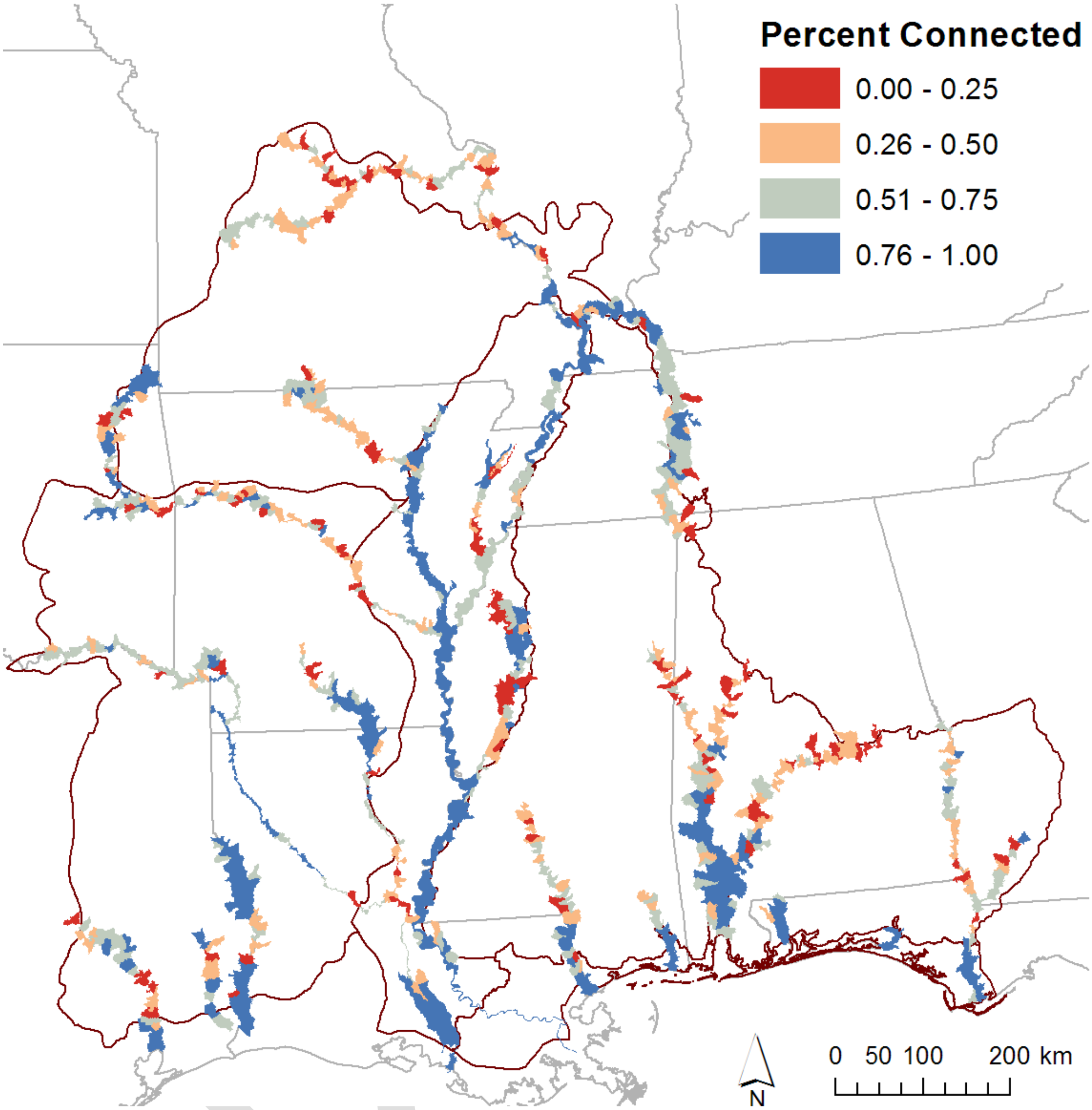

Figure 26. The percent total area of intermittent inundation that is connected to mainstem big rivers within the GCPO.

