Sturgeon Chub (*Macrhybopsis gelida*) and Sicklefin Chub (*Macrhybopsis meeki*)

Species Status Assessment Report

September 2023

Sturgeon Chub Photo: South Dakota Game Fish and Parks

Sicklefin Chub Photo: South Dakota Game Fish and Parks

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Chapter 1: Introduction & Analytical Framework

The Species Status Assessment (SSA) framework (USFWS 2017, *entire*) is intended to support an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. This biological information is used to provide the biological support for the decision on whether or not to propose to list the species as threatened or endangered and, if so, where to propose designating critical habitat. Importantly, the SSA Report does not result in a decision by the Service on whether this species should be proposed for listing as a threatened or endangered species under the Endangered Species Act (Act). The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and the results of a proposed decision will be announced in the *Federal Register,* with appropriate opportunities for public input.

Sturgeon chubs (*Macrhybopsis gelida*) and sicklefin chubs (*Macrhybopsis meeki*) occur in turbid streams and rivers in the Missouri River and Mississippi River watersheds across 13 states. Due to the large range of both chub species, the US Fish and Wildlife Service (Service) created three science teams to provide opportunity for participation and information exchange among our many conservation partners. The first team created was the Core Team, including USFWS field-level scientists, their direct supervisors and a project manager. The second team created was the Technical Team, including the Core Team and a representative from each USFWS Ecological Services office and a representative from each relevant internal Service program (e.g., Fisheries, Refuges, etc.) from across the range of both chub species. The final team created was the Project Team, which included the Technical Team and representatives from all affected State agencies, Tribes, Universities, utilities, and other Federal agencies. One call per month was held to solicit input and coordinate with the Core Team and Technical Team and two calls per month for the Project Team. In addition to the monthly calls, the Service also held several stakeholder meetings that included presentation and discussion of scientific information among all interested stakeholders. The purpose of these meetings was three-fold: (1) to increase stakeholder understanding of the SSA process, (2) provide an opportunity to present and discuss relevant science pertaining to sturgeon chub and sicklefin chub, (3) provide the Service with the opportunity to ask specific questions about any science that was provided at the meetings. Summaries of the science and accompanying discussion were drafted from each of the meetings and were used in the development of the SSA report, along with any other relevant information the Service received or gathered during the status review process.

The outcome of an SSA is a stand-alone science-based product independent of the application of policy or regulation. It provides foundational biological information, articulates key uncertainties, and, ultimately, characterizes the species' current and future condition and viability under various scenarios and timeframes. For the purposes of this assessment, we generally define viability as the ability of sturgeon chub and sicklefin chub to sustain populations over time. Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Smith *et al.* 2018, *entire*).

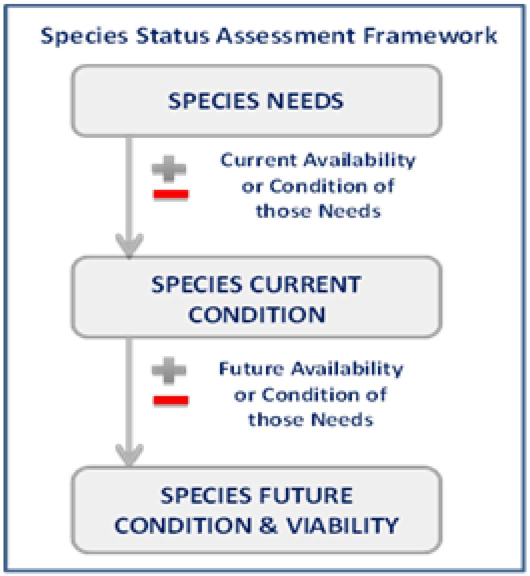


Figure 1. Generalized Species Status Assessment Framework

- **Resiliency** describes the ability of populations to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. In the absence of species-specific demographics, we evaluate resiliency based on habitat characteristics across the geographical range. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

- **Representation** describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species can adapt to environmental changes. The more representation, or diversity, a species has, the more it can adapt to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

- **Redundancy** describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

To evaluate the biological status of sturgeon chub and sicklefin chub, both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, potential stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.

The format for this SSA Report includes the introduction and analytical framework (Chapter 1), the biology and resource needs of individuals and populations (Chapter 2), the historical and current distribution of sturgeon chub and sicklefin chub and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3), the likely causes of the current and future status of the species and determining which of these risk factors affect the species' viability and to what degree (Chapter 4) and concluding with a description of the viability in terms of resiliency, redundancy, and representation (Chapter 4). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to sturgeon chubs and sicklefin chubs.

Chapter 2: Species Needs

In this chapter, we document the specific ecological needs of sturgeon chubs and sicklefin chubs, at the individual, population, and species levels. Documenting the ecological needs of both chub species provides a description of the foundational needs of both species, upon which comparisons can then be made in later chapters to help assess species current condition and expected future condition. In this chapter, we note instances where ecological needs apply to both species and also note instances where ecological needs are different between the two chub species.

Sturgeon chubs and sicklefin chubs belong to the same genus of fishes and in general, have similar latitudinal and longitudinal distributions, habitat requirements and are subject to similar stressors. Therefore, both chub species are addressed in this status assessment. Despite the similarities between the two chub species, we identify differences between the species when relevant and important to the assessment of species status.

Taxonomy

Sturgeon Chub

Sturgeon chub collected from the Milk River, Montana from 1853-1855 were first described as *Gobio gelidus* by Girard in 1856. The species was described as *Ceratichthys gelidus* in 1882 by Jordan and Gilbert but consolidated the genus *Ceratichthys* into *Hybopsis* in 1896. Sturgeon chub were placed in the subgenus *Macrhybopsis* by Cockerell and Allison in 1909. Jordan raised the subgenus *Macrhybopsis* to genus status in 1920 and then changed the species name to *gelida* in 1930. Several genera of cyprinids were merged into the genus *Hybopsis* by Bailey in 1951 and included the return of sturgeon chub to the genus *Hybopsis*. In 1989, Mayden changed the sturgeon chub to the genus *Macrhybopsis*. The current genus and species of sturgeon chub is *Macrhybopsis gelida* (Rahel & Thel, 2004, pp. 10-11). The current, full taxonomy of sturgeon chub is below.

Table 1. Taxonomy of sturgeon chub

Kingdom	Animalia
Phylum	Chordata
Class	Teleostei
Order	Cypriniformes
Family	Leuciscidae
Genus	*Macrhybopsis*
Species	*gelida*

<u>Sicklefin Chub</u>

Sicklefin chubs were first collected in 1885 from the Missouri River near St. Joseph, Missouri, by Jordan and Meek, but were initially misidentified as sturgeon chubs. Specimens from later collections in 1896 by Jordan and Evermann, made in the same general area of the Missouri River near St. Joseph, Missouri, were identified as *Hybopsis meeki*. The sicklefin chub was placed in the genus *Macrhybopsis*. (USFWS, 2001b, p. 3). The current, full taxonomy of sicklefin chub is below.

Table 2. Taxonomy of sicklefin chub.

Kingdom	Animalia
Phylum	Chordata
Class	Teleostei
Order	Cypriniformes
Family	Leuciscidae
Genus	*Macrhybopsis*
Species	*meeki*

Species Description

<u>Sturgeon Chub</u>

The sturgeon chub is a small benthic minnow with a slender, streamlined body that inhabits mainstem turbid rivers and some of their tributaries. Sturgeon chub have a long snout with a small mouth that does not protrude beyond the snout, with a barbel at each corner (Cross and Collins 1995, pp. 75-76, Pflieger 1997, p. 134). The snout is flattened and long, extending past the upper lip. The eyes of the sturgeon chub are small and can be partially covered. The body shape is streamlined, flattened on the belly, curved dorsally, and have taste buds or external papillae (Pflieger 1997, p. 134). The dorsal fin has eight fin rays and is closer to the tip of the snout than to the base of the caudal fin (Cross and Collins 1995, pp. 75-76, Pflieger 1997, pp. 134-135). The caudal fin is large and deeply forked and the pectoral and anal fins are large and have compound taste buds. These characteristics are common for a fish that resides in a high turbidity environment. In addition to the taste buds located on the fins, sturgeon chub have dense sensory organs under their lower jaw (Werdon 1992, p. 3).

Adults are dusky or light brown dorsally with silvery sides and stomachs (Cross and Collins 1995 pp. 75-76, Pflieger 1997 pp. 134-135). Sturgeon chub have no distinctive markings, but some specimens may have speckling and most scales above the lateral line are keeled. All fins are clear although the lower lobe of the caudal fin is darker than the upper lobe. The lower margin of the ventral caudal lobe has a whitish color. Young of year have an external morphology identical to adults (Stewart 1981). Adult sturgeon chubs typically vary in length from 43 mm (1.7 in.; Pflieger 1997 pp.134-135) to over 100 mm (3.9 in.; Werdon 1992, pp. 12-13, 32; Grisak 1996, p. 67; Magruder 2022, p. 26).

Sturgeon Chub, Photo Courtesy of South Dakota Game Fish and Parks

Sicklefin Chub

The sicklefin chub is a small minnow that inhabits large, turbid rivers, such as the mainstem Missouri and Mississippi Rivers. Like sturgeon chub, sicklefin chubs have also evolved specific adaptations to turbid, riverine habitats. The body shape is fusiform with long sickle-shaped pectoral fins, a deeply forked caudal fin, small eyes, and external sensory organs, termed compound taste buds (Dieterman & Galat, 2005, p. 561). The coloration is light green to brown from above and can have dark brown and silver specks, and silver sides (Page & Burr, 2011, p. 210). It is distinguished from the sturgeon chub by long, sickle-shaped pectoral fins, that when depressed extends beyond pelvic fin insertion and the absence of ridge-like projections on its scales (Steffensen *et al*., 2014., p. 50-51). Sicklefin chub use barbels and external taste buds to locate food as their eyes are small and of little value in turbid waters.

Sicklefin Chub, Photo Courtesy of South Dakota Game Fish and Parks

Species Ecological Needs

Individuals

This section focuses on the ecological needs of individuals at each life stage. Both sturgeon chubs and sicklefin chubs exhibit the typical life stages of fish: egg, larva, fry, juvenile, and adult. The larva/fry/juvenile life stages are combined in this SSA, due to a general lack of information regarding those life stages.

Eggs

Direct observations of egg-laying by sturgeon chubs or sicklefin chubs has not been observed in the wild. However, observations of both chub species with spawning characteristics (e.g., presence of breeding tubercles, visible eggs or milt when squeezed) have been observed across the range of the species from June through September (Table 3; Werdon 1992, pp. 12, 14; Grisak 1996, pp. 41-42; Pflieger 1997, pp 134-137; Dieterman *et al*. 2006, pp. 188-122). Eggs are presumed to be spawned in the water column during these months, where they water harden, become semi-buoyant (Dieterman and Galat 2004, p. 584; Albers and Wildhaber 2017, pp. 10, 13-14), and drift downstream (Reeves 2006, *entire*; Albers and Wildhaber 2017, pp. 10, 13-14;). Development of eggs is driven by water temperature (Platania and Altenbach 1998, *entire*), taking on average 77.7 degree days to hatch for sicklefin chub in a laboratory setting (Albers and Wildhaber 2017; pp. 8, 10, 14). A degree day is a measure of the accumulation of thermal units, where 1 degree day is equal to 1°C for 1 day (e.g., 5 days at 8°C equals 40 degree days).

Table 3. Life stages of sturgeon chub and sicklefin chub observed or expected by month, across the range of the species.

Life Stage	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Egg						X	X	X	X			
Juv.						X	X	X	X	X	X	X
Adult	X	X	X	X	X	X	X	X	X	X	X	X

Larva/Fry/Juvenile

Larval sturgeon chubs and sicklefin chubs continue to drift in river currents and swim vertically in the water column, with energy provided by the egg yolk sac. In a laboratory setting, sicklefin chub development progressed from hatch to horizontal swimming in 122.9 degree days (Albers and Wildhaber 2017, p. 10). Estimated time to yolk sac absorption and external feeding is 166.5 degree days (Albers and Wildhaber 2017, p. 10). Once development of larvae progress to horizontal swimming, larval chubs are considered fry. Fry are presumed to move horizontally to shallow water nursery habitats, based on frequent captures of juvenile-aged chubs near shorelines (Gelwicks *et al*. 1996, *entire*; Grady and Milligan 1998, *entire*; Dieterman and Galat 2004, p. 584). Larva/fry/juvenile development rates of sturgeon chubs appear greater than that described for sicklefin chubs (Starks et al. 2016, pp. 1339, 1346). Fry of both chub species feed on midge pupae and Cladocera/midge larvae, with sicklefin chubs having a more varied diet than sturgeon chubs (Starks et al. 2016, p. 1338).

Sturgeon chub and sicklefin chub larvae need unfragmented reaches of river as they develop from vertical swimmers to horizontal swimmers. Length of unfragmented reaches needed for larval development varies and is dependent on water temperature, flow velocity, and habitat complexity, among other variables (Platania and Altenbach 1998, *entire*; Dieterman and Galat 2004, p. 584; Albers and Wildhaber 2017, p. 14). If larvae drift into a reservoir or still water habitat before they are a horizontal swimmer, it is presumed they settle to the bottom and experience high mortality (Dieterman and Galat 2004, p. 584; Albers and Wildhaber 2017, p. 15).

Adult

Feeding

Adults of both chub species feed on midge pupae and Cladocera/midge larvae, with sicklefin chubs having a more varied diet than sturgeon chubs (Starks et al. 2016, p. 1338). Other direct observations of diet for these species include pieces of unidentifiable aquatic and terrestrial insects (Reigh and Elsen 1979, *entire*; Stewart 1981, *entire;* Dieterman *et al.* 2014*, entire;* Nocomis 2014*, entire*).

Breeding

As described earlier, observations of both chub species with spawning characteristics (e.g., presence of breeding tubercles, visible eggs or milt when squeezed) have been observed across the range of the species from June through September (Table 3; Werdon 1992, p. 32; Grisak 1996, pp. 41-42, 50-51; Dieterman *et al*. 2006, pp. 118-122; Stewart 1981, *entire*). Some individuals of both chub species appear sexually mature at Age-2, with most reproductive capacity at Ages-2 and 3 (Werdon 1992, pp. 12-14, 32; Grisak 1996, pp. 39, 42-44), with most individuals not living past Age-4 (Stewart 1981, pp. 28-32; Pflieger 1997, p. 137). Both chub species have relatively high fecundity and spawn multiple times during the summer season (Werdon 1992, pp. 12-14, 32; Dieterman *et al*. 2006, pp. 118-122; Albers and Wildhaber 2017, pp. 6, 12; Starks et al. 2016, p. 1341, 1345). The majority of spawning for both species appears to occur when water temperatures are between 20 and 23.2°C (Dieterman *et al*. 2006, p. 119; Albers and Wildhaber 2017, pp. 8-12). It is presumed that both species spawn in mainstem rivers and with primarily sturgeon chub spawning in tributaries, given the presence of adults with spawning characteristics captured in these habitats (Grisak 1996, pp. 41-42, 50-51; Dieterman *et al*. 2006, pp. 118-122; Magruder 2022, pp. 99-100).

Sheltering

Adults of both sturgeon chubs and sicklefin chubs are often captured over silt, sand or gravel substrates (Werdon 1992, pp. 15-17; Grisak 1996, pp. 31-32, 51; Fisher 1999, pp. 34; Galat *et al*. 2004, pp. 262; Grady and Milligan 1998, *entire*; Everett *et al*. 2004, pp. 189; Reeves 2006, pp. 11, 152; Ridenour *et al*. 2009; Welker and Scarneccia 2004; Welker and Scarneccia 2006; Wildhaber *et al*. 2012) in water depths typically greater than 2 meters (hereafter m.; 6.6 ft.; Grisak 1996, pp. 33, 35, 45, 48; Reeves 2006, pp. 56; Ridenour *et al*. 2009, pp. 480). Water velocities in sheltering habitat are typically greater than .47 meters per second (hereafter, m/s;

1.5 feet per second; hereafter ft/s; Werdon 1992, pp. 15-16; Grisak 1996, pp. 33, 36) and turbidity is generally greater than 80 nephelometric turbidity units (hereafter, NTUs; Dieterman 2000, p. 130; Dietermann and Galat 2004, pp. 581-584).

Table 4. Resource and life stage table.

RESOURCE NEED	EGG	JUVENILE	ADULT	CITATION
Water temperature	**77.7 (+-10.5) degree days to hatch**	**122.9 (+- 14.1) degree days to mean start of horizontal swimming**	**14 – 26°C* (57 – 79°F)**	**Albers and Wildhaber 2017**
Drift distance	**Flow/temperature dependent**	**Flow/temperature dependent**		**Dieterman and Galat 2004; Albers and Wildhaber 2017**
Water depth (m)		**0.2 – 0.5 m. (0.7-1.6 ft.)**	**Typically >2 m. (6.6 ft.)****	**Grisak 1996, Reeves 2006, Ridenour *et al.* 2009, Dieterman 2000; Magruder 2022**
Substrate			**Sand, silt, gravel**	**Werdon 1992, Grisak 1996, Fisher 1999, Grady and Milligan 1998, Dieterman 2000; Everett *et al*. 2004, Galat *et al*. 2004, Welker and Scarneccia 2004, Reeves 2006, Welker and Scarneccia 2006, Ridenour *et al*. 2009, Wildhaber *et al*. 2012**
Velocity			**0.3 – 0.9 (m/s) (1.5 – 3.0 ft./s)**	**Grisak 1996, Dieterman 2000; Magruder 2022**
Turbidity (NTU)			**>80, maximum unknown**	**Dieterman and Galat 2004**
Food		**Insect larvae**	**Insect larvae**	**Reigh and Elsen 1979, Stewart 1981, Nocomis 2014, Starks et al. 2016**
Spawning water temperatures			**20.1 – 23.2°C (68.2 – 73.8°F)**	**Albers and Wildhaber 2017**
Flow constancy			**Variable**	**Dieterman and Galat 2004**

*Water temperatures when adults have been sampled.

**Water depths where adult chubs are typically found in large rivers; depths are likely shallower in smaller tributaries.

Population and Species Needs

In this section we use the 3Rs - resiliency, redundancy, and representation – to generally describe the needs of the populations and species. The 3Rs incorporate demographic and habitat factors.

Resiliency

The ability of populations of the species to withstand stochastic events (arising from random factors)

Resilient populations of both chub species need large enough areas of connected riverine habitat to fulfill their life history needs (e.g., spawning, egg/larval drift distances, suitable water temperatures, feeding/sheltering habitat) and provide refugia from habitat-altering stochastic events (e.g., extreme flows from intense, sustained drought or increased variability in precipitation). These life history needs must be met within areas of habitat that can support enough sturgeon chubs or sicklefin chubs to survive, reproduce, and perpetuate the species. Resilient populations must be robust enough in size to avoid genetic effects from inbreeding and conserve or at least minimize loss of genetic variation representing the adaptive capacity of the species to adapt to future novel changes in the environment.

Redundancy

The ability of a species to withstand catastrophic events: rare destructive natural events or episodes involving many populations and occurring suddenly/unexpectedly.

Redundancy is about spreading the risk of catastrophic events to the species. This can be measured through the duplication and distribution of resilient populations across the range of the species. At a species level, the populations become an important unit for measuring redundancy. The greater the number of resilient sturgeon chub and sicklefin chub populations distributed across the species' range, the better the species are able to withstand catastrophic events, such as an oil spill or other contamination scenario that was spread downstream by flowing water.

Representation

The ability of the species to adapt to changing environmental conditions.

Representation can be measured through the breadth of genetic diversity within and among populations, and the ecological diversity (also called environmental variation or diversity) across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human-caused) in its environment. Loss of representation can lead to lower viability because of diminished adaptive capacity. Populations of both chub species would have high representation when they exhibit high levels of genetic variation, which is typically caused by large effective population sizes within the populations. Large effective population sizes promote the conservation of genetic variation among generations of the chub species and increase the species' ability to adapt to future novel change in the environment.

Summary

Species viability and persistence requires resilient populations distributed across adequate portions of the species' range to provide redundancy and ensure genetic and ecological representation. Sufficient genetic and ecological representation are important at this larger scale because they are surrogates for adaptive potential, which allows the species to persist, despite changing habitat conditions. Adequate representation contributes to population viability and increased likelihood of species persistence.

Chapter 3: Current Condition

The current condition of sturgeon chubs and sicklefin chubs was assessed using the best available information from multiple sources. These sources included peer-reviewed literature, unpublished data, species surveys and information gathered from Project and Technical Team members during monthly calls and several online stakeholder meetings.

Historical and Current Distribution

To describe historical and current distribution of both chub species, we plotted all known chub occurrence data points that could be reliably assigned to a specific waterbody, whether through GPS coordinates or a textual description, using ArcGIS Pro (version 2.9.5). For historical distribution, we identified the most upstream point of occurrence for each chub species in each waterbody, regardless of sampling date, and presumed historical occupancy from that point downstream to the most downstream historical observation (typically in the mainstem Mississippi River for both chub species). This approach was taken for several reasons. First, occurrence of both chub species is correlated with increased turbidity (Dieterman 2000, p. 130; Dieterman and Galat 2004, p. 581; Magruder 2022, p. 28). In general, historical turbidity levels in occupied streams tended to increase in the downstream direction (Blevins 2007, *entire*). Thus, it was reasonable to assume that if either chub species were found at a particular point in a given stream, it would likely be found downstream of that point also. Second, an examination of more current chub occupancy often revealed chub occupancy downstream of these most upstream points, thus providing another line of evidence of chub occurrence in the downstream direction. Third, this approach ensured that the mapped distributions of both chub species were consistent with, but not outside the bounds of, the historical survey data. Previous attempts to describe historical distribution through the use of hydrologic unit codes resulted in distributions of both chub species outside the bounds of known distributions, simply due to the arrangement and size of hydrologic unit codes on the landscape. Finally, historically there were no/few known barriers to fish movement within the range of both chub species. Thus, it was reasonable to assume that without barriers to preclude movement, both chub species would be expected to be widely distributed among habitats that were both suitable and accessible to them.

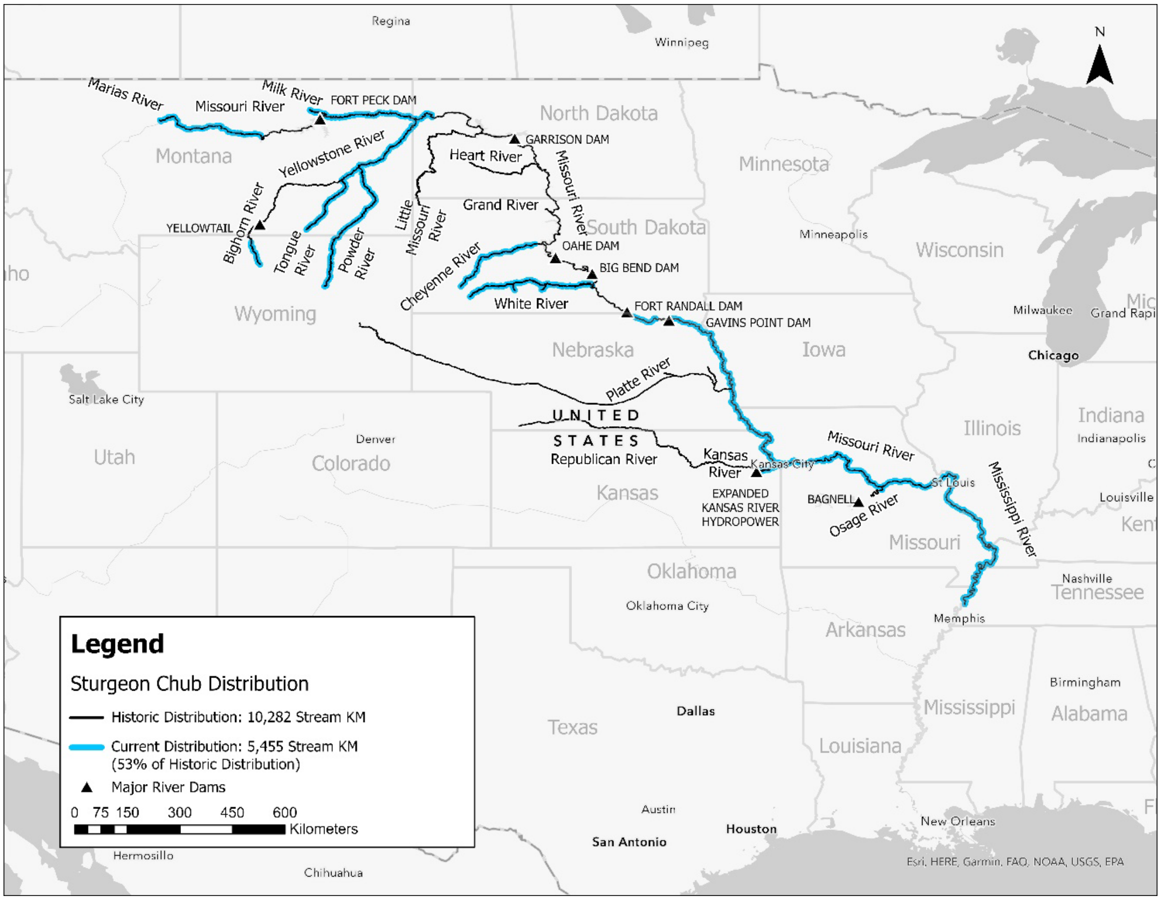
For current distribution, we plotted all chub occurrences since 2001. Next, we presumed current occupancy from that point downstream to one of the following features; 1) the most downstream current occurrence point in the same waterbody, or 2) the upstream extent of a reservoir, whichever came first. This approach was taken for several reasons. First, similar to historical distribution, occurrence of both chub species is correlated with increased turbidity. In general, turbidity levels in occupied streams tend to increase in the downstream direction. Thus, it was reasonable to assume that if either chub species was found at a particular point in a given stream, it would likely be found downstream of that point. Second, an examination of more current chub occupancy often revealed chub occupancy downstream of these most upstream points; another line of evidence of chub occurrence in the downstream direction. Third, we were not aware of any known chub occurrences in reservoirs, thus we used the upstream extent of mainstem reservoirs as a downstream boundary for current chub distribution in certain reaches. Both species of chubs did occur below mainstem reservoirs in some rivers, and this point marked the start of another current occupied reach until one of the two above-mentioned features were again met in the downstream direction.

The point in time for differentiating historical versus current distribution for both chub species was selected to be 2001. There are many tradeoffs when selecting any point in time to compare/contrast distributional data. However, 2001 is a reasonable time threshold to delineate historic and current distributions of both chub species for the following reasons:

1) The year 2001 was the date of the last status review for both the chub species, which allows us to better make comparisons of species viability.
2) Shortly before the year 2001, field biologists were switching from seines to benthic trawls to more effectively sample chubs and increasing their efforts to document chub presence; a result of several studies noting the effectiveness of trawling over seining in the mid-late 1990s (Grisak 1996, pp. 21-23; Herzog *et al*. 2005, p. 601; Herzog *et al*. 2009, p. 105). This sampling modification resulted in a change in known chub distribution, relative to the 2001 finding.
3) By using an approximate 20-year period for describing current condition, it increased the chances that a greater proportion of the range of both chub species has been sampled, reducing the risk of biasing depiction of chub distributions due to lack of sampling, as opposed to sampling with no detections.

Sturgeon chub

Sturgeon chub were historically found in many streams and rivers in the Missouri and Mississippi river watersheds and are currently still relatively widespread across their former range (Figure 2). Transient individuals may exist outside the estimated historical range; however we estimated historical range based on the best available information. We estimate that sturgeon chubs historically occupied about 10,282 rkm (6,389 rmi.) of riverine habitat, and currently occupy about 5,455 rkm (3390 rmi.) of riverine habitat (Table 5). Accordingly, sturgeon chub currently occupy about 53% of their known historical range.



Esri, HERE, Garmin, FAO, NOAA, USGS, EPA

Figure 2. Current and Historic Range of Sturgeon Chub.

In 2001, we estimated that sturgeon chub occupied about 55% of their historical range in the Missouri River basin. In our current analysis, we estimate that sturgeon chub occupies approximately 49% of their historic range in the Missouri River basin, and 53% of their historical range throughout their entire range (including Mississippi River and tributaries, Figure 2). The estimate from 2001 and our current estimate are different because of the amount of current information available relative to 2001, increased sampling, newer mapping technology, and improved sampling techniques. The change in percent of occupied historical habitat between 2001 and current does not necessarily indicate a range reduction during that time period, as different methods were used to calculate the percentages and different datasets and mapping technology were used. Since the 2001 finding, partners throughout the sturgeon chubs range have increased sampling for both chub species. One example of increased sampling is the Pallid Sturgeon Population Assessment Program (PSPAP). PSPAP began to monitor the status of the endangered pallid sturgeon using benthic trawling. Due to the effectiveness of benthic trawling capturing sturgeon chub and sicklefin chub, crews were able to catch both chub species as part of the PSPAP monitoring, since they tend to occupy similar habitat as pallid sturgeon (Herzog 2004, p. 17). In addition to PSPAP data, we received information from several State and Federal agencies to help refine the historical and current ranges of sturgeon chub and sicklefin chub. Another improvement since 2001 was the utilization of ArcGIS, which we used to sort, analyze, and display large distributional datasets, which was not done in 2001.

Table 5. Current Distribution of Sturgeon Chub.

Current Distribution of Sturgeon Chub[a]		**River Kilometers (River Miles)**
Missouri River and Marias River Upstream of Fort Peck Lake		288 (179)
Bighorn River Upstream of Bighorn Lake		102 (63)
Missouri River, Milk River, Yellowstone River, Powder River and Tongue River Upstream of Lake Sakakawea		1,748 (1,086)
Cheyenne River		299 (186)
White River and Tributaries		632 (393)
Missouri River from Fort Randall Dam to Lewis and Clark Lake		85 (53)
Downstream of Gavins Point Dam on the Missouri River, Mississippi River and tributaries		2,300 (1,429)
	TOTAL	5,455 (3,390)

[a] General river and stream segments are listed in this table. For a more accurate visualization of actual reaches of the rivers and streams listed in this table that are currently occupied by sturgeon chub, refer to Figure 2.

In addition to utilizing mainstem river habitat, sturgeon chubs utilize several tributaries to the mainstem Yellowstone River and Missouri River. The 2001 Finding analyzed habitat factors for sturgeon chub and found 30 historic tributaries that had adequate habitat in the Missouri River Basin. Four tributaries were found in Wyoming, nine in Montana, five in North Dakota, six in South Dakota, six in Nebraska, and four in Kansas (USFWS 2001b p. 38). Of the 30 identified tributaries, 11 were occupied by sturgeon chub in 2001. For this SSA, data received from partners indicated 21 tributaries that were historically occupied across the sturgeon chub range. Of the 21 identified tributaries, 12 are currently known to be occupied. The 2001 finding primarily focused on Missouri River data for sturgeon chub since there was a lack of data for the Mississippi River, whereas this SSA was able to obtain data throughout their entire range (i.e., Missouri and Mississippi River basins). Since 2001, several projects have occurred on the Mississippi River and we now have a better understanding of sturgeon chub distribution.

Habitat in the mainstem Missouri River that was historically occupied but not currently occupied by sturgeon chub is primarily due to the influence of mainstem dams. For example, in North Dakota and South Dakota, the Missouri River has been extensively altered by the construction and operation of Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point dams. Garrison, Oahe, and Big Bend dams have created primarily reservoir habitat, with little remaining riverine habitat in both states. However, between Fort Randall Dam and Gavins Point Dam there is a stretch of riverine habitat that is suitable for sturgeon chub. These dams and associated reservoirs are the primary reason for the current sturgeon chub distribution in both states because the habitat is not currently conducive to the life history strategies of sturgeon chub. Extensive reservoir habitat and tailwaters with low turbidity and cooler water temperatures are believed to preclude or reduce sturgeon chub occupancy in these reaches. However, in South Dakota, sturgeon chub currently occupy the Cheyenne, White, and Little White rivers, and Pass Creek (Figure 2). These tributary habitats in South Dakota have not been as affected by dam construction.

Sicklefin chub

Sicklefin chubs were historically found primarily in the mainstem Missouri and Mississippi rivers and some of the larger tributaries (Figure 3). Currently, we estimate that sicklefin chubs are still relatively widespread across their former range (Figure 3). Historically, we estimate that sicklefin chubs occupied about 5,349 rkm (3,324 rmi.) of habitat, and currently occupy about 3,996 rkm (2,483 rmi.) of riverine habitat (Table 6). Accordingly, sicklefin chubs currently occupy about 75% of their known historical range.

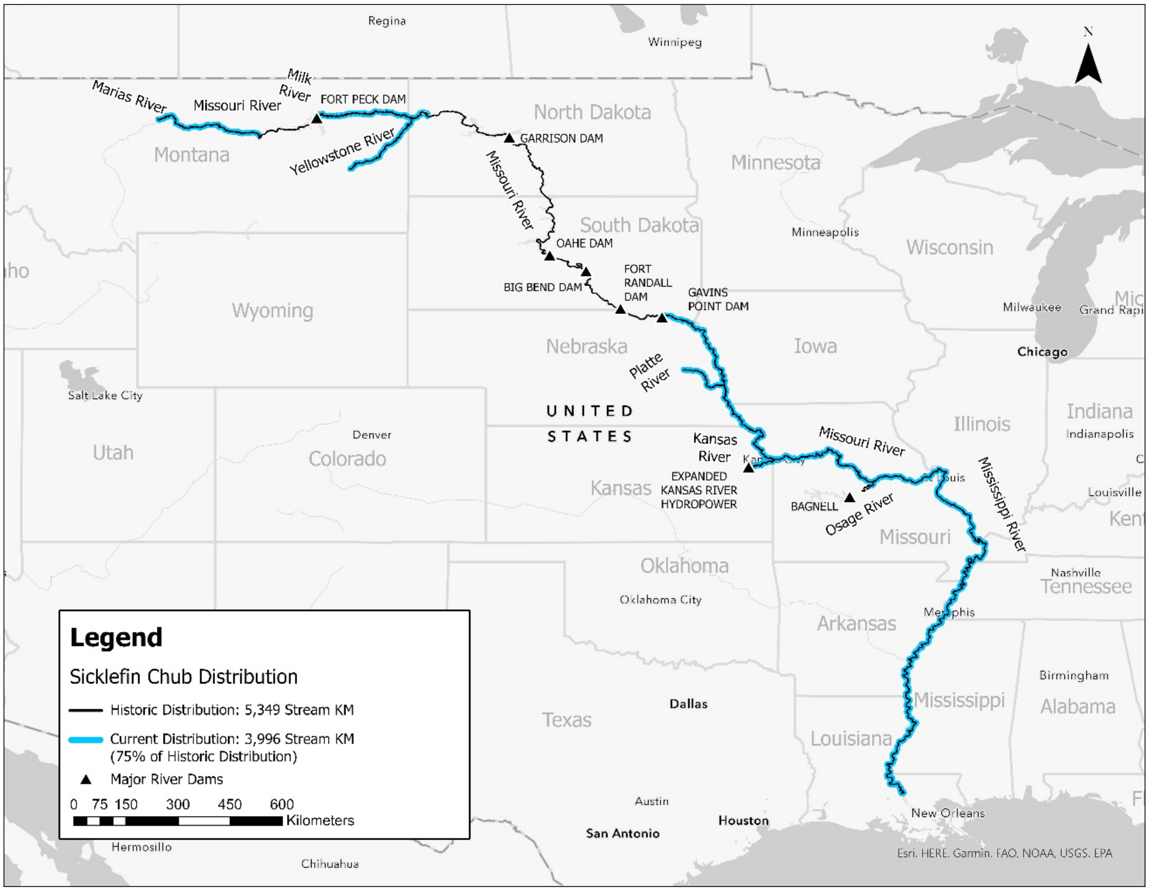


Figure 3. Current and Historic Range of Sicklefin Chub.

In 2001, we estimated the historical/current range of sicklefin chub to be 54% in the Missouri River, compared to 65% from our current analysis. The estimate from 2001 and our current estimate are different because of the amount of current available information relative to 2001, due to increased sampling, newer mapping technology, and improved sampling techniques. The change in percent of occupied historical habitat between 2001 and current does not necessarily indicate a range expansion during that time period, as different methods were used to calculate the percentages and different datasets and mapping technology were used.

Table 6. Current Distribution of Sicklefin Chub.

Current Distribution of Sicklefin Chub[a]		**River Kilometers (River Miles)**
Missouri River and Marias River Upstream of Fort Peck Lake		288 (179)
Milk River, Missouri River, and Yellowstone River Upstream of Lake Sakakawea		625 (388)
Downstream of Gavins Point Dam on the Missouri River, Mississippi River and tributaries		3,084 (1,916)
	TOTAL	3,997 (2483)

[a] General river and stream segments are listed in this table. For a more accurate visualization of actual reaches of the rivers and streams listed in this table that are currently occupied by sicklefin chub, refer to Figure 3.

River Basin Overview

Sturgeon chub and sicklefin chub are present in the Missouri River and Mississippi River basins and multiple associated tributaries. Sicklefin chub primarily utilize mainstem river habitats, whereas sturgeon chub utilize both mainstem river and tributary habitat in both river basins. The Missouri River and Mississippi River are the two longest rivers in the lower 48 states and drain a significant portion of the United States. To describe both river basins, we separated them into the Missouri River, Middle Mississippi River (MMR), and Lower Mississippi River (LMR).

Missouri River Basin

The Missouri River is the longest river in the United States extending 4215 rkm (2,619 rmi.) from its source in Montana to the Mississippi River just upstream from St. Louis, Missouri (Figure 4). The Missouri River basin has a total drainage area of 1.4 million square kilometers (529,350 square miles), including about 25,123 square kilometers (9,700 square miles) in Canada. Drainage area within the United States includes portions or all of Nebraska, Montana, Wyoming, North Dakota, South Dakota, Kansas, Missouri, and smaller parts of Iowa, Colorado, and Minnesota (Master Water Control Manual, 2018, pp. III-1). Missouri River dams and associated hydrology are primarily managed by the U.S. Army Corps of Engineers (Corps). Authorized purposes for the mainstem reservoir system include flood control, navigation, hydropower, water supply, water quality control, irrigation, recreation, and fish and wildlife

(Master Water Control Manual, 2018, pp. IV-1).

The Missouri River is complex and heavily engineered. There are six Missouri River Mainstem Reservoir System dams, including (in order from upstream to downstream) Fort Peck, Garrison, Oahe, Big Bend, Fort Randall and Gavins Point. These six dams have created reservoirs that contain about 9-million-hectare meters (72.4 million acre-feet) of storage capacity and comprise the largest reservoir system in the United States, containing 84 percent of the installed capacity in the basin's Federal hydroelectric power system (Master Water Control Manual, 2018, pp. IV-1). They also provide almost all the reservoir downstream flow support on the Missouri River and help flood risk reduction for over 809,000 hectares (2 million acres) of land in the floodplain of the Missouri River (Master Water Control Manual, 2018, pp. IV-1). At normal levels, these reservoirs provide a water surface area of 404,000 hectares (1 million acres) for recreation (Master Water Control Manual, 2018, pp. IV-1). Construction began on the six mainstem dams in 1933 with Fort Peck Dam. Fort Peck Dam was completed in 1939 with Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point dams following with the final dam completed in 1963. Construction of the mainstem dams altered the Missouri River from a once diverse, braided river to a regulated, constricted river where sediment loads have been significantly reduced and flow altered. The lower 750 miles of the lower Missouri River have been channelized. The historic river channel was highly diverse and miles wide at places, whereas the current river is 200 meters wide with uniform depth. The amount of available habitat for both chub species has been significantly reduced.

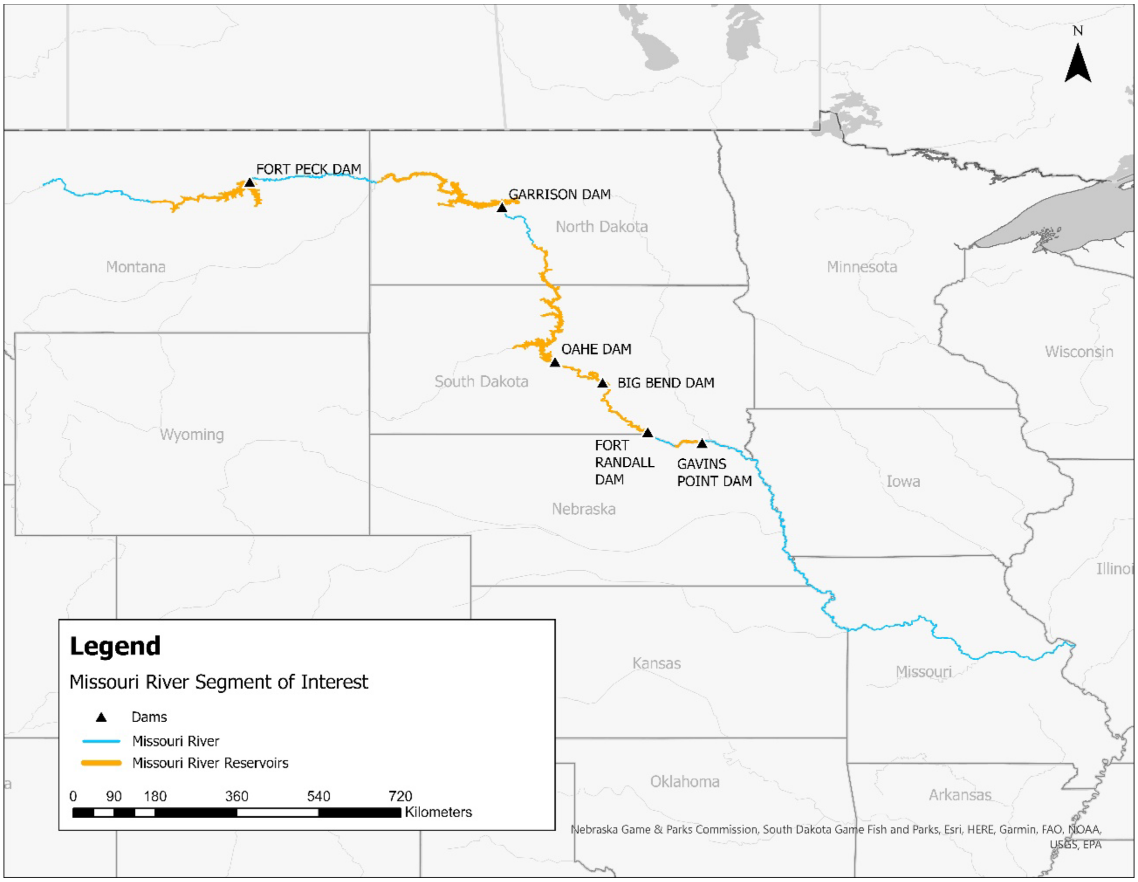


Figure 4. Missouri River, Dams, and associated reservoirs from headwaters to mouth of Mississippi River.

Middle Mississippi River

The MMR extends from the confluence of the Missouri River to the confluence of the Ohio River (Figure 5). This reach is approximately 314 rkm (195 rmi.) long. Regulation of the MMR began in 1881. By 1973, the MMR had experienced construction of levees, more than 161 rkm (100 rmi.) of revetments, and installation of more than 800 dikes to maintain a minimum navigation channel depth of 2.7 meters (9 feet) (Simons *et al*. 1974, p. 12).

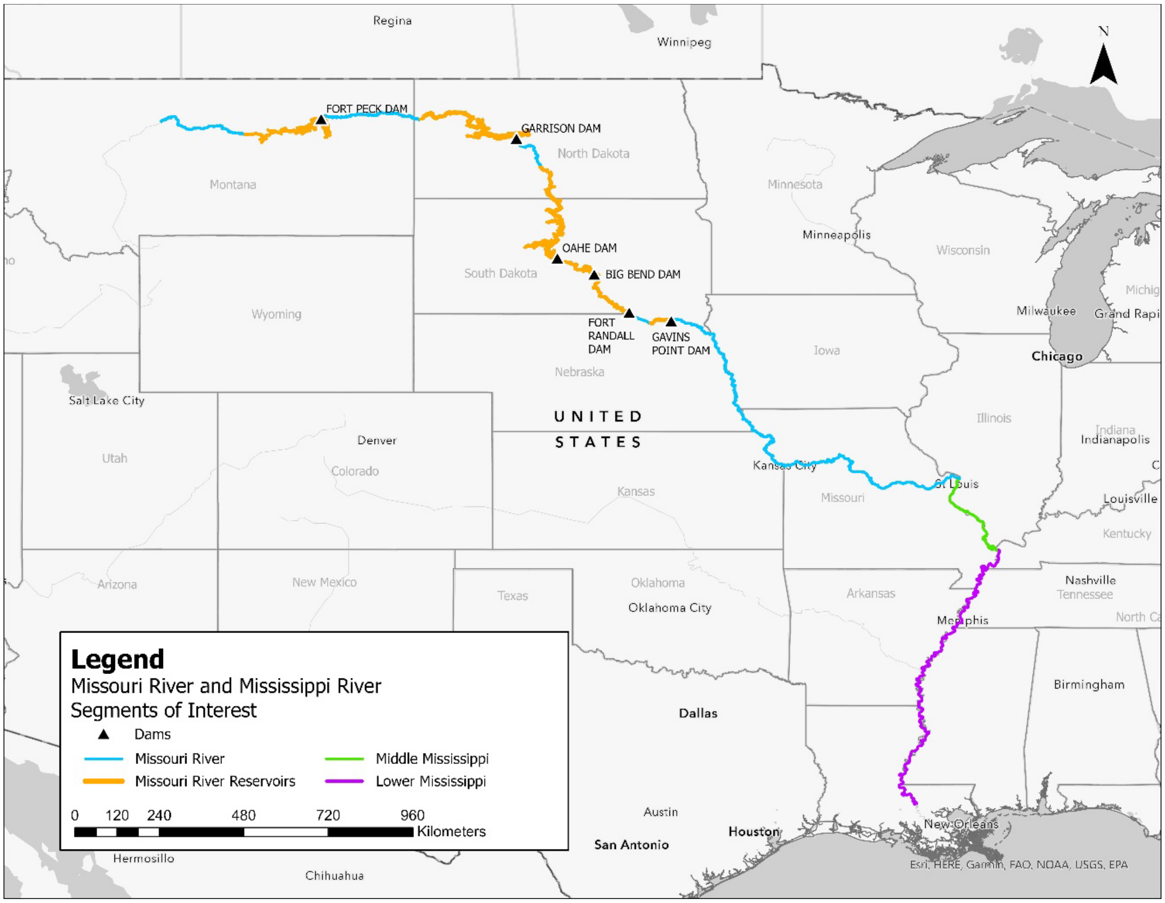


Figure 5. Middle Mississippi River Basin (Green).

Lower Mississippi River

The LMR extends downstream from the confluence of the Ohio River for approximately 1534 rkm (953 rmi.) to the Head of Passes, where the river divides into several distributaries which empty into the Gulf of Mexico (Figure 6, Killgore *et al*. 2014, p. 1). Throughout the LMR, channel and riparian habitat has been highly altered. Levees, revetments, dikes, flood storage reservoirs, floodways, and other river managing structures have been constructed in the channel to facilitate low-water navigation and reduced flooding on adjacent lands. Construction of these channel modification structures has resulted in one of the most highly engineered, large river channels in the world (Killgore *et al*. 2014, p. 1).