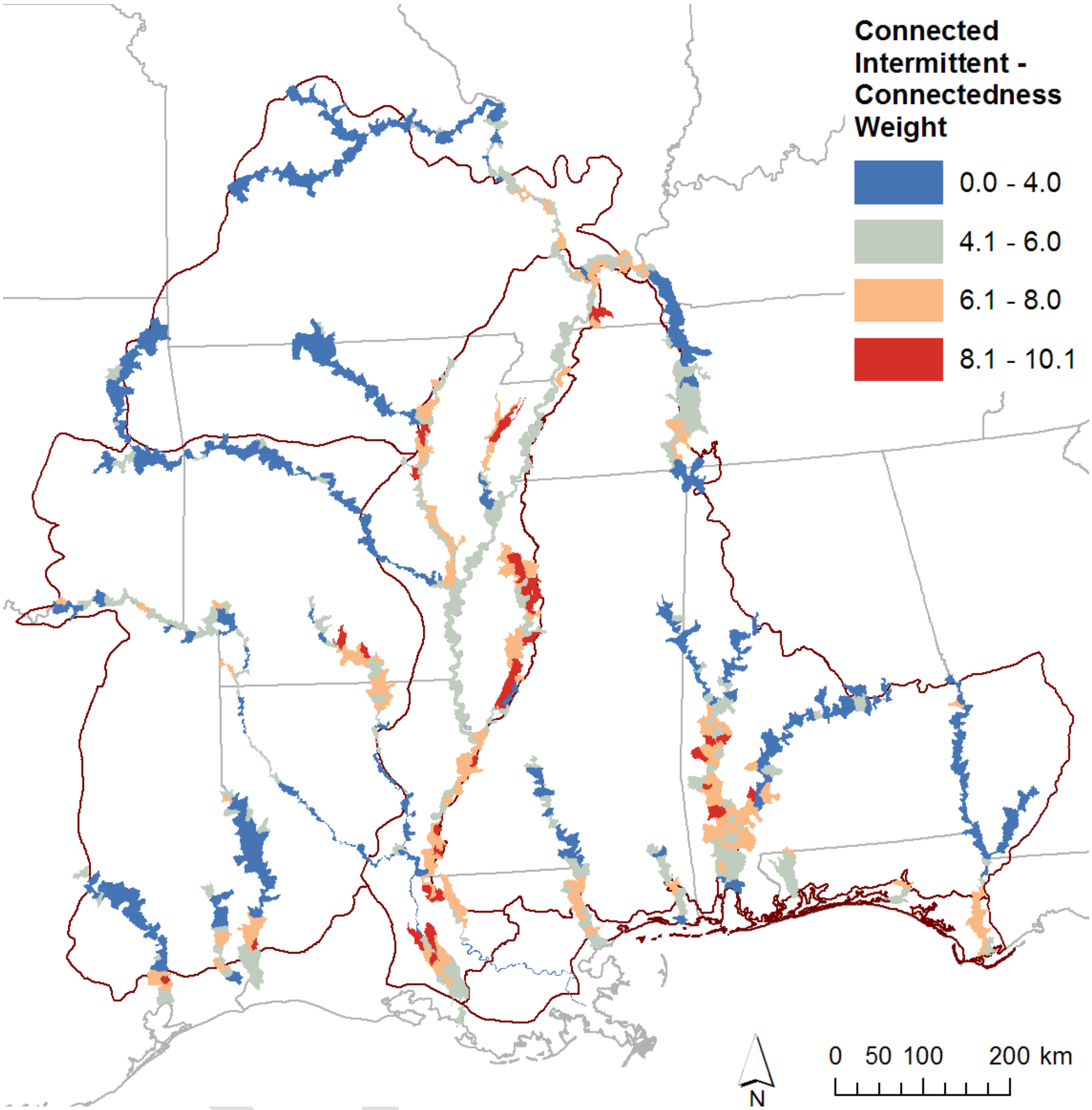

Figure 27. The area-weighted connectivity (area weighted mean) of intermittent inundation within the GCPO.