The Mississippi River levee system has highly altered the natural patterns of surface water drainage and has reduced the floodplain by over 80% (Baker *et al*. 1991, p. 317). A significant loss in secondary channels and connectivity to floodplains has occurred. Historically, the LMR inundated the 30-124 mile wide floodplain during high water but today the levee system only allows access to a 5 mile-wide floodplain (Guntren *et al*. 2016, p.1). Despite many changes, the LMR remains unimpounded and experiences a semi-natural flood hydrograph. The amount of sediment input to the system has been significantly reduced through river alterations and impoundments present on all major tributaries to the LMR. Despite reduced sediment input, large quantities of stored sediment are available in the river channel and are typically accessed during flooding periods (Killgore *et al*., p. 2).

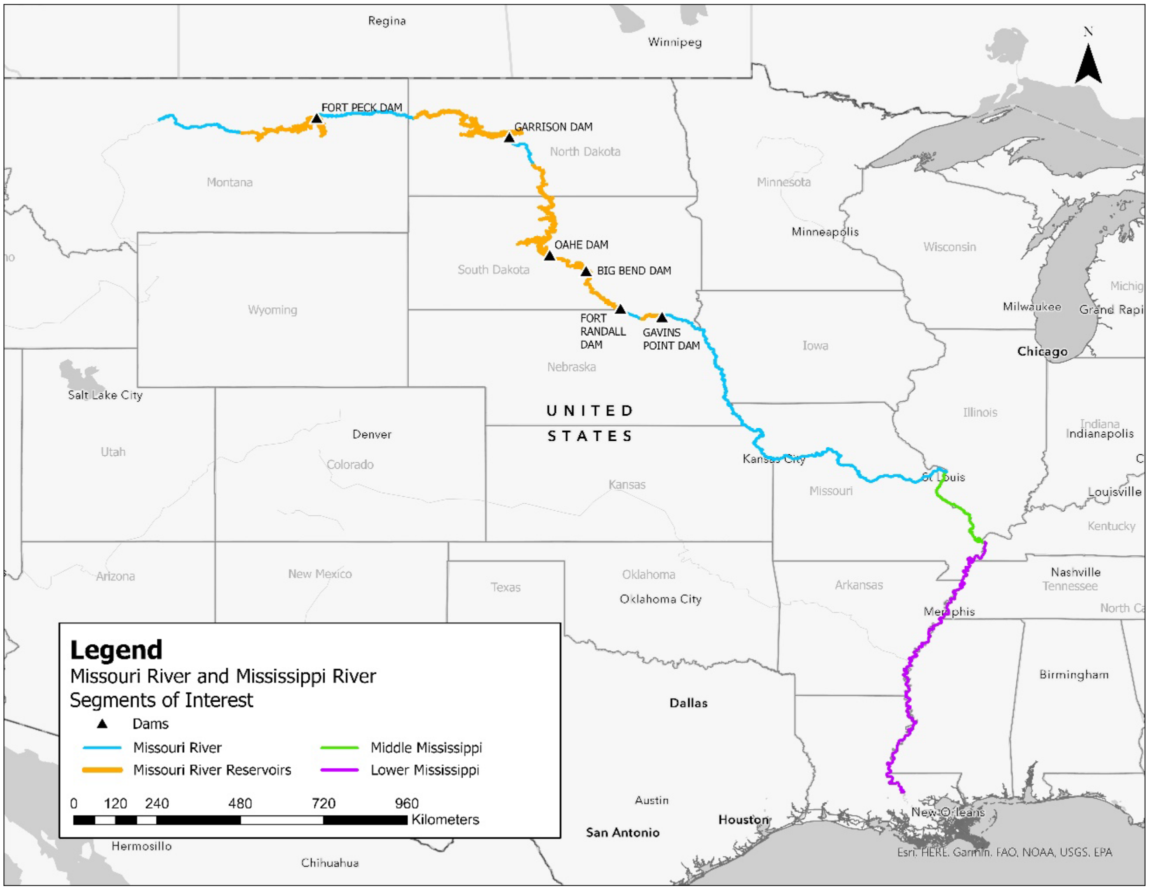


Figure 6. Lower Mississippi River Basin (Purple).

Current Status of Sturgeon Chub and Sicklefin Chub

To assess the current status of sturgeon chub and sicklefin chub, we collaborated with our many conservation partners to conduct a range-wide genetic assessment for both chub species. This effort allowed for the collection and interpretation of several important genetic metrics to gauge the current status of both chub species. We note that this information is essentially a "snapshot in time" and represents the current state of knowledge regarding the genetics of both chub species. For more information on species' trends, see the "Current Trends of Sturgeon Chub and Sicklefin Chub" section below.

Range-wide Genetics Assessment

Fin clips were collected from sturgeon chub and sicklefin chub and were used to conduct a range-wide genetics assessment across the range of both chub species. Fin clips were analyzed following the methods described in Heist *et al*. 2022 (pp. 2-3) to determine potential population structure and estimate effective population size.

Population structure (sturgeon chub)

Results from the sturgeon chub population structure analysis indicated three fairly distinct genetic clusters (Heist *et al*. 2022, pp. 3-6; hereafter referred to as populations). The first population was from the Upper Missouri River basin, including a segment of the Missouri River and lower Marias River above Fort Peck Reservoir, the Missouri River below Fort Peck Reservoir and above Lake Sakakawea, and segments of the Yellowstone, Powder, Tongue and Bighorn rivers (Figure 7). The second population was from three tributaries to the Missouri River in South Dakota; the Cheyenne, White and Little White rivers (Figure 7). The third population was from segments of the lower Missouri river and Mississippi rivers, namely Gavins Point Dam on the Missouri River downstream to the confluence with the Mississippi River, then further downstream the Mississippi River to approximately northern Arkansas/Tennessee (Figure 7).

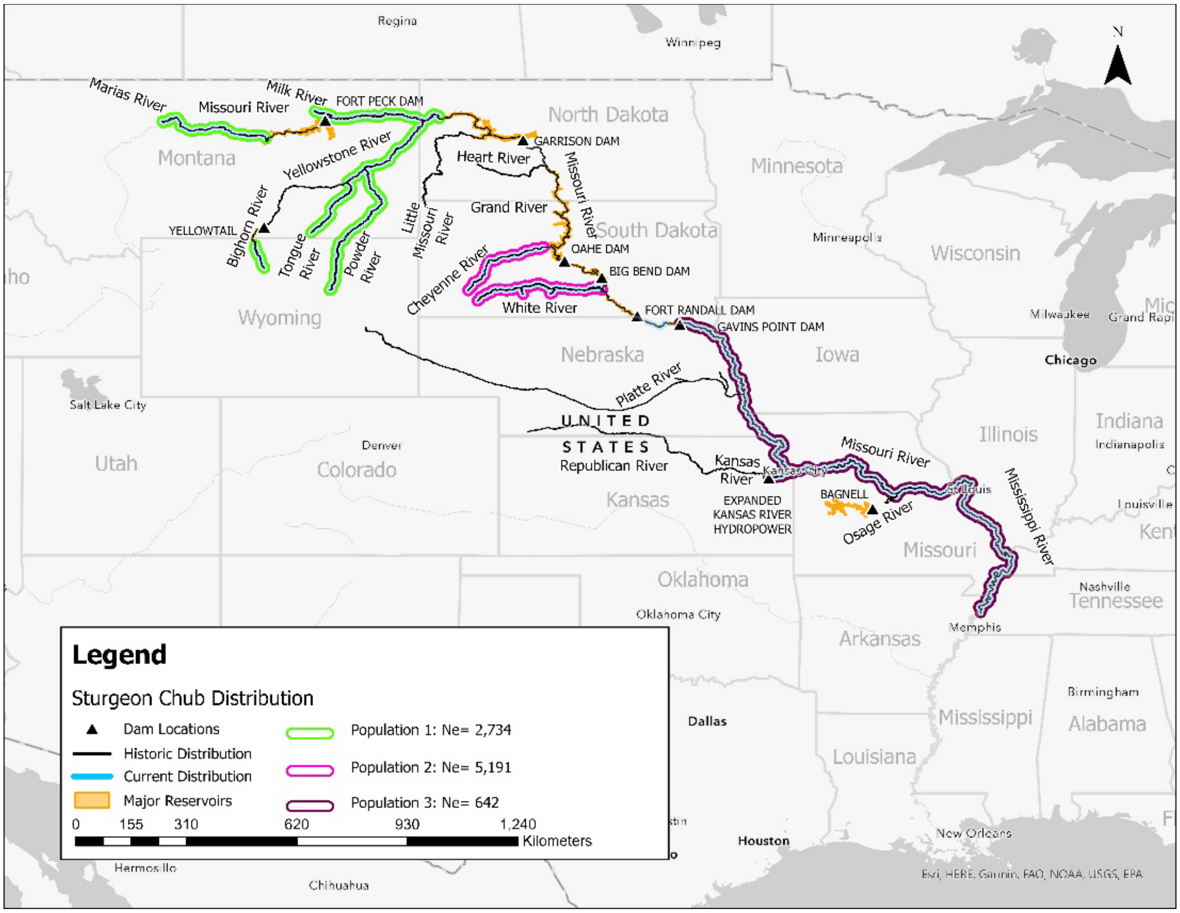


Figure 7. Sturgeon chub genetic distribution and effective population size (Ne).

Population structure (sicklefin chub)

Results from the sicklefin chub population structure analysis indicated two populations, which were less distinct than for the sturgeon chub (Heist *et al*. 2022, pp. 6-9). The first population was from the Upper Missouri River basin, including a segment of the Missouri River above Fort Peck Reservoir, the Missouri River below Fort Peck Reservoir and above Lake Sakakawea, and a segment of the Yellowstone River (Figure 8). The second population was from segments of the lower Missouri river and Mississippi rivers, namely Gavins Point Dam on the Missouri River downstream to the confluence with the Mississippi River, then further downstream the Mississippi River to approximately Louisiana (Figure 8).

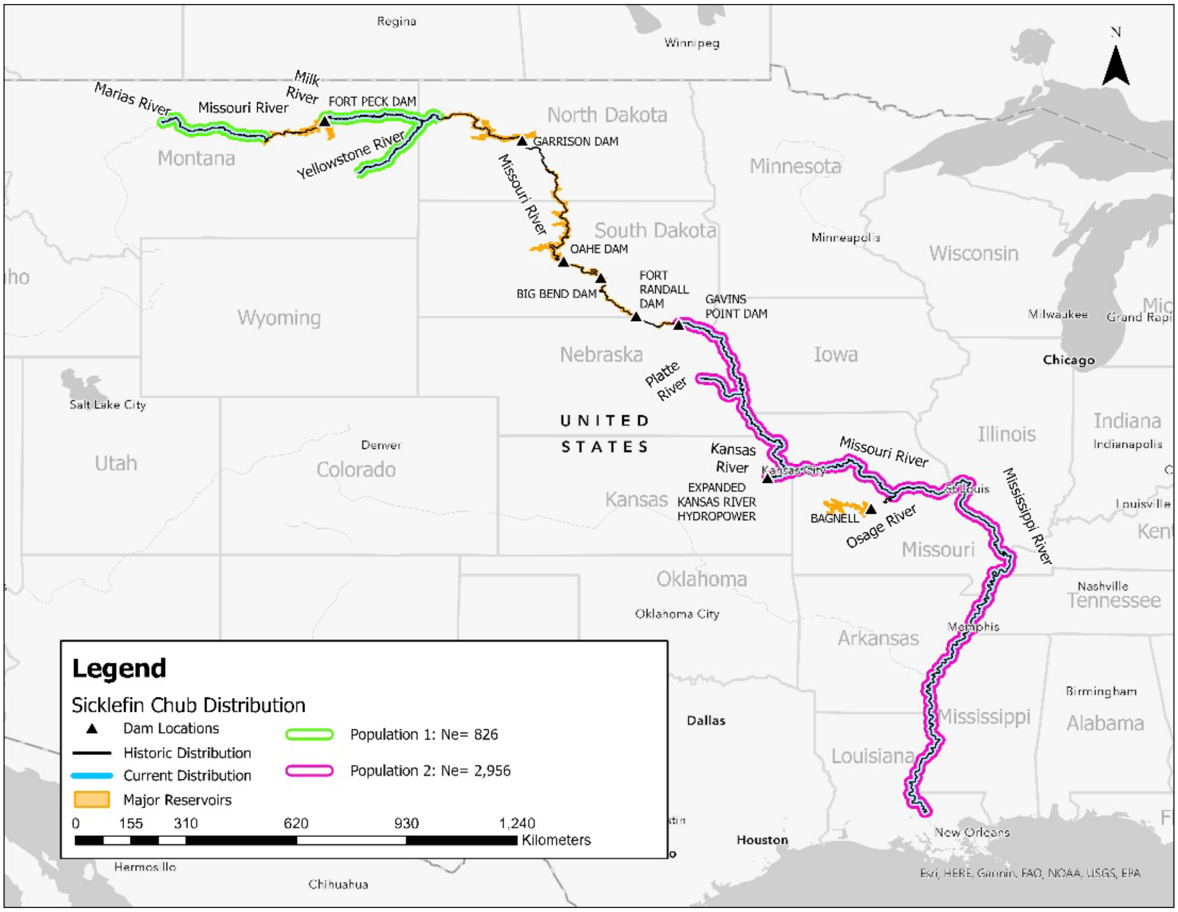


Figure 8. Sicklefin chub genetic distribution and effective population size (Ne).

Effective population size (sturgeon chub and sicklefin chub)

Effective population size (N_e) is a statistic often used to inform population and evolutionary viability (Kovach *et al.* 2019, pp. 3, 7, 8). Specifically, N_e is a critical parameter in conservation genetic theory that dictates the rate at which genetic variation is lost and inbreeding accumulates within a population (Franklin 1983, *entire*). In general, when N_e estimates are greater than 500, no genetic variation is expected to be lost in the population due to adequate numbers of breeding adults passing on their genetics to many offspring. Estimates of N_e from 50 to 499 generally indicate genetic variation is expected to be lost in the population, with slower rates of loss at higher estimates within this range and faster rates of loss at lower estimates within this range. Estimates of N_e less than 50 are typically cause for concern because of the possibility of inbreeding effects in the population.

Effective population size estimates for the three populations of sturgeon chubs and two populations of sicklefin chubs all exceeded 500, varying from 642 to 5191 (Table 7; Heist *et al.* 2022, p. 6). All estimates of effective population size for both chub species are considered sufficient for maintaining adaptive genetic variation over the long-term and reflect robust numbers of breeding adults with no concern for inbreeding in any of the populations (Heist *et al.* 2022, p. 9).

> Multiple caveats/limitations apply to the genetic results in the range-wide genetic assessment. First, we note that the lower confidence intervals for 4 of the 5 effective population size estimates extend below 500, reflecting uncertainty in the point estimates of effective population size and the possibility that the true effective population size is less than 500 (Table 7). Second, in this type of analysis, the confidence intervals are often not precise, particularly as the point estimates increase and upper confidence limits often extend to infinity, as they did in this analysis (Heist *et al*. 2022, p. 9). Third, sampling was done at a range-wide scale and the sampling design did not account for the presence of known barriers or limited connectivity among populations (Heist *et al*. 2022, p. 9). These are all limitations of the study design and methods used to obtain the genetic results and effective population size estimates. However, despite these limitations, the genetic results indicate that all populations of both chub species are large enough to avoid the loss of adaptive variation due to small population size (Heist *et al*. 2022, p. 9). Further, genetic differentiation between populations within species was low (Heist *et al*. 2022, pp. 6, 9). This result is important because even though some of the existing chub populations (or parts of populations) are presumed to be relatively isolated from other populations by dams or large stretches of reservoir habitat, there was little evidence of a negative genetic effect from this presumed isolation among populations (Heist *et al*. 2022, p. 9).

Table 7. Species, population, location, effective population size (N_e), and lower and upper 95% confidence intervals.

Species	**Population**	**Location**	**N_e**	**Lower CI**	**Upper CI**
Sturgeon Chub	1	Upper Missouri River	2734	459	Infinite
Sturgeon Chub	2	South Dakota Tributaries	5191	194	Infinite
Sturgeon Chub	3	Lower Missouri/Mississippi Rivers	642	163	Infinite
Sicklefin Chub	1	Upper Missouri River	826	118	Infinite
Sicklefin Chub	2	Lower Missouri/Mississippi Rivers	2956	514	Infinite

Current Trends of Sturgeon Chubs and Sicklefin Chubs

To assess current trends of sturgeon chubs and sicklefin chubs, we used information from the U.S. Army Corps of Engineers PSPAP, as well as data collected in other efforts from our Federal and State conservation partners. Much of the data used was catch-per-unit-area (hereafter, CPUA; calculated as the number of chubs caught divided by area of water trawled) or catch-per-unit-effort (hereafter, CPUE; calculated as the number of chubs caught divided by effort expended) information for portions of all populations of sturgeon chubs and sicklefin chubs. In general, these data describe trends in the relative abundance of the chub species caught in benthic trawls and seines through time. The area of inference associated with each of these efforts varied widely. Some trends were reported over large reaches of river and/or for long time periods that comprised a significant amount of the known occupied area and multiple generations of chubs. Other efforts reported trends over smaller, specific reaches of river and/or for shorter time periods. We considered area of inference during our analysis of current condition.

Monitoring/survey efforts that covered larger reaches of occupied habitat within a given population or for longer time periods were given more weight when assessing the status of both chub species, relative to those efforts whose results applied to smaller reaches of river or shorter time periods. We are also aware of multiple studies analyzing PSPAP data for different reaches of river over varying time frames (e.g., Oldenburg et al. 2010; Senecal et al. 2015; Wildhaber et al. 2016). The results of those studies are incorporated into our larger trend analysis because the same dataset was used.

We also used 12 datasets with information ranging from 1996-2021 to conduct an occupancy analysis designed to investigate potential changes in average probability of occupancy through time within Populations 1 and 3 of sturgeon chubs and Populations 1 and 2 of sicklefin chubs (See Table 18 in Appendix 1 for more information about the datasets). We did not have enough information to analyze potential changes in average probability of occupancy through time within Population 2 of sturgeon chubs.

Catch Trends

The PSPAP dataset included CPUE data for multiple river segments within each of the areas occupied by Populations 1 and 3 of sturgeon chubs and Populations 1 and 2 of sicklefin chubs. We present this data as overall trend data because of the large overlap between the coverage of the dataset and the majority of the range of both chub species. We note that formal statistical analyses were not performed on these data, due to a lack of all available measures of variation associated with the data. However, despite this shortcoming, general trends in CPUE for both chub species were evident. Further below, we present other CPUE/CPUA data that is more river reach-specific.

Overall trends

Mean CPUE for sturgeon chubs was higher in Population 1, than Population 3 (Table 8). However, mean CPUE appeared to trend downward in Population 1 from 2006 to 2015, whereas mean CPUE appeared fairly stable in Population 3 from 2005 to 2015 (Table 8). Mean CPUE for sicklefin chubs was higher in Population 2, than Population 1 (Table 9). Mean CPUE appeared to trend downward in Population 1 from 2006 to 2015, whereas mean CPUE in Population 2, although more variable, appeared fairly stable from 2005 to 2015 (Table 9). Statistical analysis of CPUE trends was precluded by lack of available measures of variation associated with the data. However, our intent with presenting this data was to show general information about the distribution of sampling, in space and time, and relative abundance of both chub species conducted under the Pallid Sturgeon Population Assessment Program.

Table 8. Mean catch-per-unit-effort data from the Pallid Sturgeon Population Assessment Program for Populations 1 and 3 of sturgeon chubs, by river segment and year. Green cells indicate higher catch rates of sturgeon chubs and red cells indicate lower catch rates of sturgeon chubs. Differences in tint within the green and red colored cells indicate intermediate values of catch rates for sturgeon chubs. No measures of variation around the mean values are presented. Averages were only calculated for years where every river segment within a population was sampled.

PSPAP River Segment	Population	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2	1	NS	0.16	0.22	0.14	0.09	0.11	0.07	0.08	0.08	0.02	0.03	NS	NS	NS
3	1	NS	0.67	0.51	0.54	0.20	0.20	0.20	0.21	0.16	0.17	0.15	NS	NS	NS
4	1	0.68	0.47	1.02	0.85	0.35	0.31	0.22	0.64	0.21	0.69	0.69	0.06	0.55	0.19
Avg.	1	NC	0.43	0.58	0.51	0.21	0.21	0.16	0.31	0.15	0.29	0.29	NC	NC	NC
6	3	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	3	0.02	0.01	0.01	0.00	0.01	0.00	NS	0.00	0.00	0.01	0.02	0.01	0.01	0.00
9	3	0.24	0.17	0.05	0.02	0.06	0.14	0.05	0.11	0.09	0.04	0.04	0.04	0.14	0.03
10	3	0.07	0.15	0.01	0.04	0.07	0.07	0.04	0.17	0.14	0.06	0.06	0.04	0.05	0.02
13	3	0.07	0.13	0.03	0.00	0.01	0.07	0.02	0.19	0.19	0.56	0.05	NS	NS	NS
14	3	0.07	0.03	0.02	0.04	0.02	0.00	0.03	0.25	0.15	0.21	0.12	NS	NS	NS
Avg.	3	0.07	0.07	0.02	0.02	0.02	0.04	NC	0.10	0.08	0.12	0.04	NC	NC	NC

NS = No sampling conducted; NC = Not calculated

Table 9. Mean catch-per-unit-effort data from the Pallid Sturgeon Population Assessment Program for Populations 1 and 2 of sicklefin chubs, by river segment and year. Green cells indicate higher catch rates of sicklefin chubs and red cells indicate lower catch rates of sicklefin chubs. Differences in tint within the green and red colored cells indicate intermediate values of catch rates for sicklefin chubs. No measures of variation around the mean values are presented. Averages were only calculated for years where every river segment within a population was sampled.

PSPAP River Segment	Population	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2	1	NS	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	NS	NS	NS
3	1	NS	0.10	0.09	0.08	0.09	0.09	0.13	0.10	0.07	0.16	0.18	NS	NS	NS
4	1	1.26	0.41	0.63	0.40	0.92	0.53	0.15	0.16	0.18	0.18	0.18	0.23	0.36	0.29
Avg.	1	NC	0.17	0.24	0.16	0.34	0.21	0.10	0.09	0.09	0.11	0.12	NC	NC	NC
6	2	0.00	0.00	0.00	0.00	0.00	0.00	NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	2	0.01	0.00	0.01	0.00	0.00	0.01	NS	0.00	0.00	0.00	0.00	0.00	0.00	0.01
8	2	0.07	0.01	0.00	0.00	0.01	0.02	NS	0.00	0.00	0.00	0.01	0.01	0.01	0.01
9	2	0.38	0.26	0.03	0.04	0.11	0.14	0.03	0.05	0.10	0.10	0.14	0.13	0.33	0.07
10	2	0.49	0.45	0.44	0.18	0.46	0.28	0.04	0.50	0.91	0.72	0.13	0.29	0.49	0.27
13	2	1.37	0.59	0.23	0.13	0.41	0.49	0.09	1.73	1.73	1.41	0.47	NS	NS	NS
14	2	0.60	0.31	0.15	0.18	0.34	0.16	0.13	3.45	0.56	2.18	0.79	NS	NS	NS
Avg.	2	0.42	0.23	0.12	0.08	0.19	0.16	NC	0.82	0.47	0.63	0.22	NC	NC	NC

NS = No sampling conducted; NC = Not calculated

Reach-specific trends

Declining trends in relative abundance of Age-0 *Machrybopsis* (combination of young-of-year sturgeon chubs and sicklefin chubs) and Age-1+ sturgeon chub have been observed in portions of Population 1. Specifically, CPUA for Age-0 *Machrybopsis* and Age-1+ sturgeon chub declined from 2004 to 2016 in a 60 rkm (37 mi.) portion of the Missouri River between Fort Peck Reservoir, MT and Lake Sakakawea, North Dakota (Braaten *et al*. 2021, pp. 328, 330, 332). The declines of these two groups of chubs were correlated with increased mean abundance of juvenile pallid sturgeon that were stocked into the river as part of recovery efforts for that species. Pallid sturgeon prey on both sturgeon chubs and sicklefin chubs; however, the correlation does not necessarily mean that abundance of pallid sturgeon was causing the declines observed in Age-0 *Machrybopsis* and Age-1+ sturgeon chub (Braaten *et al*. 2021, pp. 328, 330, 332). No definitive trends in CPUA were observed for Age-1+ sicklefin chubs through time or with abundance of pallid sturgeon in this part of the Missouri River (Braaten *et al*. 2021, pp. 328, 330, 332).

In a 314 rkm (195 rmi.) section of the Missouri River above Fort Peck Reservoir, MT, relative abundance of Age-0 *Machrybopsis* (combination of young-of-year sturgeon chubs and sicklefin chubs) was variable with no discernible trend from 2012 to 2018 (MTFWP 2022, unpublished data, pp. 5-6). Relative abundance of Age-1+ sturgeon chubs and sicklefin chubs varied, but mean relative abundance appeared relatively stable from 2012 to 2018 (MTFWP 2022, unpublished data, p. 10). Sampling protocols for this effort were similar from 2012 to 2018; however prior to 2012, uncertainty in methods denoting young-of-year chubs from adult chubs precluded meaningful analysis of CPUE trends for both Age-0 *Machrybopsis* and Age-1+ sturgeon chubs and sicklefin chubs for this time period (MTFWP 2022, unpublished data, p. 6). After 2018, the sampling protocol was changed again, thus comparisons before 2018 and after 2018 were precluded. However, from 2019-2021, relative abundance of Age-0 *Machrybopsis* and Age-1+ sturgeon chubs and sicklefin chubs appeared to increase (MTFWP 2022, unpublished data, pp. 9-10).

In the middle Powder River north of the Wyoming border, declines in relative abundance and distribution of sturgeon chubs were observed between 2005 and 2011 (Stagliano 2011, pp. 8, 12, 17). However, sturgeon chub distribution increased and relative abundance rebounded in the middle Powder River in 2012 and 2013 (Stagliano 2014, pp. 14, 15, 30).

Population 2 of sturgeon chub has consistently occupied both the Cheyenne and White Rivers since pre-1990 (Jones 2018, p. 63). Sturgeon chub have been present in similar and most recently increasing proportions in the Cheyenne and White Rivers during sampling pre-1990, 1990-2005, 2006-2016, and 2022 (Jones 2018 p. 63, Magruder 2022, p. 34, Hoagstrom 2006, p. 273). Sampling conducted on the White, Little White, and Cheyenne Rivers in 2022 found the highest abundances of sturgeon chub ever recorded in these systems. Sturgeon chub made up 7% of the total catch throughout the White River compared to the 4% reported in 2001, and 1 % reported in

2018 (Magruder 2022, p. 34, Fryda 2001 p. 18, Jones 2018, p. 23). The 2022 study also found species composition to be 3% in the Little White River, and 2% in the Cheyenne River (Magruder 2022, p. 27). The species composition numbers are higher when compared to the 2018 study and could be due to different sampling methods and gear types. Although we cannot directly compare these studies due to differing sampling regimes, there appear to be strong evidence that populations in the White and Cheyenne rivers have remained stable since sampling pre-1990.

Relative abundance of sturgeon chubs and sicklefin chubs was variable in a 425 rkm (264 rmi.) channelized section of the Missouri River along the eastern border of Nebraska from 2003 to 2012 in Population 3 (Steffensen *et al*. 2014, pp. 57-58). Relative abundance of both chub species peaked around 2005/2006 and appeared to generally decline for both chub species through 2012 (Steffensen *et al*. 2014, pp. 57-58). Relative abundance of both sturgeon chub and sicklefin chub also appeared to decline in this reach from 1971-1993 (Hesse 1994, pp. 103-104), although interpretation of this data was hindered by capture method (seining) and very low catches of either chub species regardless of year (Hesse 1994, pp. 103-106).

In summary, trends in relative abundance of sturgeon chubs in Population 1 were mixed; general overall declines in the PSPAP CPUE data, declines from 2004 to 2016 in the Missouri River from Fort Peck to Lake Sakakawea, declines in the middle Powder River from 2005 to 2011 with a rebound in 2012 and 2013, and stable to increasing from 2012 to 2021 in the Missouri River above Fort Peck Reservoir. Trends in relative abundance of sicklefin chubs in Population 1 were also mixed. Overall general trends in relative abundance of sicklefin chubs in Population 1 appeared to decline through time, while trends were not discernible from 2004 to 2016 in the Missouri River from Fort Peck Dam to Lake Sakakawea, and stable to increasing from 2012 to 2021 in the Missouri River above Fort Peck Reservoir. Relative abundance trends for Population 2 of sturgeon chubs appear to be stable from pre-1990 to current. Overall general trends in relative abundance of sturgeon chubs in Population 3 appear stable, with the exception of one river segment highly impacted by dams and channelization in Nebraska. Overall general trends in relative abundance of sicklefin chubs in Population 2 appeared stable, again with the exception of one river segment highly impacted by dams and channelization in Nebraska.

Occupancy Trends

In addition to exploring catch trends, we also explored potential trends in occupancy using 12 datasets provided by our partners (See Table 18 in Appendix 1 for more information about the datasets). We were particularly interested in if probability of occupancy (the probability that either chub species occurred at a given site) changed through time. To perform the occupancy analysis, we first used ArcGIS Pro to overlay a fishnet of hexagons across the entire historical range for both chub species. Hexagon size was 2.5 kilometers, based upon point clustering of sampling data. After the hexagon fishnet was built, sampling data was checked to ensure duplicates were removed for a single sampling event and capture records were reviewed to ensure duplicate species records for one sampling event were removed.

All sampling records provided by the PSPAP sampling crew from 1996 to 2021 were included in the occupancy analysis. In addition, data provided by Montana Fish, Wildlife & Parks for the Missouri River upstream of Fort Peck Reservoir were included for the 2001 to 2017 time period. Changes to the sampling protocol used by Montana Fish, Wildlife & Parks starting in 2018 precluded the use of post-2018 data in this analysis. Additional datasets were used if sampling parameters were met for this analysis (See Table 18 in Appendix 1 for more information about the datasets). The PSPAP and Montana Fish, Wildlife & Parks, and other data allowed for the occupancy trend analysis for Populations 1 and 3 of sturgeon chub and Populations 1 and 2 of sicklefin chub.

To calculate occupancy frequency, an aggregate points tool in ArcGIS Pro was used to sum the number of unique sampling points and species capture records within a hexagon for two time periods. The determined time periods for the frequency change analysis were 1996- 2011 and 2012- 2021, based on an observed bimodal distribution in the sampling data and a low between the peaks occurring in 2011 and 2012. A minimum of ten sampling events for both time periods within a hexagon were required for it to be used in the occupancy frequency analysis. The occupancy frequency for a time period within a hexagon was calculated by dividing the number of species occurrences by the number of sampling events for each species (# of sampling events with one or more species records/ total # of sampling events). The range of values from this computation was 0 to 1. A value of zero meant no individuals of a species were documented across all sampling events and a value of one meant all sampling events documented at least one individual of a particular species.

To calculate the occupancy frequency at the hexagon level, we subtracted the occupancy frequency for years 2012 to 2021 from years 1996 to 2011. Range in values were -1 to 1. A value of -1 meant all sampling locations had at least one individual species documented at all sampling locations during 1996- 2011 but no detections of that species during all sampling events during 2012- 2021, thus a decline in occupancy frequency. Conversely, a value of 1 meant no individuals of a particular species were documented at any of the sampling locations during 1996 to 2011, but during 2012 to 2021 all sampling locations detected at least one individual of a particular species, thus an increase in occupancy frequency. Hexagons with a score of zero were removed from the analysis because no individuals were detected during both time periods. These situations likely stem from sampling in unsuitable habitat and they were subsequently removed from the analysis because of the concern that zero values at the hexagon level would bias the occupancy results. Due to non-normally distributed data, we used a Mann-Whitney U test to test for differences in median occupancy between the two time periods for each chub species. R 4.2.2 was used for all statistical analyses.

Results from the occupancy analysis indicated no significant difference in median overall (populations combined) occupancy frequency for sturgeon chub between the two time periods (Table 10). However, when the populations were analyzed separately, there was a statistically significant decline in occupancy in Population 1 and statistically significant increase in occupancy in Population 3 between the two time periods (Table 10). We did not detect any significant changes in occupancy for sicklefin chub overall or by population between the two time periods (Table 10). Spatially, it appears the decline in average occupancy in Population 1 of sturgeon chubs was primarily driven by sites in the Missouri River above Fort Peck, Montana, with other areas of decline in the Missouri River scattered from approximately Wolf Point, Montana to the headwaters of Lake Sakakawea (Figure 9). Spatially, it appears the increase in average occupancy in Population 3 of sturgeon chubs was primarily driven by sites in the Missouri River adjacent to and downstream of Columbia, Missouri (Figures 10 and 11). For spatial representations of occupancy changes through time for sicklefin chubs, see Appendix A.

Table 10. Descriptive statistics for probability of occupancy, and p-values for comparison between two time periods (1996-2011 and 2012-2021), by chub species and population.

			1996-2011		2012-2021		
Species	**Population**	**N**	**Median**	**SD**	**Median**	**SD**	**p-value**
Sturgeon chub	Overall	379	.07	.23	.08	.14	.49
	1	109	.40	.26	.24	.19	**<.01**
	3	270	.04	.07	.06	.06	**.05**
Sicklefin chub	Overall	384	.15	.22	.15	.16	.30
	1	92	.27	.32	.24	.15	.09
	2	292	.14	.15	.11	.15	.43

Another aspect of the occupancy analysis that we mapped was the distribution of occupancy frequencies for the entire time range of the datasets, 1996 to 2021. This analysis allowed us to create a "heat map", showing the gradient of occupancy frequencies through time and identify areas where the probability of catching either chub species was, for example, relatively high or low.

In Population 1 of both chub species, the Missouri River above Fort Peck Reservoir, Missouri River between the confluence with the Yellowstone River and above Lake Sakakawea, and the lower Yellowstone River exhibited the highest probabilities of occupancy through time (Figures 12 and 13). Despite declines in occupancy through time for Population 1 of sturgeon chubs, probability of occurrence is still considerably higher than for Population 3 of sturgeon chubs (Table 10; Figures 12, 14, 15). For population 2 of sicklefin chubs, the highest probabilities of occupancy were in the Missouri River approximate to and downstream from Columbia, Missouri to the confluence with the Mississippi River (Figures 16, 17).

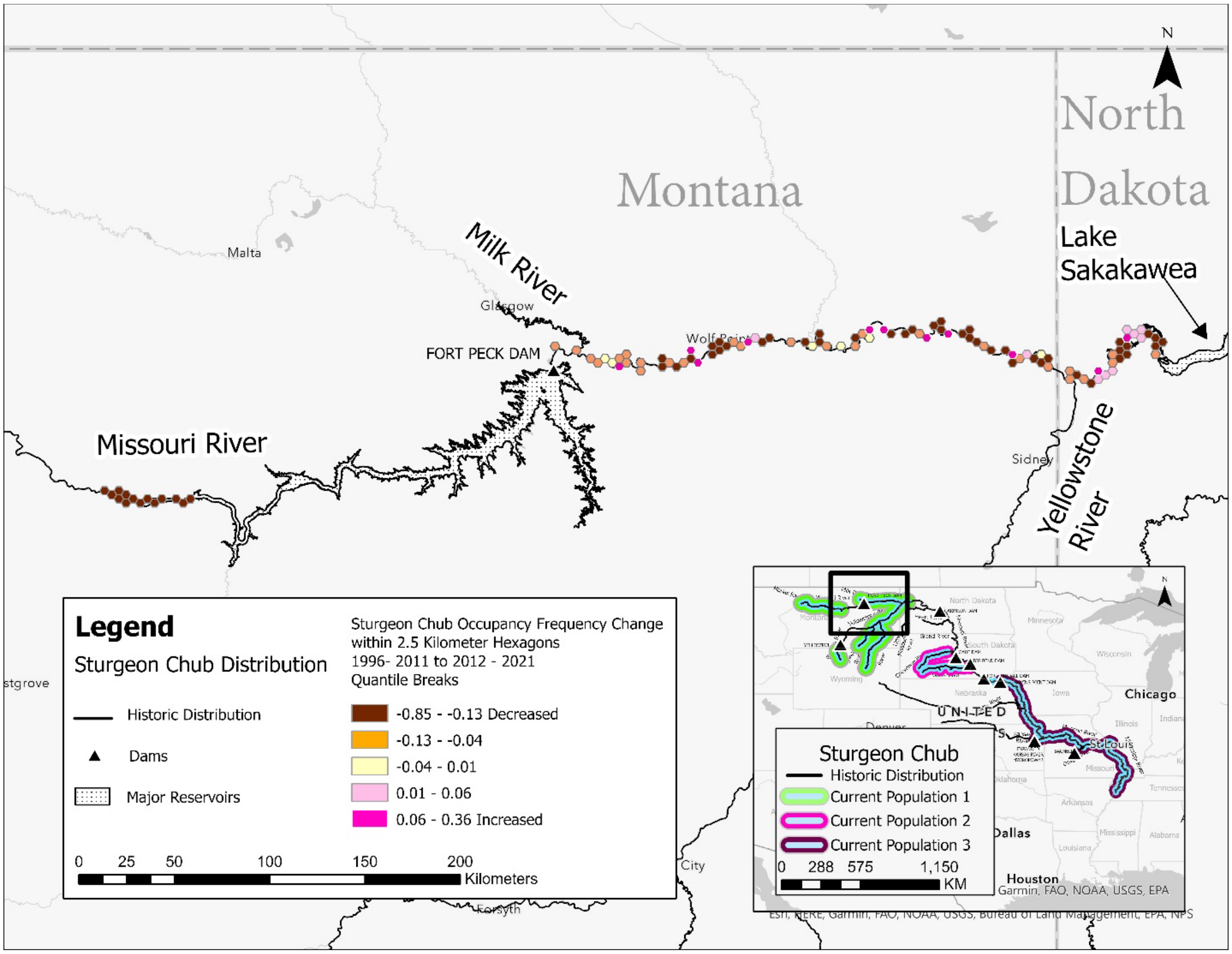


Figure 9. Sturgeon Chub Occupancy Frequency Change 1996-2011 to 2012-2021, Population 1.

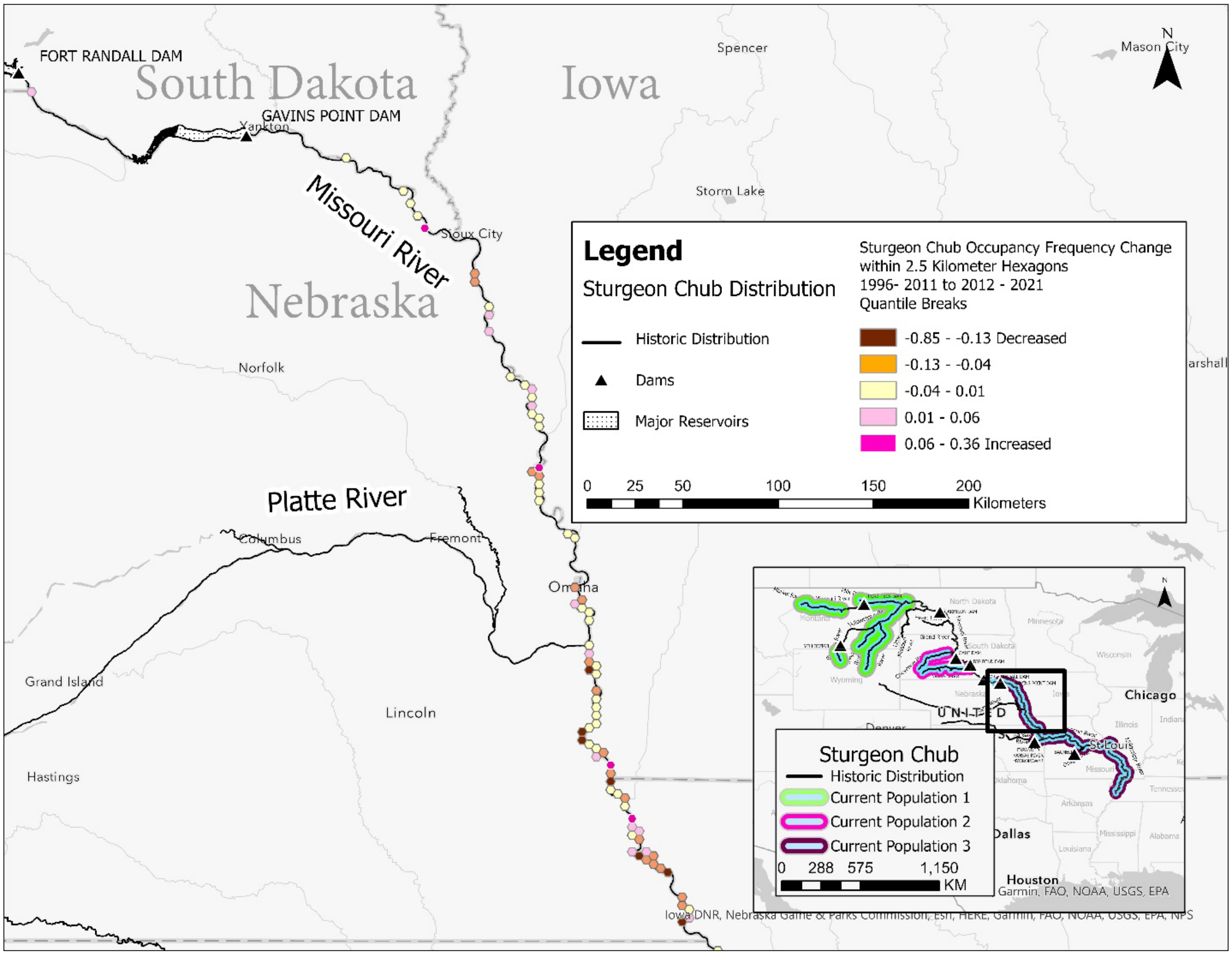


Figure 10. Sturgeon Chub Occupancy Frequency Change 1996-2011 to 2012-2021, Population 3.

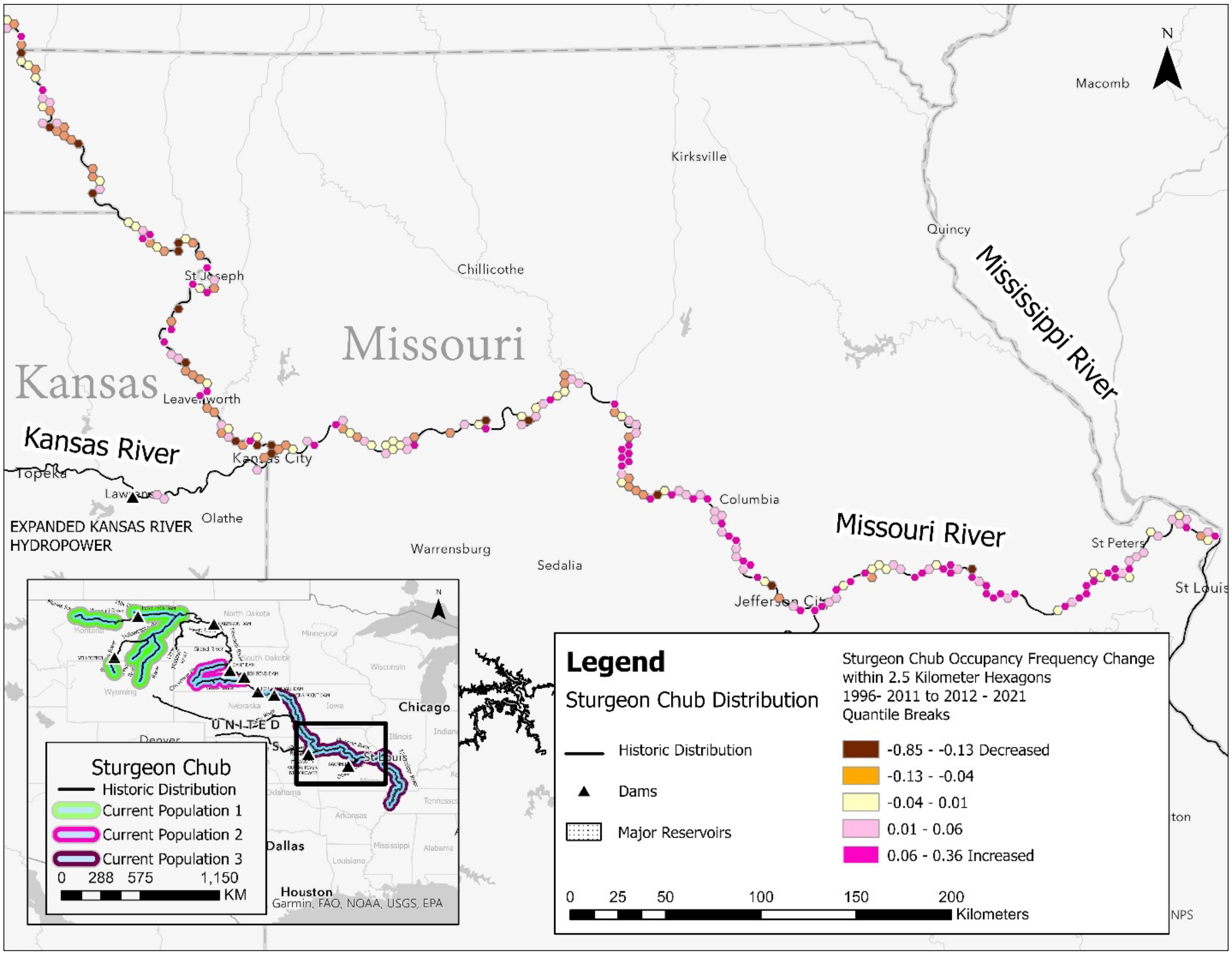


Figure 11. Sturgeon Chub Occupancy Frequency Change 1996-2011 to 2012-2021, Population 3.

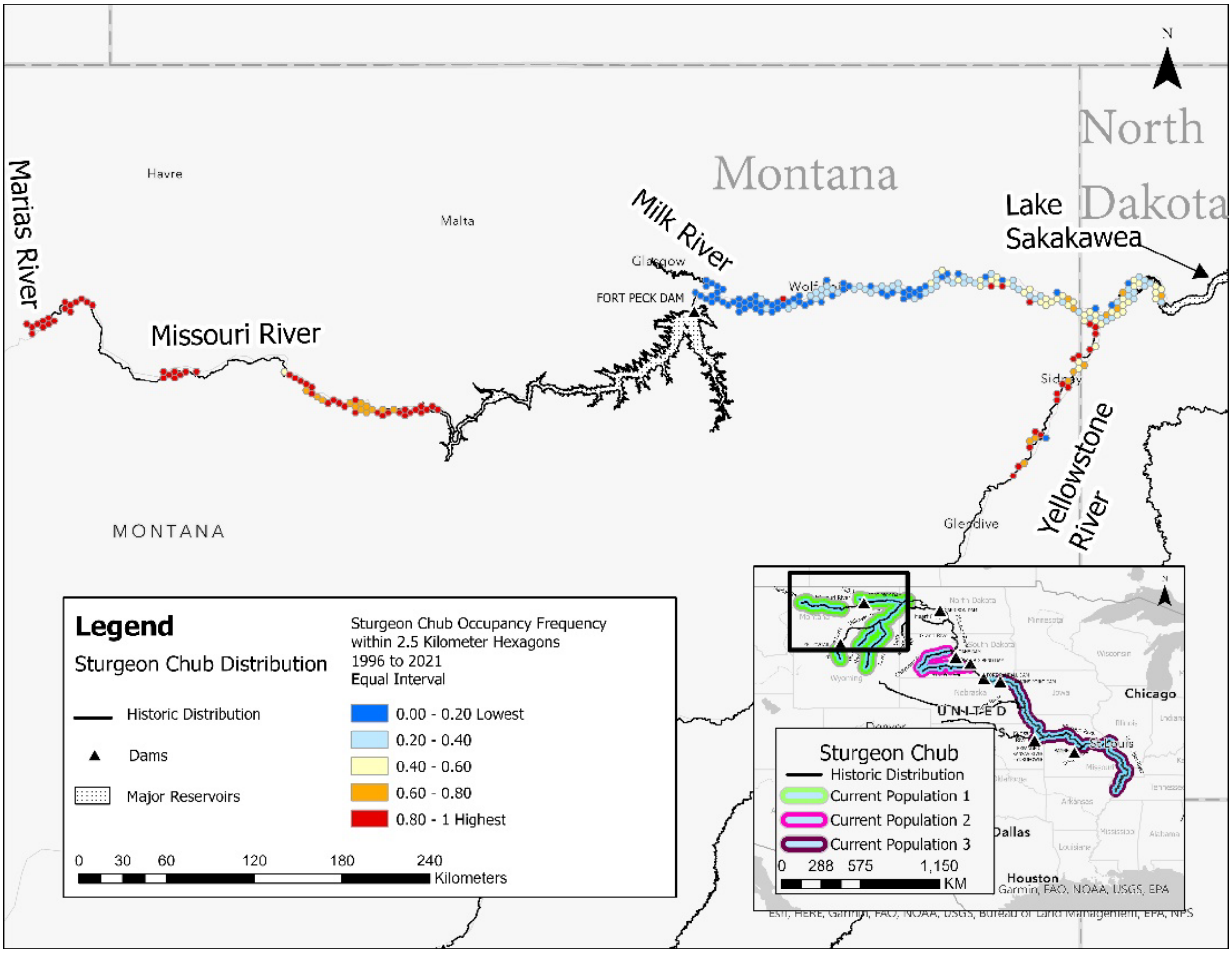


Figure 12. Sturgeon Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 1.