Links to Available Geospatial Data Outputs

- Mainstem Big Rivers – Lateral Connectedness
  - GCPO geography (raster)
  - GCPO geography (vector – polygon)

Subgeography: **MISSISSIPPI ALLUVIAL VALLEY**

Ecological System: Mainstem Big River Systems

Desired Landscape Endpoint: Vegetation on intermittently inundated floodplain

Landscape Attribute: Condition

Data Sources and Processing Methods:

We used the IF mosaic to determine the locations of all areas of intermittent inundation (inundation frequency of 10-90%) on mainstem big rivers floodplains. We also used the 2011 NLCD to identify areas having intermittent inundation and either forested or low open vegetation. NLCD landcover type was assigned to areas of intermittent inundation (see chapter: amount - intermittent inundation) using the “Con” function in ArcGIS. The amount of each landcover type in each HUC12 was then assigned using the “tabulate intersection” function in ArcGIS. The amount of forested area in each HUC12 was calculated as the sum of: (deciduous (41) + evergreen (42) + mixed forest (43) + woody wetland (90)). The amount of low vegetation in each HUC12 was calculated as the sum of: (shrub/scrub (52) + grassland (71) + pasture/hay (81) + cultivated crops (82) + emergent herbaceous (95)). Summary statistics for each landcover type were calculated in Excel.

Summary of Findings:

Based on the current analysis, forest is the predominant landcover type subject to intermittent inundation on mainstem big river floodplains throughout the GCPO (70%). Of all intermittently inundated forested cover, 89% is woody wetlands. Of all remaining landcover types subject to intermittent inundation, low open vegetation makes up 27%, and 3% is other land cover types (Table 15). The MAV has the highest area of intermittent inundation (4,903 km^2) – 65% of that intermittently inundated area is forested and 33% has open low vegetation. Figure 28 shows the distribution of forested area within HUC12 areas in the GCPO subject to intermittent inundation. Figure 29 shows the distribution of low open vegetation within HUC12 areas that is also subject to intermittent inundation. Within the MAV, areas having a relatively high area of low open vegetation are found throughout the subgeography but particularly in the upper reaches of the Tallahatchie, White and St. Francis Rivers.

Future Directions and Limitations:

The requirements for amount and configuration of forested and open low vegetation landcover will differ depending on the species endpoints under consideration. Future versions of the ISA may be able to more carefully identify necessary amounts and components of this landscape endpoint. This endpoint could also be combined with percent vegetative cover or measures of connectivity described in other chapters to establish a gradient of habitat suitability.

This assessment provides a snapshot of current landcover conditions but does not evaluate trends in landscape conversion within the floodplains of mainstem big rivers. Future versions may wish to consider a further analysis of landscape change within intermittently inundated mainstem big river systems.

Tables and Figures:

Table 15. Amount of forested and low open vegetation subject to intermittent inundation in the GCPO LCC by subgeography.**

Subgeography	Total Amount Intermittent	Amount Intermittent Forested (km^2)	% Intermittent Forested	Amount Intermittent Low veg (km^2)	% Intermittent Low Veg
East Gulf Coastal Plain	1,683	1,462	87%	188	11%
Gulf Coast	929	836	90%	73	8%
Mississippi Alluvial Valley	**7,578**	**4,903**	**65%**	**2,482**	**33%**
Ozark Highlands	485	286	59%	156	32%
West Gulf Coastal Plain	1,744	1,203	69%	471	27%
Total	12,418	8,690	70%	3,370	27%

** Note that this analysis is based upon the area of intermittent inundation that lies within the mainstem big rivers HUCs ***and*** within the boundaries of the GCPO. It does not include areas of intermittent inundation that are part of the mainstem big rivers floodplains that lie outside of the GCPO boundaries.