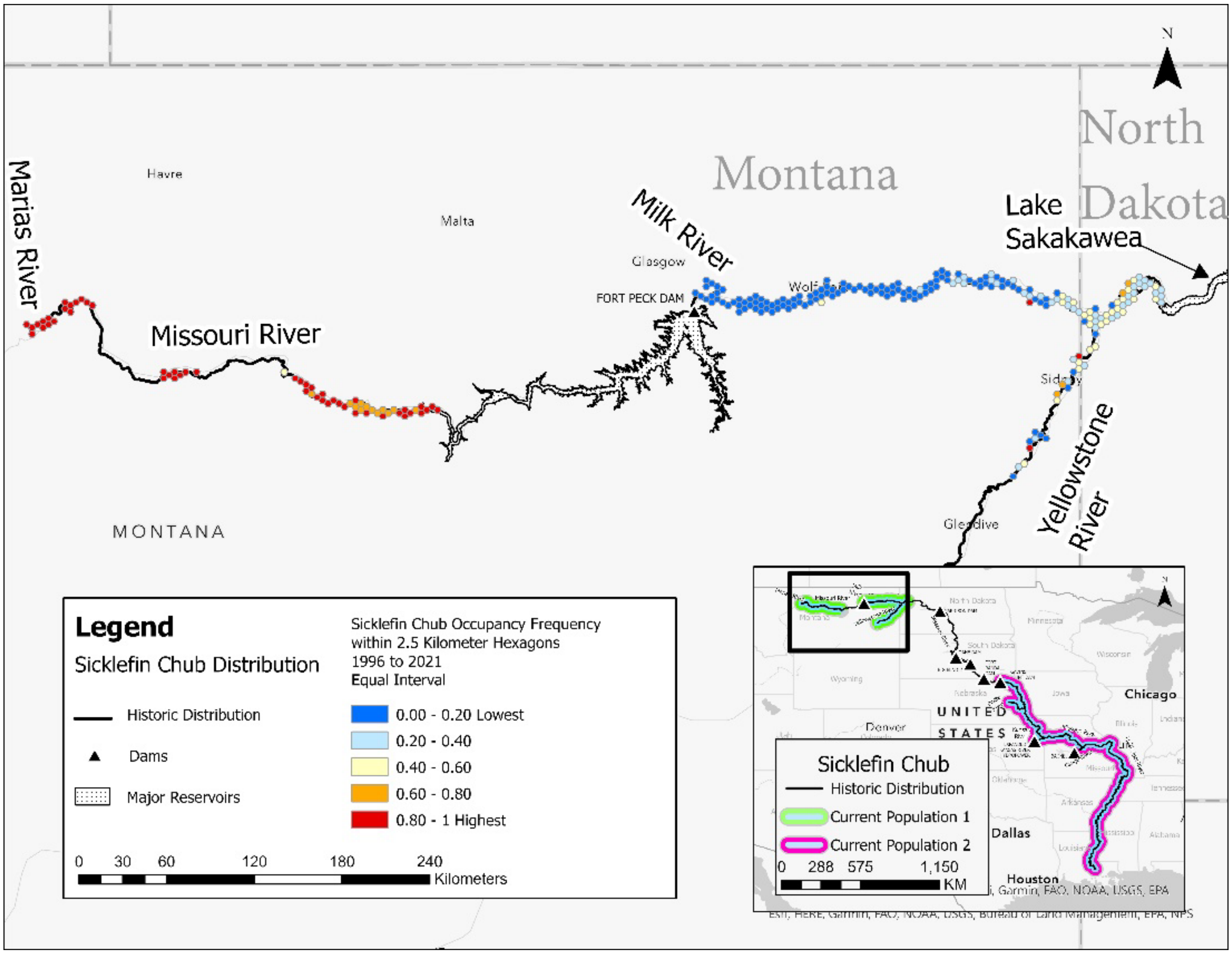


Figure 13. Sicklefin Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 1.

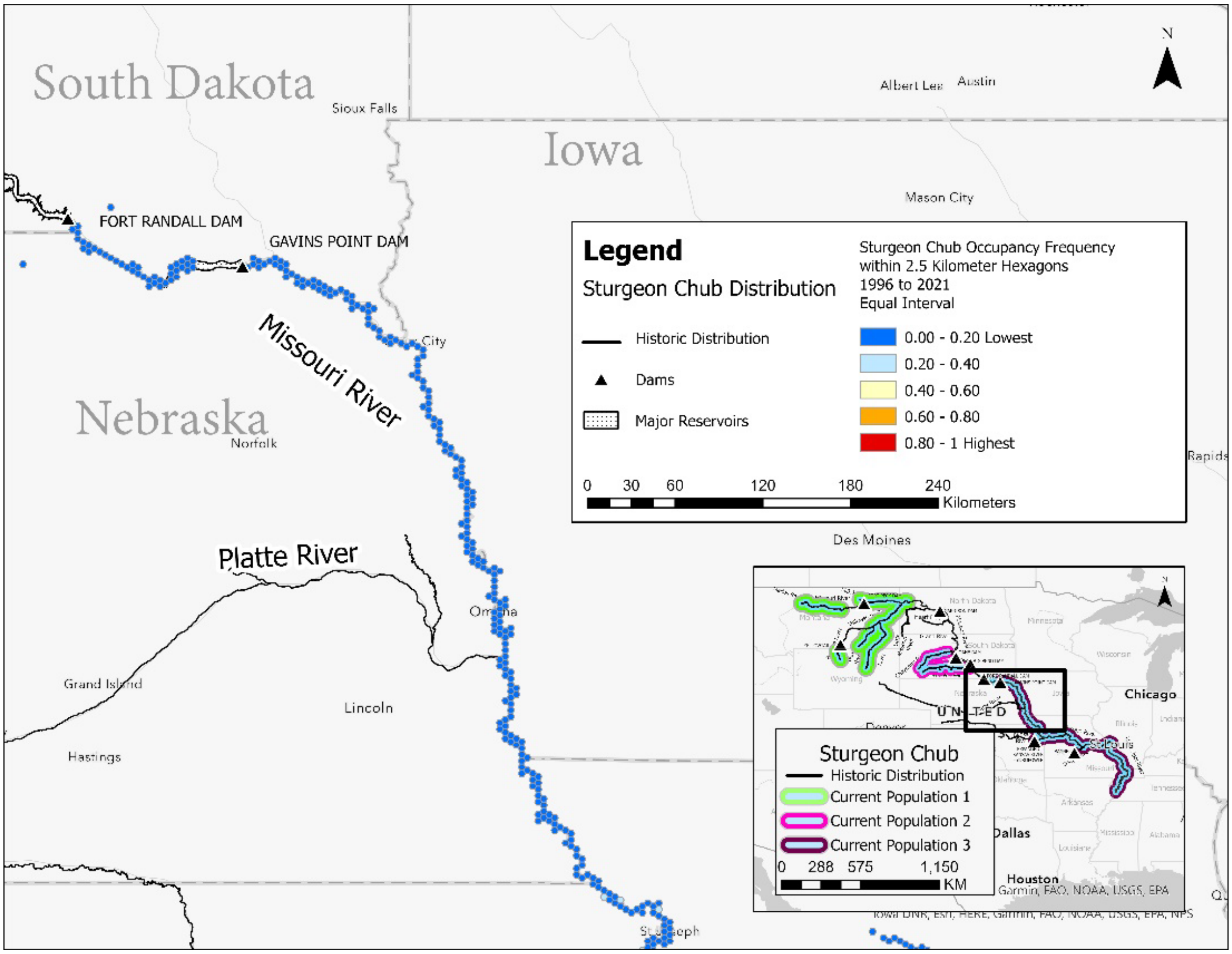


Figure 14. Sturgeon Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 3.

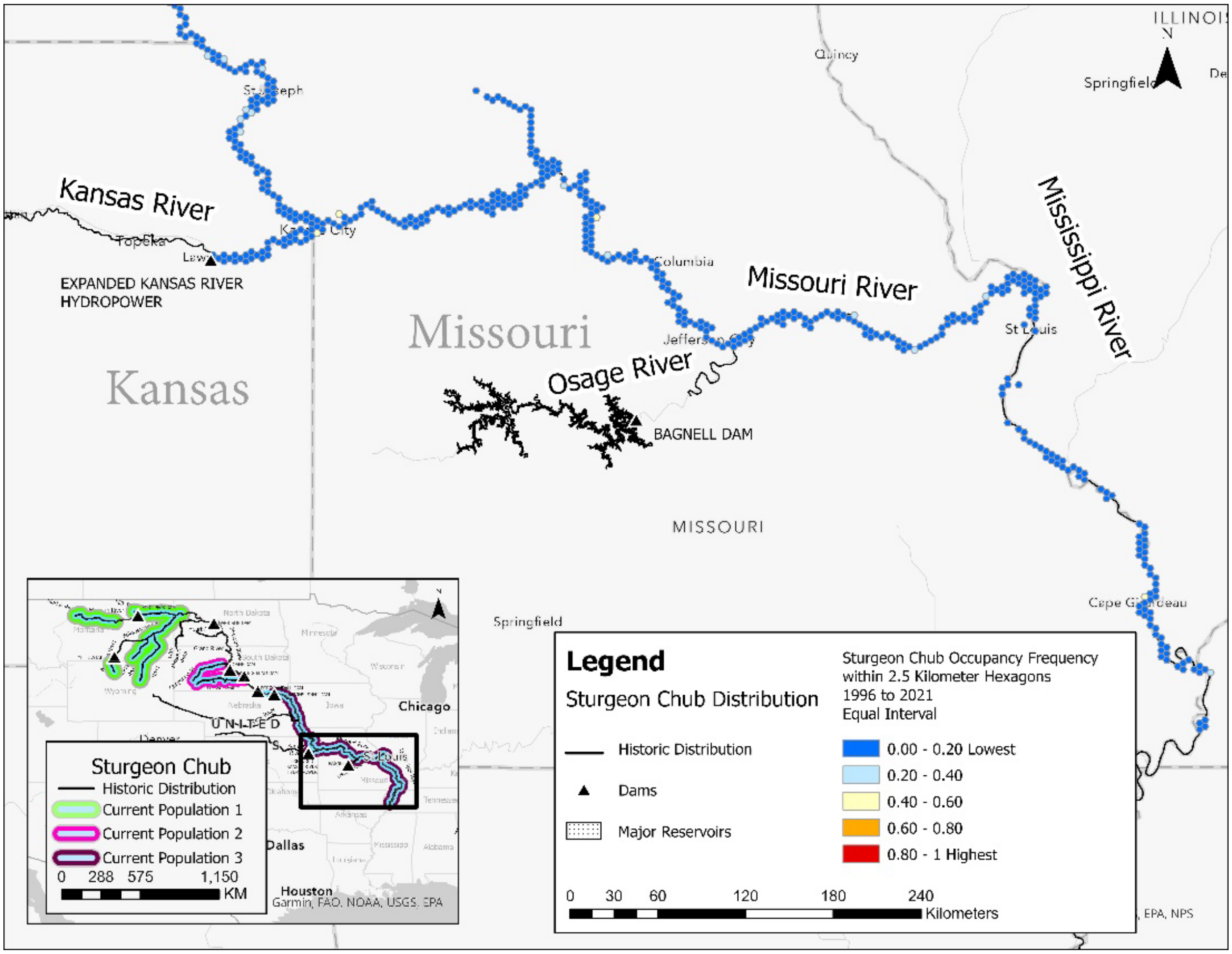


Figure 15. Sturgeon Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 3.

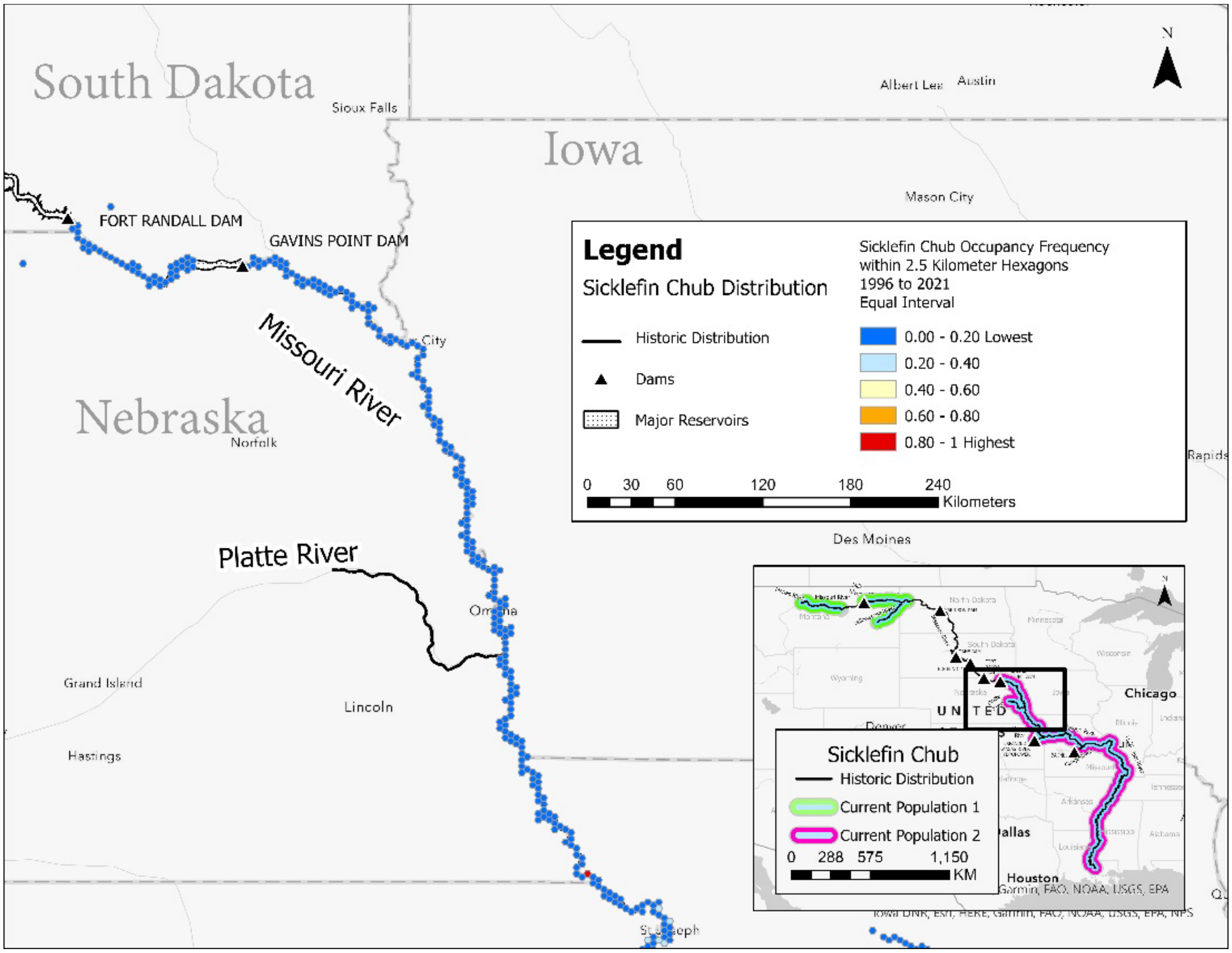


Figure 16. Sicklefin Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 2.

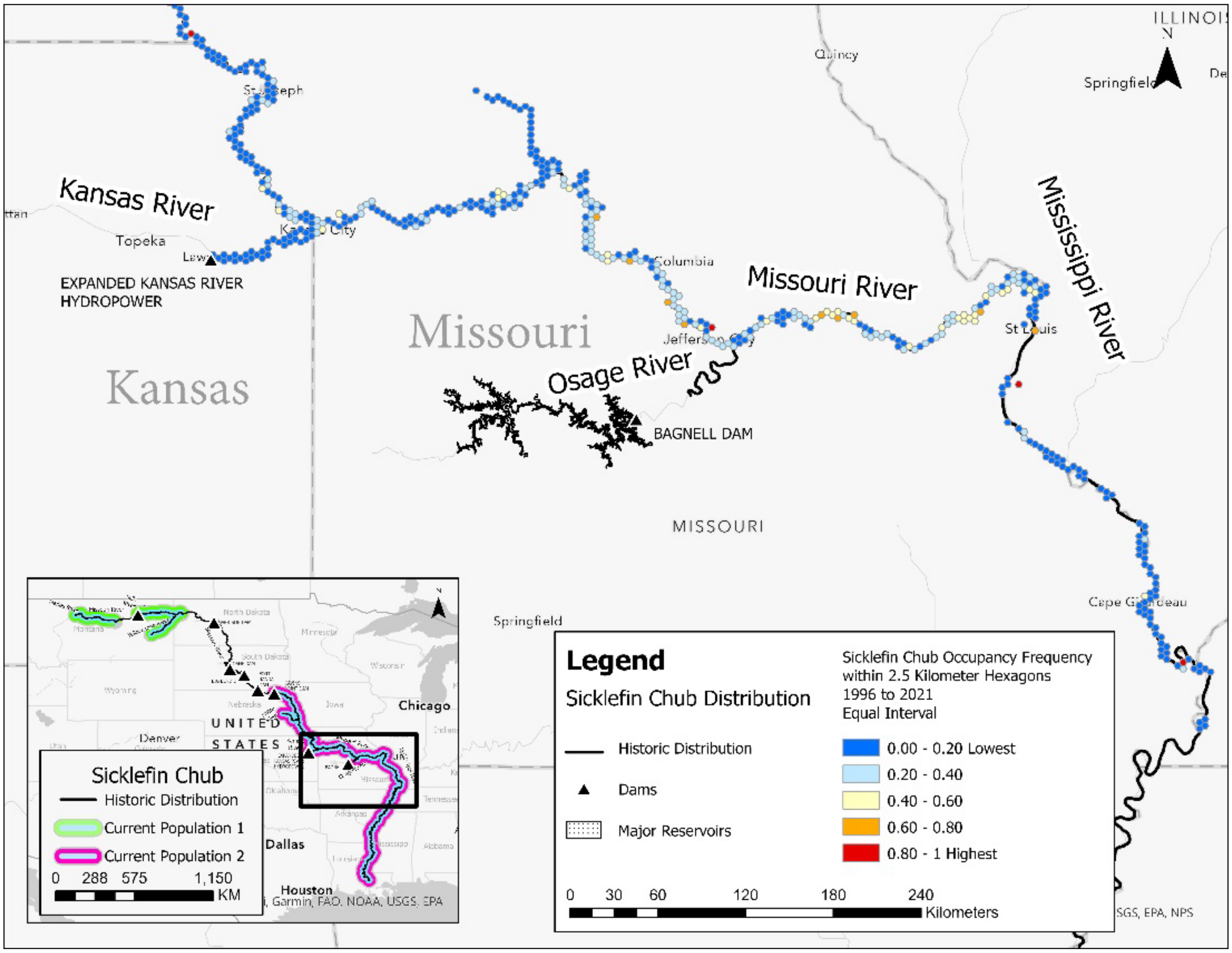


Figure 17. Sicklefin Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 2.

Summary

In summary, the probability that sturgeon chubs in the Missouri River in Population 1 are occupying a given site has declined relative to historical, on average. However, the probability that sturgeon chubs in the Missouri River in Population 3 are occupying a given site has increased relative to historical, on average. Decreases or increases in probability of occupancy are presumed to indicate similar trends in abundance; however, some contrasting relative abundance trend information was presented in the "Catch Trends" section above. No occupancy trends were discernible for either Population of sicklefin chubs. Despite declining occupancy of sturgeon chubs in Population 1 through time, probability of occupancy remains higher for sturgeon chubs in Population 1 relative to Population 3.

Stressors Potentially Contributing to Current Condition

In this chapter, we assess potential stressors that may be influencing the current conditions of sturgeon chubs and sicklefin chubs (Figure 18). Potential stressors to current condition of these species were identified from the 2001 Finding and solicitation of information from our conservation partners during stakeholder meetings in early 2022. We evaluated each potential stressor based on the best available information for sturgeon chubs and sicklefin chubs. Often, information was scarce for many of the potential stresssors identified in this chapter. In these cases, we relied on scientific theory, documented impacts of similar potential stressors to similar fish species, or professional judgement.

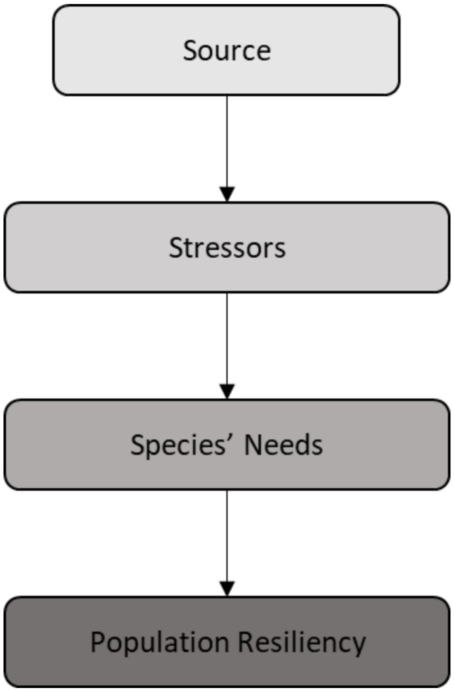


Figure 18. Stressors leading to current condition conceptual model.

<u>Missouri River Mainstem Dams/Reservoir Operations</u>

The construction, operation, and reservoir management associated with mainstem dams on the Missouri River has reduced the current range of sturgeon chubs and sicklefin chubs from historical levels. On the mainstem Missouri River, over 30 percent of riverine habitat within the range of both sturgeon chubs and sicklefin chubs has been transformed from riverine to reservoir habitat due to the six large mainstem dams. Additionally, over 20 percent of remaining river habitat before the channelized portion of the Missouri River has been altered due to downstream effects of the mainstem dams. These activities have resulted in numerous physical, chemical, hydrological, biological and ecological changes to the Missouri and Mississippi rivers. Some of the many changes include channel morphology, water temperature, turbidity, nutrients, and flow regimes.