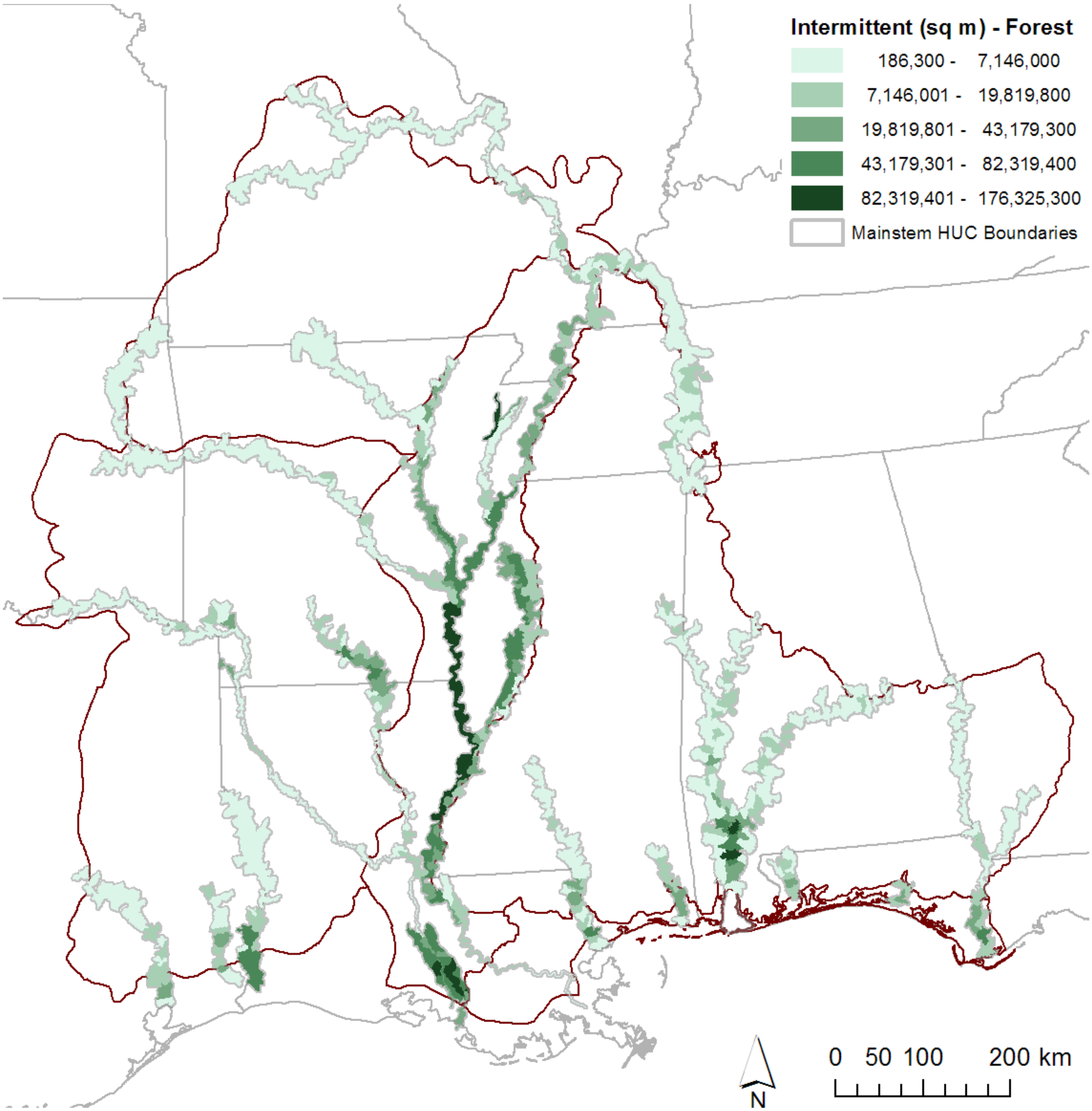

Figure 28. Amount of forested land cover which is also subject to intermittent inundation on mainstem big rivers within the GCPO.