Major influences on sturgeon chub and sicklefin chub habitat due to the construction of these mainstem dams include reduction of sediment transfer and loads, regulated flow downstream of dams, deep cold-water releases and reservoir habitat instead of riverine. The combination of dam placement and influences from altered hydrology has created fragmentation of these species which is one of the largest stressors to sturgeon chub and sicklefin chub. Before the construction of mainstem dams, the Missouri River was free flowing from its headwaters to the mouth of the Mississippi River. Since construction of the dams and associated reservoirs, sturgeon chub and sicklefin chub have been extirpated from the mainstem Missouri River in much of South Dakota and North Dakota. In the species needs chapter we discussed required habitat for both chub species. Construction of reservoir habitat removed suitable habitat from the Missouri River in both states. We note that there are several efforts underway to aid in recovery of pallid sturgeon that may benefit sturgeon chub and sicklefin chub. Test flows from Fort Peck Reservoir that are designed to mimic a more natural hydrograph and construction of interception rearing complexes in the lower Missouri River may aid in making habitat characteristics more favorable for the chub species.

Ultimately, the construction of mainstem Missouri River dams and associated reservoirs is the main stressor leading to the largest reduction in habitat. While this stressor has led to a large reduction in habitat, both species are still present above, in between, and below the six mainstem dams. Unlike sicklefin chub, sturgeon chub utilize tributaries throughout their range. This adaptation has provided refuge for sturgeon chub in areas where the Missouri River is in a reservoir state. The removal of mainstem Missouri River dams is not expected to happen in the near future. The stressor of mainstem dams, reservoir habitat and fragmentation will likely remain on the landscape for decades; however, there are no current plans to further fragment these species through the construction of new dams on the mainstem Missouri River. The largest effects on both chub species and their habitats from these dams have already occurred and are incorporated into the current condition of both chub species. Both chub species are expected to remain absent from currently unoccupied areas in North Dakota and South Dakota.

Tributary Barriers and Habitat Fragmentation

Globally, low-head dams and road stream crossings have altered stream morphology, flow regimes, and connectivity. These alterations have led to decreased recruitment and survival of aquatic organisms resulting in aquatic biodiversity loss. Recent evaluations have shown that not all potential barriers are the same and ongoing efforts across the nation are evaluating these for significance to fish and mussel movement. The life history needs and habitat connectivity for the specifically the sturgeon chub could likely be impacted by these structures. Connectivity of habitats becomes more paramount under severe conditions due to the need of this species to adapt and move to more favorable habitats and ultimately recolonize once conditions improve. Tributary barriers and habitat fragmentation are likely impacting sturgeon chub at an individual level but more information is needed to assess if this stressor is happening across a broader portion of their range, therefore potentially having an impact at a population level.

Channel Modification

Sturgeon chub and sicklefin chub evolved in dynamic, turbid, braided riverine ecosystems where channel morphology was diverse. Dynamic riverine habitats created differential flow patterns with deep, fast flowing water and associated slow, shallow water side channels that provided spawning and nursery habitat. In conjunction with the establishment of mainstem Missouri River dams and associated reservoirs, the Missouri River was being highly altered downstream of Sioux City, IA. Authorization of the Rivers and Harbors Act between 1912 and 1945 established a program to channelize the Missouri River. In addition, the Missouri River Bank Stabilization and Navigation Project (BSNP) was proposed in 1934 and was enacted to promote navigation from Sioux City, IA to the mouth of the Mississippi River. To create a uniform narrow channel that facilitated navigation, the Corps used wing dikes to create a self-dredging channel and armored the outside banks of the river to prevent erosion. The BSNP was completed in 1981, extends from Sioux City, IA, to the mouth of the Missouri River 1,183 rkm (735 rmi) and maintains a 2.7-m deep (9-ft deep) by 91-m wide (300-ft wide) channel (Master Water Control Manual 2018, pp. IV-28). Channelization of the Missouri River greatly reduced channel width and significantly reduced access to the historical floodplain (Missouri River Recovery Program 2010, p. 8, Biological Assessment 2017 p. 108). The BSNP accounted for a loss of nearly 211,000 hectares (522,000 acres) of floodplain habitat and over 1,127 rkm (700 rmi.) of river channel (Missouri River Recovery Program 2010, p. 8).

Since 1974, the Corps has implemented measures to modify the channel maintenance structures and improve fish and wildlife habitat. The Corps has restored some side-channel connections and increased habitat diversity in the channelized Lower Missouri River by notching dikes or otherwise modifying channel structures. The Corps estimates that approximately 2,100 modifications to dikes and habitat structures have been constructed (Biological Assessment 2017, p. 109). Notching dikes or revetments can increase channel width and diversity to create shallow water/sandbar complexes. More recently the Corps has implemented the BSNP Fish and Wildlife Mitigation Project that aims to compensate for losses of fish and wildlife habitat lost due to channelization.

Channelization of the Missouri River from Sioux City, IA to the confluence with the Mississippi River near St. Louis, Missouri has reduced the quantity and quality of instream habitat for both chub species. Reductions in access to shallow water nursery habitat and other diverse habitats used by both chub species has likely reduced occupancy and relative abundance of both chub species relative to historical levels. However, despite the habitat changes associated with channelization, both chub species are occupying a large portion of their historic range in these areas and channelization may only be impacting both species at an individual level at some locations throughout their range rather than at a population level.

Water Quality

Water quality in the Missouri and Mississippi rivers is currently different from what sturgeon chub and sicklefin chub evolved in. Both species require similar water quality to thrive and carry out natural life functions. One major stressor within water quality that is shown to be essential to healthy populations is the presence of turbidity. Historically both the Missouri and Mississippi rivers were turbid rivers that transported large amounts of sediment. Research has validated the correlation between turbidity and collection/presence of sturgeon chub (Dieterman and Galat 2004, p. 581, Everette et al. 2004, p. 188, Magruder 2022, p.35). Sturgeon chub appear to use more turbid environments, due primarily to high tributary use compared to primary use of mainstem habitat by sicklefin chub. Anthropogenic influences on the landscape have shaped both river systems to a point where turbidity and sediment load is greatly decreased. The Missouri River was historically called the "Big Muddy" but now the presence of reservoirs and dams store much of the sediment than the previously free flowing river and has subsequently created a much clearer river than it was historically. Sediment analysis on the Missouri River at Omaha, NE showed that sediment load was predominately 70 percent sand sized material which historically made-up 30 percent of sediment size pre-dam (Master Water Control Manual 2018, pp III-11). The Missouri River in its pre-dam state transported a sediment load of 25 million tons per year in the vicinity of Fort Peck, MT; 150 million tons per year at Yankton, SD; 175 million tons per year at Omaha, NE; and approximately 250 million tons per year at Hermann, MO, near its confluence with the Mississippi River (Master Water Control Manual 2018, pp. III-11). With the placement of the six mainstem dams, sediment capture has increased significantly with deposition averaging around 76,000-acre feet (33 million tons) annually throughout the system (Master Water Control Manual 2018, pp. III-2).

Reduction in sediment transport and deep-water releases from mainstem dams have created water that is less turbid and colder than before the dams were put in place (Galat *et al*. 2005, p. 254). Sturgeon chub and sicklefin chub utilize the benthic environments where turbidity helps decrease interactions with other fish, specifically predators. Interactions between native predators is likely to have increased in areas where turbidity has decreased. Furthermore, sturgeon chub and sicklefin chub have developed a specific feeding strategy that favors turbid environments. We are not sure how decreased turbidity has affected feeding for these species, but further research could be beneficial.

Overall, changes to water quality may be affecting sturgeon chub and sicklefin chub. Turbidity and sediment transport are directly correlated. Large decreases in sediment transport due to the mainstem dams has likely had the largest impact to sturgeon chub and sicklefin chub by potentially increased interactions with predators and adapting historic feeding strategies to this new environment. It is worth noting that since the dams have been in place both sturgeon chub and sicklefin chub still occupy a representative portion of their native. We currently think water quality is a stressor that may be impacting both species at an individual level now and into the future.

Climate Change

Climate change refers to a change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2014, p. 120). Broadly, climate change is a primary driver of how ecosystems function. Changes in the atmosphere, cryosphere, oceans, and biosphere, including widespread changes in precipitation amounts, global sea level rise, elevated ocean salinity and acidification, and increases in the number and intensity of extreme weather events have been consistently observed in many ecosystems and are expected to continue in the future (IPCC 2014, pp. 2–4)

The broad range in latitude, longitude, elevation, and drainage area across the ranges of both chub species result in wide variations in historical climate conditions. Several extreme events have occurred in the basin including droughts and floods. A severe plains-area drought occurred in the 1930s when above-average summer temperatures and below-average precipitation prevailed for more than a decade. Numerous record floods have occurred since 2010 and in 2011, a high mountain snowpack and heavy spring rainfall produced a record flood that impacted most of the basin (Master Water Control Manual, 2018, pp. III-3). Despite extreme events and increased variation in annual weather patterns, reductions in stream discharge have been observed across the range of both chub species.

Reductions in stream discharge are positively correlated with declines in chub distribution and abundance (Perkin *et al*. 2010, pp. 8-9). The mechanism for decline is unclear but could be related to mortality from desiccation of some stream segments, increased predation in areas with large congregations of fish, lack of thermal refugia or other biotic or abiotic factors. However, regardless of the mechanism, it appears that historical discharge reductions due to climate change have primarily affected sturgeon chub and sicklefin chub populations in the smaller tributaries in their range rather than sections of the mainstem Missouri and Yellowstone rivers (Perkin *et al*. 2010, *entire*).

Historical reductions in stream discharge have affected the abundance and distribution of both chub species, contributing to their current condition. However, mainstem habitats appear to be more climate resilient than those found in smaller tributaries, likely due to the consistency of flows from current operations of the Missouri River reservoir system and the differential buffering capacity (to water temperature increases, for example) of small volumes of water in tributaries relative to large volumes of water in mainstem habitats. We currently expect climate change to impact both species at an individual level, but not likely at the population level because of the large proportion of both chub species occupying mainstem river habitats that appear more climate resilient than smaller tributary habitats. For Population 2 of sturgeon chubs which occur solely in tributary habitats, we would expect to observe some effect in the population if climate change was operating at the population level. However, it is clear from the Range-wide Genetic Assessment that Population 2 of sturgeon chubs is genetically robust, thus we have no indication that alterations to the habitat from climate change are acting at the population level.

Pollutants

A variety of pollutants exist in the current range of sturgeon chub and sicklefin chub. Due to the large scale of the Missouri and Mississippi river watersheds it is possible that pollutants have caused harm to both sturgeon chub and sicklefin chub currently and historically. The number of different pollutants that are flushed through both watersheds are likely large. The Pallid Sturgeon Basin-Wide Contaminants Assessment analyzed four different management units that are classified as the Great Plains Management Unit (GPMU), Central Lowlands Management Unit (CLMU), Interior Highlands Management Unit (IHMU), and Coastal Plains Management Unit (CPMU, Figure 19).

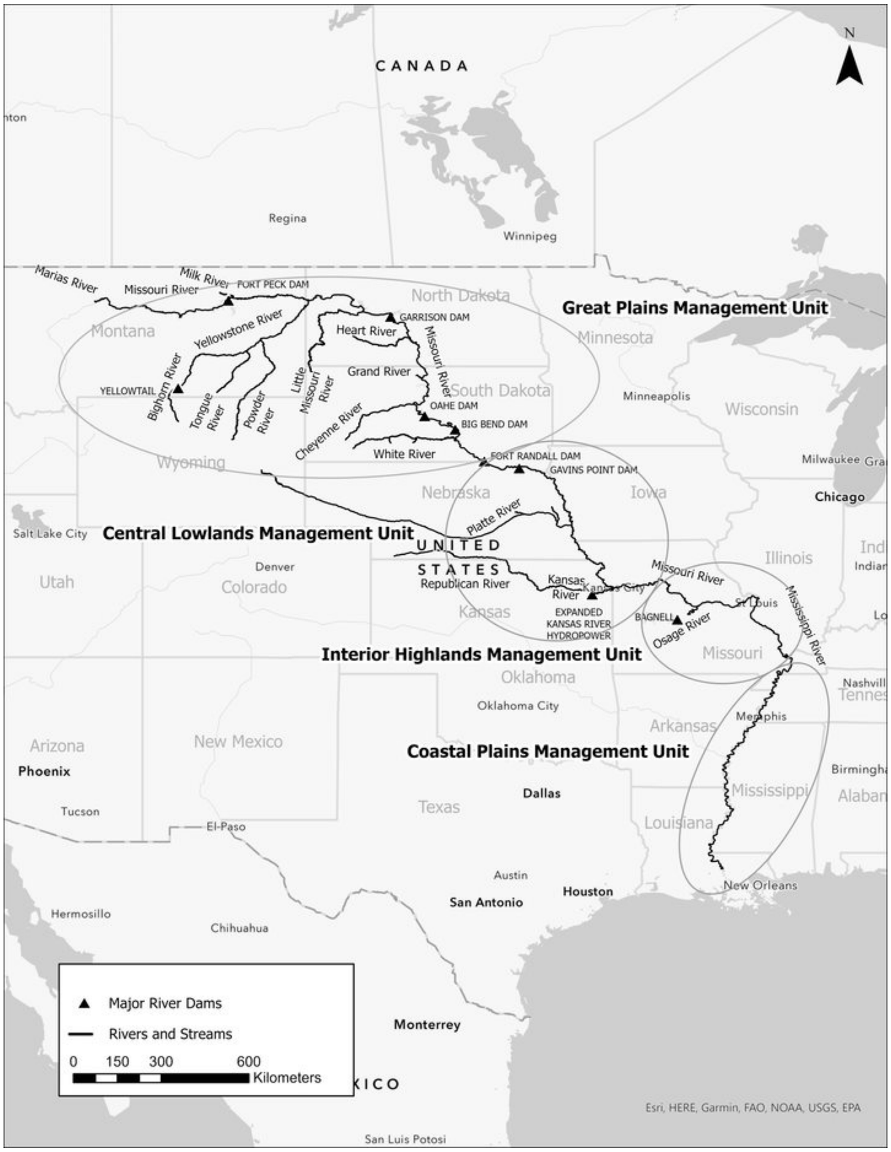


Figure 19. Pallid sturgeon management units used for pollution analysis

According to the Pallid Sturgeon Basin-Wide Contaminants Assessment 2019, metals are the main contaminate of concern for the GPMU, selenium for the CLMU, triazine herbicides are potentially of concern in all but the GPMU, Polychlorinated biphenyls and Dichlorodiphenyltrichloroethane and its metabolites exceeded benchmarks in samples from the CLMU, IHMU, and CPMU (Webb *et al*. 2019, pp. 3-4). Observed concentrations of nutrients and indicators of nutrient pollution were above benchmark levels throughout the pallid sturgeon's range (which overlaps with both chub species); however, the significance for sturgeon chub and sicklefin chub health is unknown. Very little information exists on contemporary contaminants of concern such as the natural and synthetic estrogens (estradiol, ethinyl estradiol, and estrone) or polybrominated diphenyls (Webb *et al*. 2019, pp. 3-4).

A variety of pollutants within the Missouri and Mississippi rivers have caused agencies to examine fish flesh for presence of toxins (i.e., Mercury). Current information examining sturgeon chub and sicklefin chub response to pollutants is not known. In portions of sturgeon chub and sicklefin chub ranges they are subject to water quality impacts and contamination associated with oil development and transport of crude oil products. There have been pipelines that have ruptured and spilled large amounts of crude oil in tributaries, which eventually reached mainstem rivers throughout both chubs ranges. Several spills have been documented in Montana and North Dakota. Another spill happened in June 1995, that occurred into an irrigation canal near the confluence that reached the Missouri River. In addition to oil spills barge accidents have occurred on the Mississippi River and resulted in the release of contaminants. Due to the volume of flow and dilution factor in the Yellowstone, Missouri, and Mississippi rivers, the potential for oil spills and release of other contaminants impacting sturgeon chub and sicklefin chub habitat at a population level is considered low, although direct impacts to individual chubs could be large. State and Federal agencies have programs in place to address spills of oil and other contaminants. These programs attempt to minimize any impacts that a spill might have on habitat for fish and wildlife.

Hundreds of pollutants are consistently flushed through the Missouri River and Mississippi River, and it is difficult to determine the effects on sturgeon chub and sicklefin chub from these pollutants. Research has documented how pollutants can harm freshwater fishes but due to lack of information on sturgeon chub and sicklefin chub it does not appear that pollution has directly contributed to the reduction of species range. This stressor is likely impacting both species at a point source individual level at current condition. If a major pollutant release does occur within the Missouri or Mississippi River Basins, this stressor could be exacerbated and affect a larger portion of these species' ranges. Also, due to there being multiple populations of each species, there is redundancy throughout their range to prevent a collapse of either species populations from pollutants.

Impingement/Entrainment

Power plant intakes along the Missouri River have the potential for impingement and entrainment of fishes including sturgeon chub and sicklefin chub. Entrainment of fishes is when fish pass through a designated device such as a screen surrounding a water intake. Impingement is when the fish makes physical contact to a device such as a screen and is unable to remove itself from the screen due to intake velocities being greater than the fish can swim. Both entrainment and impingement can be fatal to fishes at all life stages. Prior to the 2001 finding, a study was completed that examined impingement at two nuclear power plants and one coal burning power plant on the Missouri River in Nebraska. These pre 2001 studies reported low numbers for both sturgeon chub and sicklefin chub in the intakes (Service 1993, p. 33). These studies that were completed in 1973 and 1977, found one sicklefin chub and two sturgeon chubs impinged at the Fort Calhoun Nuclear Station. Sampling occurred twice daily from May to September and once daily from October to April. Only one sturgeon chub was reported to be impinged at Cooper Nuclear Power Plant during these studies. Sampling at Cooper Nuclear Power Plant occurred five sampling times per week. Two sicklefin chub and one sturgeon chub were impinged at the Iatan Power Plant intake during 12, 24-hour surveys between October 5 and December 31, 1980 (Geo-Marine, Inc. 1981, *entire*.). This 4-year power plant intake study focusing on impingement, entrainment, and water temperature effects on Missouri River fish populations did not find changes in fish community due to power plant operations. Overall impacts to the aquatic communities near these power plants were considered minimal (Hesse 1982, *entire*).

The power plant intake study in Nebraska was redone in 2016 and 2017 to see if entrainment numbers differed from the 1970's. This study found that over 11 million Leuciscids were entrained during the 2016 study and over 29 million cyprinids were estimated to be entrained from May to October 2017 for the two powerplants studied on the Missouri River in Nebraska (Bailey *et al*. 2019, p. 42). Researchers were largely unable to specify taxonomy beyond family (leuciscids).This number is large and further research is needed to determine in sturgeon or sicklefin chub are among the species being entrained from these power plants. If they are, the large number of power plants along the Missouri River and Mississippi River could be impacting both chub species.

Due to the large volume of flow in these river systems, power plant intakes withdraw a fraction of total volume passing the facility; However, the cumulative effects of multiple facilities have not been studied. Further research on impacts to sturgeon chub and sicklefin chub in smaller tributaries where power plants are present since the volume of water passing through may not be as large as the Missouri River and Mississippi River. As of 2015 there were 15 active power plants on the Missouri River from Sioux City, IA to St. Louis, MO. Combined effects of water intakes in these systems are likely impacting both species at an individual level. There is potential to cumulatively impact species at a population level however, further research is needed to address this.

Predation

Being small Leucisid fishes, both the sturgeon chub and sicklefin chub are continually at risk of predation in their natural environment by larger, predatory fishes. Since 2001, diet studies have been conducted on the Missouri River primarily focusing on large native predators. Research has documented pallid sturgeon (*Scaphirhynchus albus*) as being a predator to both sturgeon chub and sicklefin chub through these studies (Gerrity *et al*. 2006, p. 606). One primary reason pallid sturgeon diet studies have been completed is to better understand the dietary needs of these fish.

Pallid sturgeon are federally endangered and thus heavily studied. Juvenile pallid sturgeon prefer habitat that is similar to that of both chub species. Diet studies showed that pallid sturgeon are known to consume sturgeon chub and sicklefin chub along with other species (Gerrity *et al.* 2006, p. 606) so increased numbers of pallid sturgeon in the system will inevitably increase interactions. Data has indicated that concentrations of chubs are in similar proximity to pallid sturgeon locations. Due to channelization, decreased habitat may increase interactions with predators. Native predators may have increased abundances due to the changes in habitat throughout the channelized segments of the Missouri River. In addition to pallid sturgeon as known predators, walleye (*Sander vitreus*), sauger (*Sander canadensis*), smallmouth bass (*Micropterus dolomieu*) and species of catfish have been known to consume these chub species (Rahel and Thel 2001, p. 26).

In the upper Missouri River, construction of large dam reservoirs has significantly changed historic habitat from a diverse turbid riverine system to a large clear water reservoir system along with clear cold-water releases from the dams. Clearer water is expected to make both chub species more visible to predators. Sturgeon chub and sicklefin chub are preyed upon by sauger in the Missouri River in Montana (Rahel and Thel 2001, p. 25). Sturgeon chub and sicklefin chub combined were the second most common food item in saugers collected from August to November 1980 in a reach of the river above Fort Peck Reservoir. They were found in 21 percent of the fish collected for stomach analysis. The stomach contents of sauger and burbot collected in the Yellowstone River were evaluated in 1975 and 1976 (Elser *et al.* 1977, pp. 122, 124). Sturgeon chub were found in the stomachs of the sauger (4.7 percent) and one burbot (7.7 percent) (Elser *et al.* 1977, pp. 122, 124). Habitat alterations from the implementation of mainstem reservoirs has improved habitat for some native and non-native predators such as walleye and smallmouth bass. Increased number of walleye and smallmouth bass in these systems have potentially increased interactions with chubs. Sampling in these areas have caught walleye and sauger in similar habitats as both chub species (Stakeholder Predation Meeting).

Overlap in habitat between pallid sturgeon and both chubs have been a concern to professionals in recent years. Recent literature has shown a decline in chub numbers where a large portion of pallid sturgeon have been stocked. This decline is potentially correlated to pallid stocking, but further research needs to occur to validate this concern. For this SSA we used occupancy modeling to address probability of occupancy for two of the three populations of sturgeon chub and both populations of sicklefin chub. Statistically, sturgeon chub and sicklefin chub occupancy has not changed throughout their range pre and post 2012. When looking at a population level, Population 1 for both sturgeon chub and sicklefin chub is showing a decreasing trend in occupancy post 2012. A large portion of hatchery raised pallid sturgeon were stocked in the same areas where we are seeing a decline in occupancy for both species (Braaten *et al.* 2021, pp. 23-24). Though we do not have research showing high predation in this area, it should be a location where further studies can be focused. Pallid sturgeon stocking has and will continue to decrease in recent/coming years (Braaten *et al.* 2021, p.17). Further research on this stretch focusing on predation is needed to look further into this stressor.

Sturgeon chub and sicklefin chub populations evolved with piscivorous fish in the Missouri River Basin and the Mississippi River. The best commercial and biological information available indicates that predation by piscivorous fish is currently happening but is not currently quantifiable and we do not know the scope of this impact. Future diet studies may help address this stressor and help identify individual level effects between each population of sturgeon chub and sicklefin chub. Currently it does not appear to be affecting the continued existence of the sturgeon chub and sicklefin chub in locations where turbidity levels and flow conditions are adequate to support their populations.

Hybridization

Hybridization of sturgeon chub and sicklefin chub is not a common occurrence. Studies have noted the presence of chub hybrids in collection from the Missouri River. One speckled chub/sturgeon chub and one sturgeon chub/sicklefin chub in a sample of 18,400 fish was collected near Easley, Missouri (river mile 177.3 to 169.9) in 1982 and 1983 (Grace and Pflieger 1985. p. 3). There were 18 reported speckled chub/sturgeon chub hybrids reported in collections made in 1994 (Gelwicks *et al*. 1996. p. 35). These hybrids that were collected were from the Iowa-Missouri border at the confluence of the Missouri and Mississippi rivers. Hybrids were also identified in the most recent genetics project that was conducted in 2021-2022. A total of 3 hybrids located in the Missouri River in North Dakota and Missouri were identified from over 400 samples collected (Heist *et al*. 2022. p. 2). It is worth noting that the 3 identified hybrids could have been a factor of poor sample quality or cross contamination. While hybrids have been documented we do not expect hybridization to be occurring in significant enough levels to impact sturgeon chub and sicklefin chub. This stressor appears to be affecting both chub species on a rare individual level and future monitoring could be beneficial.

Summary of Stressors

There are numerous potential stressors on the landscape acting on both chub species and their habitats. We focused on potential stressors that are currently impacting both chub species based on stakeholder input, scientific research, published literature, and technical reports. Most of the analyzed stressors have the potential to affect these species on multiple levels and some of the stressors have acted on the individual level and population level in the past. However, most of the analyzed stressors appear to have had larger effects, even some at the population level, historically, but currently these stressors are only likely affecting both chub species at the individual level.

The stressor with the largest historical effects on both chub species and their habitats is the construction and operation of the Missouri River mainstem dams. Mainstem dams and reservoirs have been present on the Missouri River for approximately 70 years and will most likely be on the landscape for the indefinite future. The short-lived nature of both chub species necessitates there have been dozens of generations of chubs since the construction of the dams. Any population level effects from the mainstem dams and associated habitat alterations would be expected to affect both chub species within the first few generations of chubs (i.e., 5-10 years). These initial, large magnitude effects largely contributed to and are incorporated into the current condition of both chub species. Thus, we do not expect large magnitude population-level effects on either chub species from the continued presence and operation of the Missouri River mainstem dams and reservoirs. However, we do expect ongoing effects to both chub species from the continued presence and operation of the dams, as well as other stressors, but at the individual level.

Climate change and the predicted effects to stream hydrology was one stressor that the scientific literature indicated the most potential for population-level effects to both chub species in the future. Thus, climate change was carried forward into the Future Conditions chapter and was the focus of analysis for potential effects to both chub species and their habitats.

Current Resiliency, Redundancy, and Representation

Resiliency

Resiliency is the ability of a species to withstand stochastic events and is often measured by metrics such as abundance, or the size and growth rate of populations. In this case, we did not have estimates of true abundance or population growth rates. However, we did have estimates of genetic effective population size, occupancy frequencies, and CPUA and CPUE (both of which are indexes to abundance) data from standardized benthic trawling surveys. Thus, we used these metrics to describe the genetic and demographic resiliency of both chub species across their ranges.

Effective population size (N_e) is a statistic often used to inform population and evolutionary viability (Kovach *et al.* 2019, pp. 3, 7, 8). Specifically, N_e is a critical parameter in conservation genetic theory that dictates the rate at which genetic variation is lost and inbreeding accumulates within a population (Franklin 1983, *entire*). In general, when N_e estimates are greater than 500, no genetic variation is being lost from the population due to adequate numbers of breeding adults passing on their genetics to many offspring. Estimates of N_e that fall between about 50 and 500 generally indicate some level of genetic variation being lost from the population, with slower rates of loss on the higher end of this range and faster rates of loss on the lower end of this range. Estimates of N_e less than 50 can be cause for concern because of the increased potential for inbreeding effects in the population. For these reasons, we categorized the resiliency condition for N_e as high if estimates were 500 or greater, moderate when the estimates were 50-499, and low if the estimates were less than 50 (Table 11).

Occupancy, CPUA and CPUE can help inform trends in relative abundance of both chub species. When these values increase through time, it is assumed that actual abundance in the population also has increased. When repeat sampling is done within a standardized, randomized sampling design, such as the PSPAP, inferences can be made about the status and trends of chub abundance. We used any trend data that was available and that was collected within a standardized, randomized sampling design. For assessing resiliency from the trend data, we categorized populations as highly resilient if there were stable or increasing trends in occupancy, CPUA and/or CPUE (Table 11). We categorized populations as moderately resilient if multiple contrasting (mixed) trends were present (Table 11). We categorized populations as having low resilience if solely declining trends were present (Table 11).

We also assessed the resiliency of populations of both chub species by using unfragmented stream length as a habitat metric. Unfragmented stream length is an important predictor of population status for fish species, like sturgeon chub and sicklefin chub, whose eggs and larvae drift in the water column while developing. Short stream fragments may not provide enough drift distance for full development of chub larvae. If larvae drift into a reservoir or still water habitat before they develop to horizontal swimming, it is presumed they settle to the bottom and experience high mortality (Dieterman and Galat 2004, p. 584; Albers and Wildhaber 2017, p. 15). Unfragmented stream habitat is also a surrogate for many of the abiotic conditions needed by chubs to complete their life history. Greater unfragmented stream lengths are more likely to contain turbidity levels, water temperatures, habitat diversity and flow regimes that more closely resemble historical conditions that favor chub population resilience.

Table 11. Resiliency condition category table.

Resiliency Condition Category	***Effective Population Size***	***Occupancy, CPUA, CPUE trends***	***Unfragmented stream length (rkm)***
HIGH	**>500**	**Increasing/stable**	**>297 rkm (sturgeon chub)** **>301 rkm (sicklefin chub)**
MODERATE	**51-499**	**Mixed**	**250 – 297 rkm (sturgeon chub)** **250 – 301 rkm (sicklefin chub)**
LOW	**<50**	**Declining**	**<250 rkm (both species)**

A minimum stream fragment length threshold of 297 rkm has been estimated for sturgeon chub to be able to meet their life history needs (Perkin and Gido 2011, p. 374). Populations residing in stream fragments >297 rkm are associated with population persistence, while those residing in stream fragments <297 rkm are associated with declining or extirpated population status (Perkin and Gido 2011, pp. 374-381). For resiliency of sturgeon chub populations, we categorized stream segments >297 rkm as high resilience, because of the association between segments of this length or longer and stable sturgeon chub populations (Table 11). We categorized stream segments from 250 rkm to 296 rkm as moderate resilience because this range includes lengths less than those associated with chub persistence, but above the 95% CI of those associated with extirpation (Perkin and Gido 2011, p. 378; Table 11). Stream segments less than 250 rkm were rated as having low resilience, as shown by extirpations of populations in stream segments of 250 rkm or less (Figure 2 in Perkin and Gido 2011, p. 378; Table 11).

Although minimum stream fragment length for sicklefin chub persistence has not been estimated, probability of sicklefin chub presence was highest in river segments that are at least 301 rkm downstream of a dam (Dieterman and Galat 2004, pp. 581, 584). While this metric was estimated using a different method than those derived for sturgeon chub by Perkin and Gido 2011, it is similar in that longer river segments retain the characteristics of more natural flow regimes, turbidity and water temperatures that are more representative of historical conditions; all factors that have been correlated with higher probabilities of chub occurrence and persistence. Given these similarities and the similarities between sturgeon chub and sicklefin chub life history, we find it reasonable to characterize resiliency as high for sicklefin chub populations with one or more sections of stream length greater than 301 rkm, those between 250 rkm and 301 rkm as having moderate resiliency, and those stream fragments less than 250 rkm as having low resiliency (Table 11).

Resiliency of all populations of sturgeon chubs and sicklefin chubs were ranked high for effective population size (Table 12). Effective population size estimates were greater than 500 for all populations and indicate ample numbers of breeding individuals to preclude any loss of genetic variation through time. We note that the effective population size estimates incorporate the effects of many of the potential stressors from a historical sense. Given that both chub species have short generation times, population level effects from stressors are expected to be manifested within the populations relatively quickly. While estimates of effective population size are a “snapshot in time”, they do incorporate effects from historical stressors acting at the population level. Given the amount of habitat fragmentation that occurred historically, the presence of robust genetic effective population estimates despite that level of fragmentation, is encouraging and indicative of higher resilience.

Resiliency of sturgeon chub populations relative to our trend data (Occupancy, CPUA, CPUE) was mixed. We observed declining occupancy and CPUA, but stable to increasing CPUE within different segments of Population 1. Therefore, we categorized resiliency as moderate for Population 1 (Table 12). We had stable trend information on Population 2, thus resiliency is high (Table 12). Resiliency of Population 3 was ranked high for trend information, due to increasing occupancy through time (Table 12). Resiliency of Population 1 of sicklefin chubs was ranked moderate, due to stable occupancy, but mixed trends in relative abundance. Resiliency of Population 2 of sicklefin chubs was ranked high, due to stable trends in both occupancy and relative abundance through time.

Resiliency of all populations for both chub species were ranked high when considering unfragmented stream length (Table 12). All populations of both species occupy habitats with one or greater stream fragments meeting or exceeding the minimum thresholds estimated in the scientific literature (e.g., >297 rkm for sturgeon chubs and >301 rkm for sicklefin chubs) to support chub persistence (Tables 13 and 12). The lower Missouri River and parts of the

Mississippi River provide primarily one long stream fragment for Population 3 of sturgeon chubs and Population 2 of sicklefin chubs. While this reach of river is considered a single stream fragment, the entire length could be delineated into multiple reaches for either chub species that met or exceeded the minimum thresholds.

We note that there are portions of both sturgeon chub and sicklefin chub populations that are self-sustaining in stream fragments shorter than 297 rkm and 301 rkm, respectively. For sturgeon chub, the portion of Population 1 occurring in the Bighorn River and for both chub species occurring in the Missouri River/Lower Marias River above Fort Peck Reservoir are examples of self-sustaining portions of populations in stream segments less than the minimum estimated stream lengths needed for population viability (Table 13). While stream fragment thresholds are useful guidelines and were helpful for our resiliency analysis, we note that factors such as velocity, channel morphology, water temperature and habitat heterogeneity are present in sufficient quantity and arrangement in some systems to reduce the amount of unfragmented stream length necessary for both chub species to fulfill their life history requirements.

Table 12. Current condition resiliency analysis.

Species	**Population**	***Effective Population Size***	***Occupancy, CPUA, CPUE trends***	***Unfragmented Stream Length (rkm)***
Sturgeon Chub	1	**High**	**Moderate**	**High**
	2	**High**	**High**	**High**
	3	**High**	**High**	**High**
Sicklefin Chub	1	**High**	**Moderate**	**High**
	2	**High**	**High**	**High**

Table 13. Sturgeon chub unfragmented stream length drift distances.

Population	**Segment**	**Location**	**River Kilometers (River Miles)**
1	1-1	Marias River to Fort Peck Lake	285 (177)
	1-2	Missouri River to Fort Peck Lake	285 (177)
	2-1	Bighorn River to Bighorn Lake	102 (63)
	3-1	Missouri River from Fort Peck Dam to Lake Sakakawea	360 (224)
	3-2	Milk River to Lake Sakakawea	462 (287)
	3-3	Yellowstone River to Lake Sakakawea	360 (224)

	3-4	Tongue River to Lake Sakakawea	685 (426)
	3-5	Powder River to Lake Sakakawea	956 (596)
2	1-1	Cheyenne River to Lake Oahe	299 (186)
	2-1	White River to Lake Francis Case	564 (351)
	2-2	Pass Creek to White River to Lake Francis Case	403 (250)
	2-3	Little White River to White River to Lake Francis Case	228 (142)
3	1-1	Gavins Point Dam to Mississippi River near Memphis, TN	2193 (1363)
	1-2	Kansas River to Mississippi River near Memphis, TN	1575 (979)
	1-3	Osage River to Mississippi River near Memphis, TN	1130 (702)

Table 14. Sicklefin chub unfragmented stream lengths drift distances.

Population	**Segment**	**Location**	**River Kilometers (River Miles)**
1	1-1	Marias River to Fort Peck Lake	285 (177)
	1-2	Missouri River to Fort Peck Lake	285 (177)
	1-3	Missouri River from Fort Peck Dam to Lake Sakakawea	360 (224)
	1-4	Milk River to Lake Sakakawea	353 (219)
	1-5	Yellowstone River to Lake Sakakawea	320 (199)
2	1-1	Gavins Point Dam to Mississippi River near Baton Rouge, LA	3097 (1924)
	1-2	Platte River to Mississippi River near Baton Rouge, LA	2889 (1795)
	1-3	Kansas River to Mississippi River near Baton Rouge, LA	2480 (1541)
	1-4	Osage River to Mississippi River near Baton Rouge, LA	2038 (1266)

Redundancy

Redundancy describes the ability of a species to withstand catastrophic events and is often measured by the number of populations, their resiliency, and their distribution and connectivity across the landscape. For this SSA, we used these factors to describe redundancy of the populations of chubs defined in the range-wide genetic assessment.

Three populations of sturgeon chub were identified in the range-wide genetic assessment (Heist *et al*. 2022, pp. 3-5). Each population resides in a large geographic area and is separated from the other populations by mainstem dams on the Missouri River and associated reservoir habitat. It is unclear if sturgeon chubs move downstream through the reservoir habitats and dams to interact with downstream populations, but no upstream interaction among populations is expected due to the lack of upstream fish passage at all hydroelectric dams on the mainstem Missouri River.

The current number and distribution of sturgeon chub populations increases the redundancy of the species in several ways. First, three populations of sturgeon chubs increases the probability the species can persist in the face of a catastrophic event, relative to if there were fewer populations. Risk of extirpation from catastrophic events is reduced as the number of populations increases. Second, the three populations are distributed across a wide range and are physically separated from one another by primarily dams on the mainstem Missouri River and associated reservoir habitat. This physical separation among the three populations reduces the probability of a catastrophic event affecting all three populations simultaneously.

Two populations of sicklefin chubs were identified in the range-wide genetic assessment (Heist *et al*. 2022, p. 6). Each population resides in a large geographic area and is separated from the other population by mainstem dams on the Missouri River and associated reservoir habitat. It is unclear if sicklefin chubs move downstream through the reservoir habitats and dams to interact with downstream populations, but no upstream interaction among populations is expected due to the lack of upstream fish passage at all hydroelectric dams on the mainstem Missouri River.

The current number and distribution of sicklefin chub populations increases the redundancy of the species in several ways. First, two populations of sicklefin chub increases the probability that the species can persist in the face of a catastrophic event, relative to if there were fewer populations. Risk of extirpation from catastrophic events is reduced as the number of populations increases. Second, the two populations are distributed across a wide range and are physically separated from one another by primarily dams on the mainstem Missouri River and associated reservoir habitat. This physical separation among the two populations reduces the probability of a catastrophic event affecting all three populations simultaneously.

Within populations, there is also redundancy among occupied stream segments. The distribution of occupied stream segments within populations also increases the margin of safety against a catastrophic event for both chub species. For example, a catastrophic event affecting chubs in the mainstem Missouri River above Fort Peck Reservoir would not be expected to also affect occupied reaches of the Yellowstone River because of the large distance between the two occupied stream reaches and their independence due to the dendritic pattern of the Missouri River watershed.

Representation

Representation describes the ability of a species to adapt to changing environmental conditions and is often measured by the breadth of genetic or environmental diversity within and among populations. In this section, we rely on both genetic and environmental diversity to describe representation of both chub species.

In the Chub Range-Wide Genetic Assessment, estimates of genetic variation were precluded by poor tissue and DNA quality in some samples for both species. However, several lines of indirect evidence indicate that genetic variation is likely high. First, effective population sizes for all chub populations for both species were greater than 500; a level at which loss of adaptive variation is not expected. In general, populations where effective population sizes consistently remain over 500 are expected to have higher genetic variation relative to those less than 500, due to the gradual loss of that variation through time when effective population sizes decrease to less than approximately 500 (Frankham et al. 2014, entire). Second, relative measures of genetic diversity were high, compared to other, similar species (Kovach 2022, pers. comm.). Given these lines of evidence, it appears genetic variation in both chub species is high, along with the future adaptive potential that the genetic variation represents.

While declines in distribution from historical levels for both chub species are well documented, both species still occupy representative portions of their historical range (53% for sturgeon chub and 75% for sicklefin chub) where suitable habitat remains.

Chapter 4: Future Condition

In this chapter, we describe the methods used to project the condition of sturgeon chub and sicklefin chub populations in the future. We outline our rationale for the methods we chose and address uncertainty in our projections. The results are then summarized in the terms of resiliency, redundancy, and representation.

Numerous potential stressors to sturgeon chubs and sicklefin chubs were discussed in the Current Condition chapter of this SSA. Habitat fragmentation and associated habitat changes (e.g., reduced stream fragment length, decreased turbidity, altered flow regimes) from mainstem Missouri River dams were the primary stressors contributing to the current condition of both chub species and reduced distribution relative to historical distribution. However, when looking to the future, we have no indication that the construction of additional dams, the demolition of existing dams, or major differences in dam operations are likely to occur. Similarly, we have no information to indicate that most of the other potential stressors identified in the Current Condition chapter are going to change in the future at levels meaningful to the persistence of both chub species. However, the one stressor that we do have information on and reason to believe that it could act at a frequency and scale to potentially affect chub populations is climate change. Thus, we focus our future conditions analysis on the predicted effects of climate change to chub habitat and populations, under multiple emissions scenarios, out to mid-century.

The terms “climate” and “climate change” are defined by the Intergovernmental Panel on Climate Change (IPCC). The term “climate” refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2014, pp. 119–120). The term “climate change” thus refers to a change in the mean or variability of one or more measures of climate (e.g., temperature or precipitation) that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2014, p. 120).

Scientific measurements spanning several decades demonstrate that changes in climate are occurring; since the 1950s many of the observed changes are unprecedented over decades to millennia (IPCC 2014, p. 40). Examples include warming of the global climate system, and substantial increases in precipitation in some regions of the world and decreases in other regions. (For these and other examples, see IPCC 2014, pp. 40–44; and Solomon *et al*. 2007, pp. 35–54, 82–85). Results of scientific analyses presented by the IPCC show that most of the observed increase in global average temperature since the mid-20th century cannot be explained by natural variability in climate, and is "extremely likely" (defined by the IPCC as 95 percent or higher probability) due to the observed increase in greenhouse gas (GHG) concentrations in the atmosphere as a result of human activities, particularly carbon dioxide emissions from use of fossil fuels (IPCC 2014, p. 48 and figures 1.9 and 1.10; Solomon *et al*. 2007, pp. 21–35).

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of GHG emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions (e.g., Meehl *et al*. 2007, *entire*; Ganguly *et al*. 2009, pp. 11555, 15558; Prinn *et al*. 2011, pp. 527, 529). All combinations of models and emissions scenarios yield very similar projections of increases in the most common measure of climate change, average global surface temperature (commonly known as global warming), until about 2050 (IPCC 2014, p. 11; Ray *et al.* 2010, p. 11). Although projections of the magnitude and rate of warming differ after about 2050, the overall trajectory of all the projections is one of increased global warming through the end of this century, even for the projections based on scenarios that assume that GHG emissions will stabilize or decline. Thus, there is strong scientific support for projections that warming will continue through the 21st century, and that the magnitude and rate of change will be influenced substantially by the extent of GHG emissions (IPCC 2014, p. 57; Meehl *et al*. 2007, pp. 760–764 and 797–811; Ganguly *et al*. 2009, pp. 15555–15558; Prinn *et al*. 2011, pp. 527, 529). (See IPCC 2014, pp. 9–13, for a summary of other global projections of climate-related changes, such as frequency of heat waves and changes in precipitation.)

Various changes in climate may have direct or indirect effects on species. These effects may be positive, neutral, or negative, and they may change over time, depending on the species and other relevant considerations, such as interactions of climate with other variables (IPCC 2014, pp. 6–7; 10–14). Identifying likely effects often involves aspects of climate change vulnerability analysis. Vulnerability refers to the degree to which a species (or system) is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the type, magnitude, and rate of climate change and variation to which a species is exposed, its sensitivity, and its adaptive capacity (IPCC 2014, pp. 70, 72; see also Glick *et al.* 2011, pp. 19–22). There is no single method for conducting such analyses that applies to all situations (Glick *et al.* 2011, p. 3). We use our expert judgment and appropriate analytical approaches to weigh relevant information, including uncertainty, in our consideration of various aspects of climate change.

Any model (representation of something) carries with it some level of uncertainty. Consequently, there is uncertainty in climate projections and related impacts across and within different regions of the world (e.g., Glick *et al.* 2011, pp. 68–73; Deser *et al.* 2012, *entire*; International Panel on Climate Change (IPCC) 2014, pp. 12-14). This uncertainty can come from multiple sources, including type, amount, and quality of evidence, changing likelihoods of diverse outcomes, ambiguously defined concepts or terminology, or human behavior (IPCC 2014, pp. 37, 56, 58, 128). Methods developed to convey uncertainty in climate projections include quantifying uncertainty (IPCC 2014, p. 2) or analyzing for trends among climate projections (IPCC 2014, pp. 8, 10). Also, uncertainty in climate projections can be reduced by using more regionalized data to produce higher resolution, more accurate climate projections (Glick *et al.* 2011, pp. 58–61). This uncertainty was considered in this analysis. We note that despite the inherent uncertainties associated with climate models/projections, empirical data are used to develop climate models. These models and their associated projections often constitute the best available science, in the absence of other relevant information.

Stream hydrology is sensitive to climate change and influences many of the basic physical and biological processes in aquatic systems. Stream hydrology not only affects the structure of aquatic systems across space and time, but influences the life history and phenology (timing of life-cycle events) of aquatic organisms such as fishes. For example, the timing of snowmelt runoff can be an environmental cue that triggers spawning migrations in fishes (Brenkman *et al.* 2001, pp. 981, 984), and the timing of floods relative to spawning and emergence can affect population establishment and persistence (Fausch *et al.* 2001, pp. 1438, 1450).

Climate-induced changes to the hydrology of the rivers and stream occupied by sturgeon chubs and sicklefin chubs are predicted in the future. A consistent pattern in the scientific literature includes changes to mean annual discharge in rivers and streams across the range of both chub species. Change in mean annual discharge has been correlated with chub distribution and abundance, with more extirpations of pelagic-spawning fish communities (which include sturgeon chub and sicklefin chub) with decreasing stream discharge (Perkin *et al.* 2010, pp. 8-9). Mean annual changes in discharge under varying climate scenarios have been modelled across much of the range of chubs and provide a reasonable way to assess future conditions of chub populations given a changing climate. Thus, the focus of our analysis is investigating the potential effects of measured and predicted changes in mean annual discharge on the resiliency, redundancy, and representation of both chub species.

We investigated the potential effects of predicted changes in mean annual discharge in several ways. First, we used future discharge predictions from across the spectrum of climate change emissions scenarios to explore uncertainty among models and emissions scenarios. Temporally, we limited our use of future discharge predictions to those extending to approximately mid-century (i.e., 2040-2069); predictions beyond that were deemed too speculative. Second, we looked at the predicted direction of change for stream discharge across the range of both chub species to explore where mean annual discharge was predicted to increase, decrease, or remain stable. Third, we investigated the magnitude of the predicted change in discharge to better understand how that may affect both chub species and their habitat. Fourth, we explored the timing and frequency aspects of predicted changes in mean annual discharge, namely patterns in annual discharge and frequency of extreme flows (both high and low). Finally, we summarized the potential effects of these predicted changes in mean annual discharge on the resiliency metrics (N_e, occupancy, and unfragmented stream length) that we defined in the Current Condition chapter.

Predictions for change in mean annual discharge were relatively consistent across the spectrum of climate change models and emissions scenarios at mid-century (Table 15). Mean annual discharge is predicted to increase across the range of both chub species by mid-century, relative to historical levels, in all future climate simulations and at all modelled locations, except for the Platte River (Table 15). The magnitude of predicted discharge increases varied across the range of both chub species (Table 15), but was estimated in the low single digits for most sections of chub habitat, with the exception of the Powder River in Wyoming and Montana, where predicted increases in discharge were larger (Table 15).

Analysis of annual variation in timing of discharge changes also revealed several patterns among stream sections across the range of both chub species. In general, annual peak discharge was predicted to occur earlier in the season, relative to historical timing (Lohmann *et al*. 1996, *entire*; Mote *et al*. 2014, *entire*; Hegewisch *et al*. 2015, *entire*; Perkin *et al*. 2010, pp. 9-14). Following peak discharge, the base flow period was predicted to occur earlier as well, with low flows predicted to be lower than during the historical low flow period (Lohmann *et al*. 1996, *entire*; Mote *et al.* 2014, *entire*; Hegewisch *et al*. 2015, *entire*; Perkin *et al*. 2010, pp. 9-14)

The frequency of extreme flows (high and low) is also predicted to increase, in concert with the other aspects of increasing mean annual flows. More extreme weather patterns including extreme precipitation are expected to produce higher frequencies of flooding, as well as longer periods of drought and associated low flow conditions.