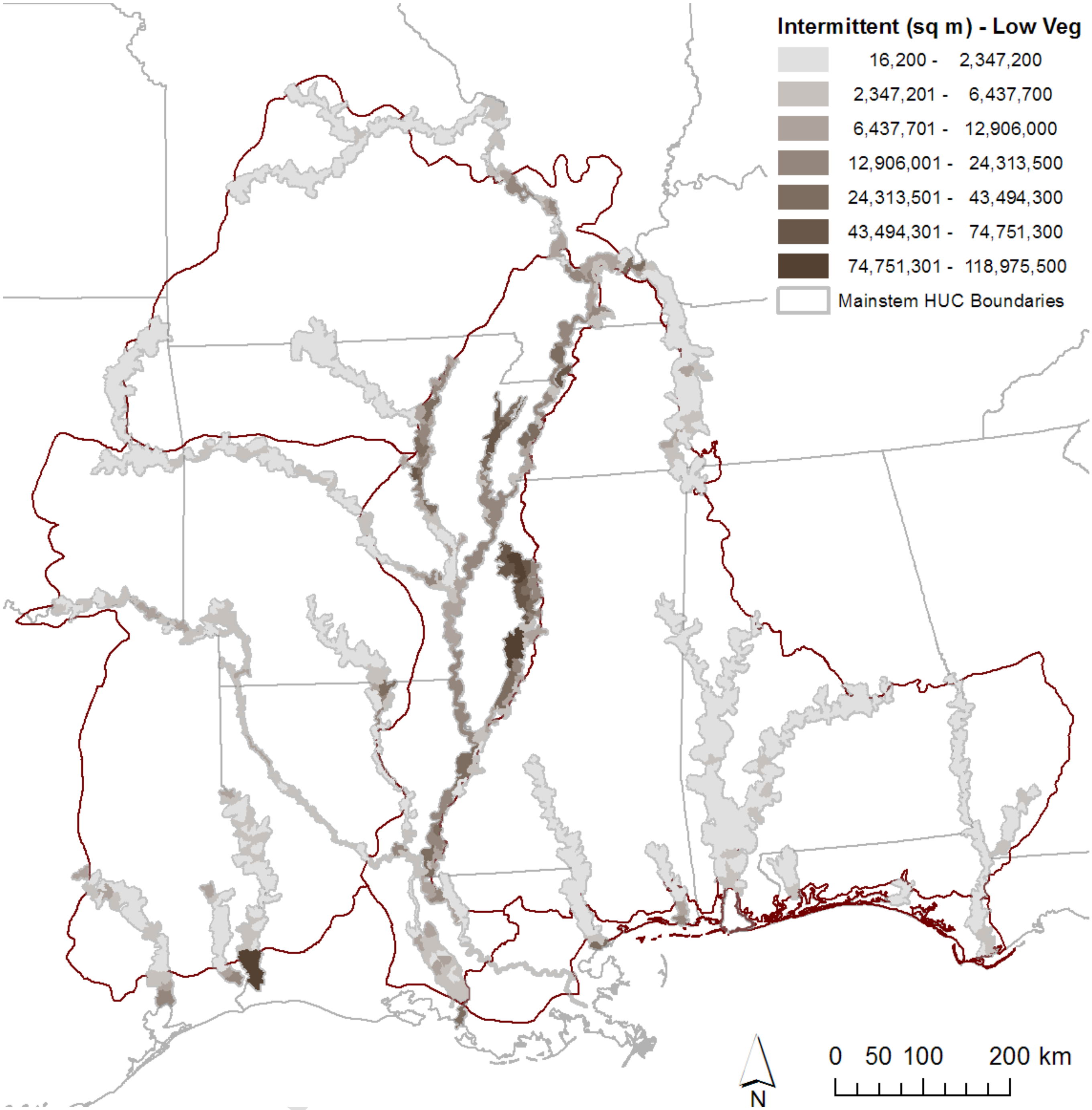

Figure 29. Amount of low, open vegetation land cover which is also subject to intermittent inundation on mainstem big rivers within the GCPO.