Effects of increases in future mean annual discharge are expected to be mixed for both chub species. Change in mean annual discharge has been shown to be correlated with chub distribution and abundance, with more extirpations of pelagic-spawning fish communities (which include sturgeon chub and sicklefin chub) with decreasing stream discharge (Perkin *et al*. 2010, pp. 8-9). Thus, increases in mean annual discharge may be beneficial for both chub species. Similarly, increased variability of flows may also be beneficial to both chub species because higher frequencies of occupancy for sicklefin chub were associated with more variable flows in the heavily regulated Missouri River (Pegg and Pierce 2002, p. 156; Dieterman and Galat 2004, pp. 581-582). However, peak flows occurring earlier in the season may be detrimental to chub species, as this may alter the combination of environmental variables that provide spawning cues (e.g., warming water temperatures, increasing flows, changes in turbidity, etc.). However, we note that both chub species possess the favorable life history trait of batch spawning (capable of having multiple spawns every year), which may provide a hedge, at least in part, against environmental stochasticity and associated disruptions to timing and frequency of discharge as a result of climate change.

The predicted effects of increased frequency of extreme flows on both chub species are also mixed. While increased frequency of high flow flooding events is likely to occur, the effect of this on both chub species is expected to be small. Both chub species evolved in stochastic prairie river environments and have experienced a wide range of flooding frequencies through time. Although this frequency is expected to increase in the future, both chub species appear to be relatively resilient to these events, based on their continued persistence through time living in dynamic river environments. However, we expect that the pattern of lower base flows in the future, relative to historic levels, will affect both chub species more than the high flow periods.

Table 15. Predicted changes in future stream discharge across the range of both chub species and multiple climate models/emissions scenarios.

Population	Species	Waterbody	Section	Predicted Discharge Direction/Magnitude (% change from historical)	Global Climate Model	Emissions Scenario	Future Time Period	Literature
1	STCH, SFCH	Missouri River[a]	Fort Peck Reservoir to Lake Sakakawea	+3.5%	20C3M	12 climate scenarios	2041-2060	Perkin *et al*. 2010
1	STCH, SFCH	Yellowstone River	Cartersville Dam to Intake Dam	+5.1%	20C3M	12 climate scenarios	2041-2060	Perkin *et al*. 2010
1	STCH	Powder River	Near confluence with Yellowstone River	+18.1%	CMIP5	RCP 4.5	2040-2069	Lohmann *et al*. 1996; Mote *et al*. 2014; Hegewisch *et al*. 2015
1	STCH	Powder River	Near confluence with Yellowstone River	+16.1%	CMIP5	RCP 8.5	2040-2069	Lohmann *et al*. 1996; Mote *et al*. 2014; Hegewisch *et al*. 2015
2	STCH	Cheyenne River	Angostura Dam to Lake Oahe	+3.5%	20C3M	12 climate scenarios	2041-2060	Perkin *et al*. 2010
2	STCH	White River	Mainstem	+1.7%	20C3M	12 climate scenarios	2041-2060	Perkin *et al*. 2010
2	SFCH	Platte River	Elm Creek, NE to Columbus, NE	-3.3%	20C3M	12 climate scenarios	2041-2060	Perkin *et al*. 2010
3	STCH	Missouri River	Between Boonville and St. Charles, MO	+3.5%			2040-2069	Qiao *et al*. 2014
2	SFCH	Missouri River	Between Boonville and St. Charles, MO	+3.5%			2040-2069	Qiao *et al*. 2014
3	STCH	Missisippi River	Between confluence of Missouri and Ohio rivers	+	CMIP5			Lewis *et al*. 2023
2	SFCH	Missisippi River	Between confluence of Missouri and Ohio rivers	+	CMIP5			Lewis *et al*. 2023
3	SFCH	Missisippi River	Near Vicksburg, MS	+	CMIP5			Lewis *et al*. 2023

[a] Missouri River was mislabeled as the Yellowstone River in Perkin *et al*. 2010.

Decreases in discharge during the base flow period may result in reducing available habitat, connectivity, and access to potential refugia for both chub species. Lower base flows are more of a concern in secondary tributaries than in the mainstem Yellowstone, Missouri, and Mississippi rivers. While amount or quality of habitat can be reduced in the mainstem portions of these rivers, historical observations of chub distributions (particularly sturgeon chubs) indicate range contractions in many of the secondary tributaries to the larger, mainstem rivers. For example, sturgeon chubs historically occurred in the Little Missouri River, but were extirpated in 1997, presumably due to segments of the river drying up during drought years. Other tributaries across the range of sturgeon chub have also exhibited the pattern of widespread historical occupancy, followed by retractions in distribution through time. While reductions in range cannot solely be attributed to changes in discharge, it likely played a key role.

Resiliency

Effects to resiliency of both chub species from predicted changes to mean annual discharge in the future are mixed. Increases to mean annual discharge may be favorable to chubs, given the observed negative correlation between chub persistence and decreasing stream discharge. However, decreased flows during the base flow period may be negative to both chub species, particularly for those populations inhabiting tributaries. Past trends in chub distribution, and particularly for sturgeon chub, indicate the largest range retractions in the secondary tributaries. These habitats are expected to have the highest probability of habitat effects (e.g., low flows, potential dewatering) into the future. Therefore, Populations 1 and 2 of sturgeon chub may be more affected by the effects of climate change than Population 3 or either sicklefin chub population. In populations 1 and 2 of sturgeon chubs, N_e and occupancy may be expected to decrease, due to the greater amount of total occupied habitat occurring within secondary tributaries (Table 16). However, if declines in these metrics are observed in the future, the magnitude of potential declines is expected to be small. Regardless of impacts to secondary tributaries, Population 1 of sturgeon chubs is still expected to have multiple mainstem and larger tributary habitats (e.g., Yellowstone River) longer than the stream length threshold of 297 rkm. Population 2 of sturgeon chub is not expected to have mainstem Missouri river habitat (same as Current Condition), but is expected to maintain multiple reaches of tributary habitat longer than 297 rkm because of the large size of the watershed and no empirical observations of dewatered reaches even under recent, intense, and lasting drought. Thus, populations 1 and 2 for sturgeon chub are predicted to have slightly decreased resiliency (but the same resiliency rankings) as current condition under expected future changes to hydrology due to climate change (Table 16). The future resiliency of both populations of sicklefin chubs is expected to remain the same as current condition because both populations occupy mainstem habitats that are expected to be more climate resilient than tributary habitats. Mainstem habitats are expected to have more consistent flow even in the future due to the moderating effects of mainstem reservoir storage and water releases. We note that both chub species have advantageous life history traits of having evolved in stochastic environments and the ability to batch spawn multiple times a season, which affords these species resiliency in the face of some potential changes.

Redundancy

Redundancy is not expected to appreciably change at the population level for both species under future predicted changes to mean annual discharge. While some changes to resiliency may be expected due to predicted disproportionate climate impacts on secondary tributaries relative to mainstem habitats, we do not expect any of the populations of either species to become extirpated or reduce the current redundancy of the species.

Representation

Declines in N_e in Populations 1 and 2 for sturgeon chub could result in declines in genetic variation, if N_e were to decline and remain less than 500 for multiple generations in the future. However, current N_e estimates are robust and any potential decline in the future may not be detectable at the population level, unless the decline was of very large magnitude. We are not expecting declines in N_e for either sicklefin chub population because the species mainly occupies mainstem habitats that are expected to have relatively consistent flow in the future, even under the most dire climate change scenarios. We do not expect such a large effect on the representation of either chub species because multiple tributary and mainstem habitat segments are expected to remain in the future. In addition, some of the effects of climate change on mainstem chub habitats are expected to be buffered by the Missouri River reservoir system, because the system was designed to increase the consistency of flows throughout the year, by storing water in reservoirs during wetter periods and releasing water from the reservoirs during drier periods. In short, both chub species are expected to remain in representative habitats across portions of their range in the future.

Table 16. Future conditions analysis.

Species	**Population**	**Genetic and Demographic Factors**		**Habitat Factors**	
		Effective Population Size	***Occupancy, CPUA, CPUE trends***	***% secondary tributary habitat***	***Unfragmented Stream Length (rkm)***
Sturgeon Chub	1	**High**	**Moderate**	**56**	**High**
	2	**High**	**High**	**100**	**High**
	3	**High**	**High**	**5**	**High**
Sicklefin Chub	1	**High**	**Moderate**	**1**	**High**
	2	**High**	**High**	**7**	**High**

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Appendix

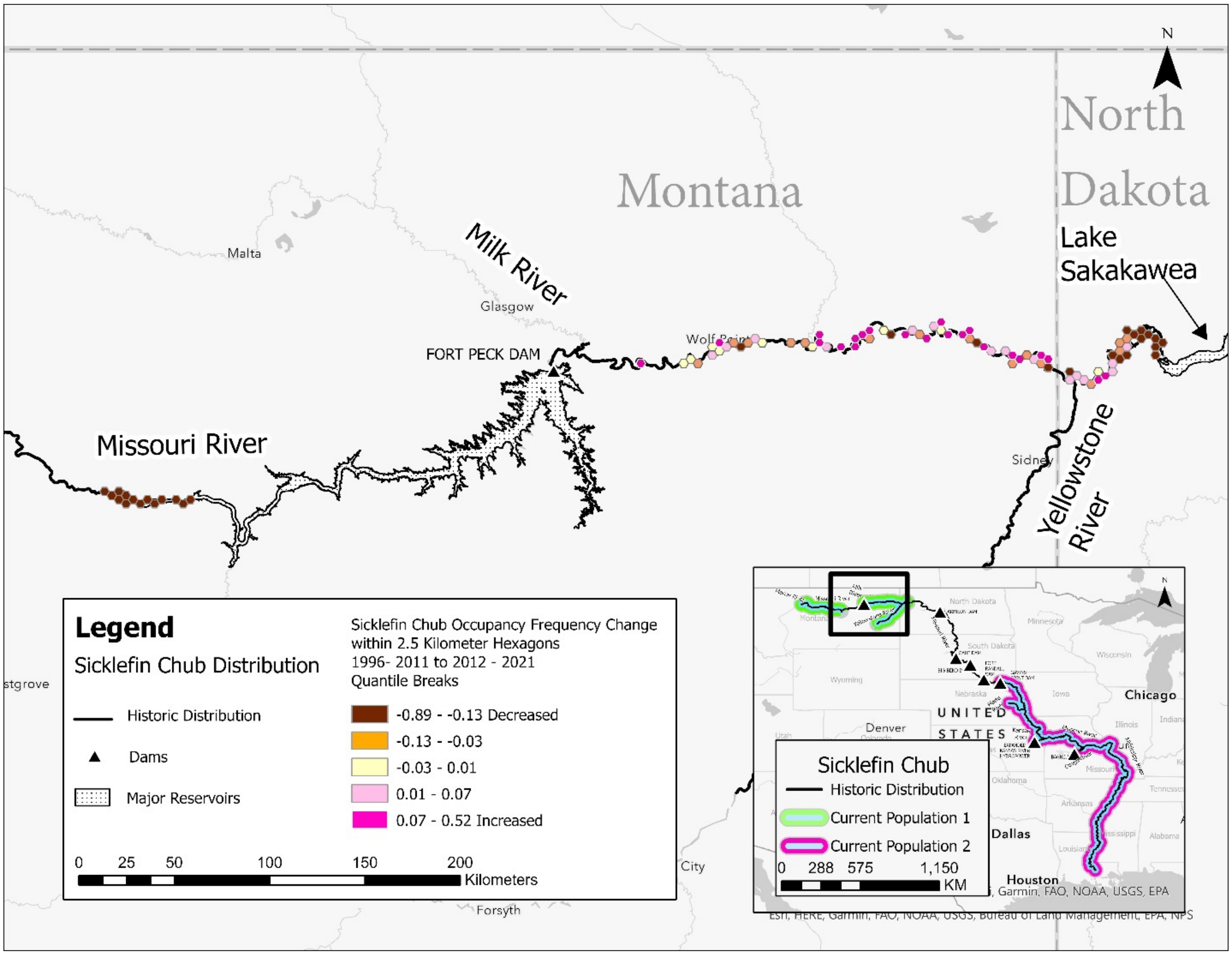

Figure 20. Sicklefin Chub Occupancy Frequency Change 1996-2011 to 2012-2021, Population 1.

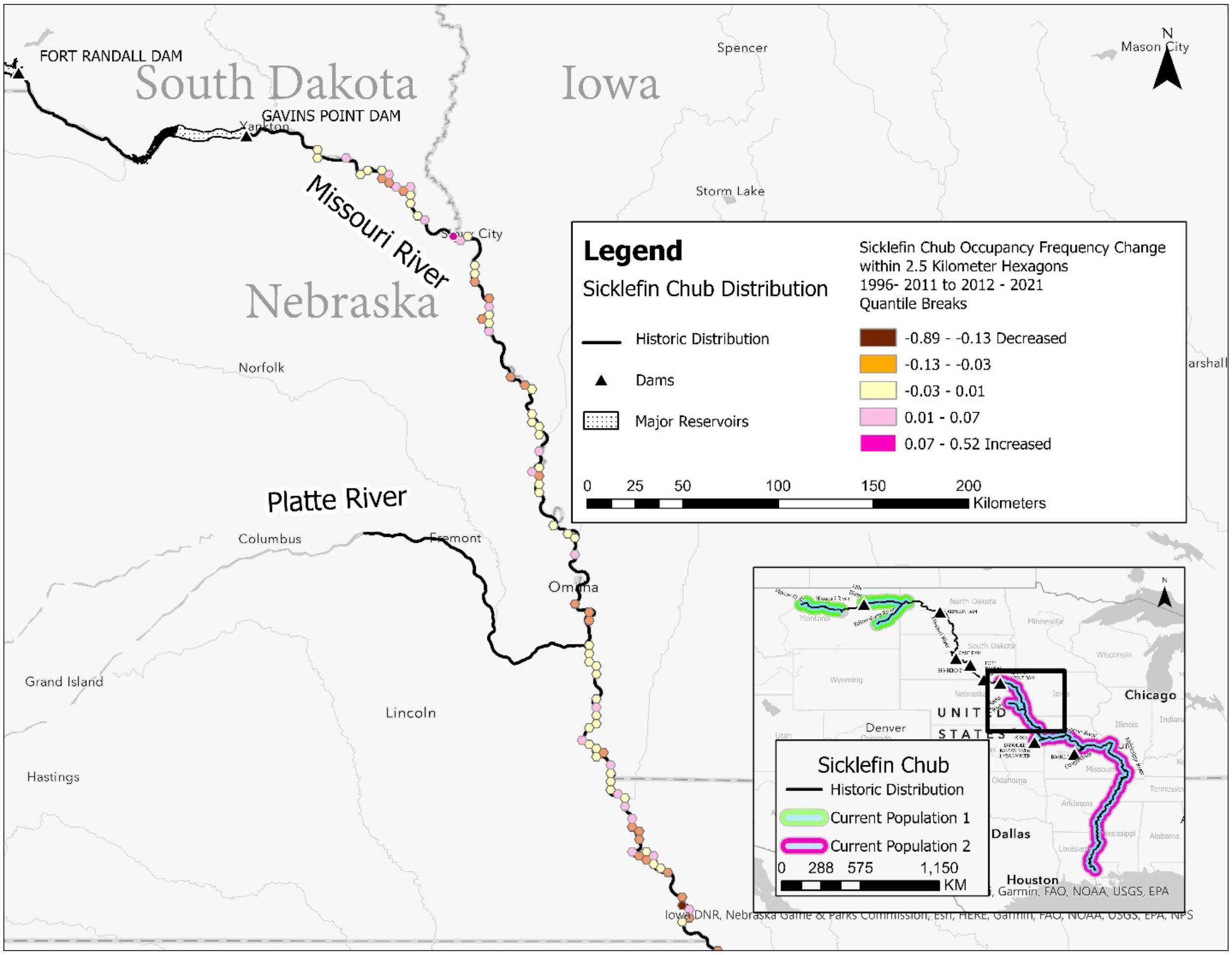

Figure 21. Sicklefin Chub Occupancy Frequency Change 1996-2011 to 2012-2021, Population 2.

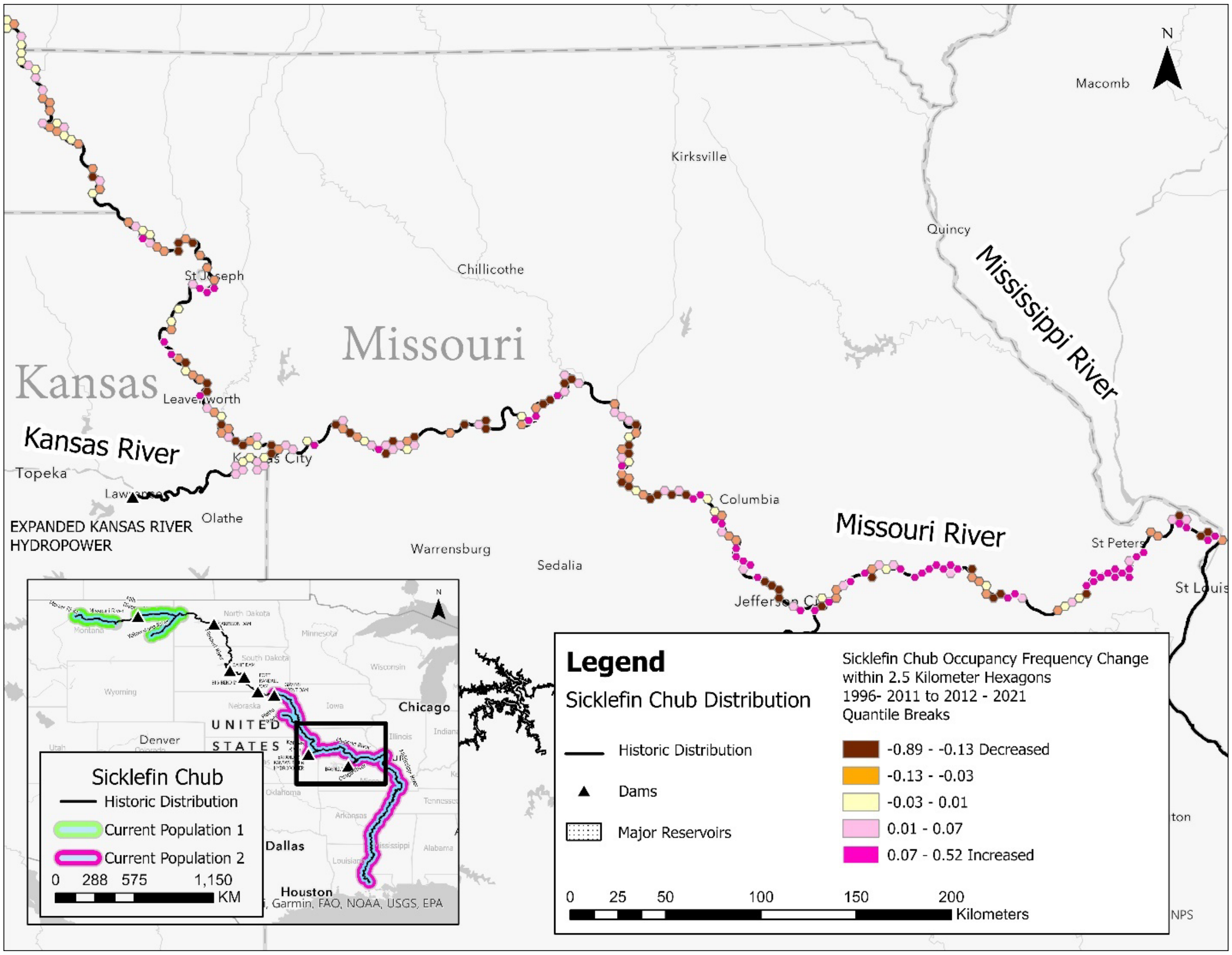

Figure 22. Sicklefin Chub Occupancy Frequency Change 1996-2011 to 2012-2021, Population 2.

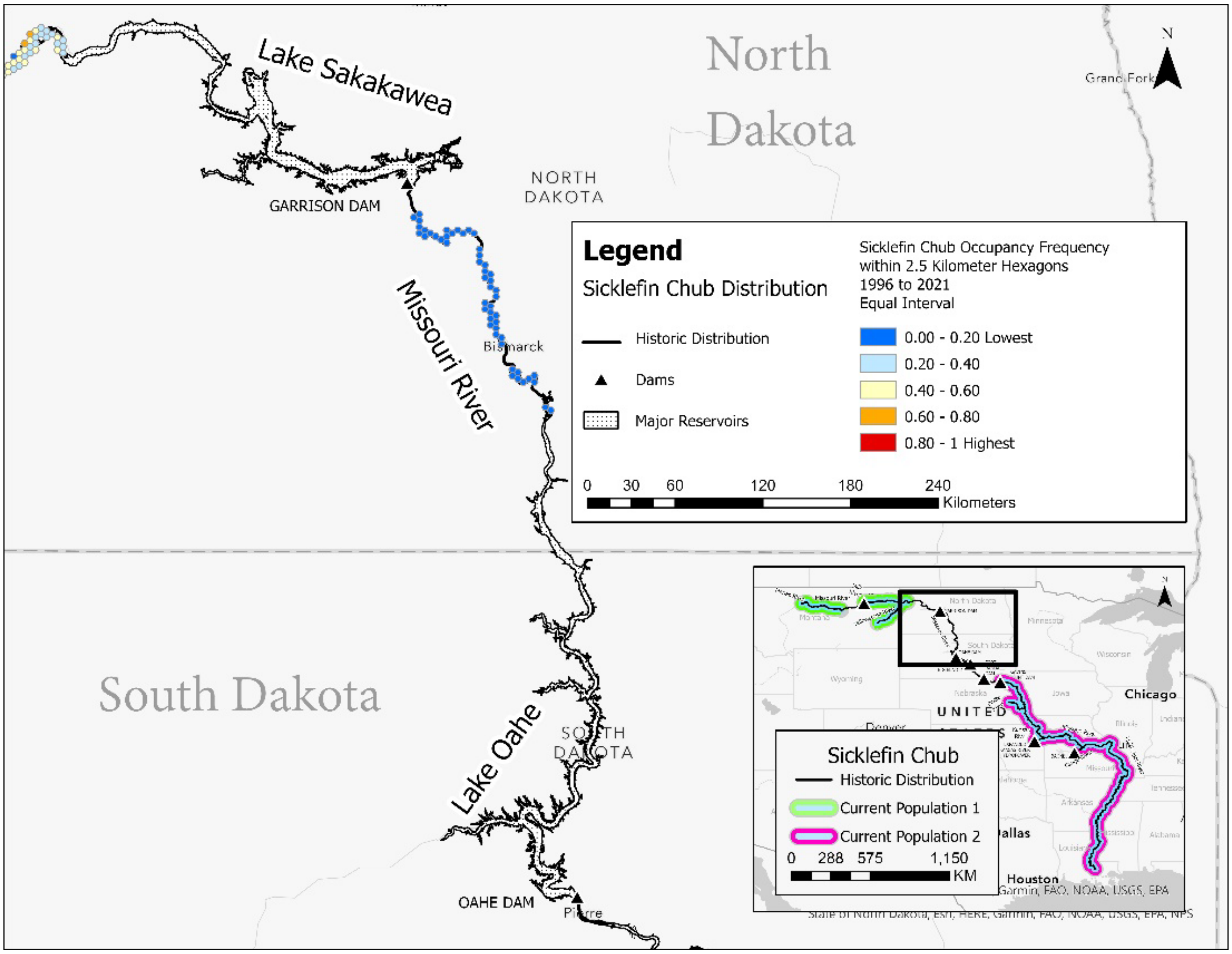

Figure 23. Sicklefin Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 1.

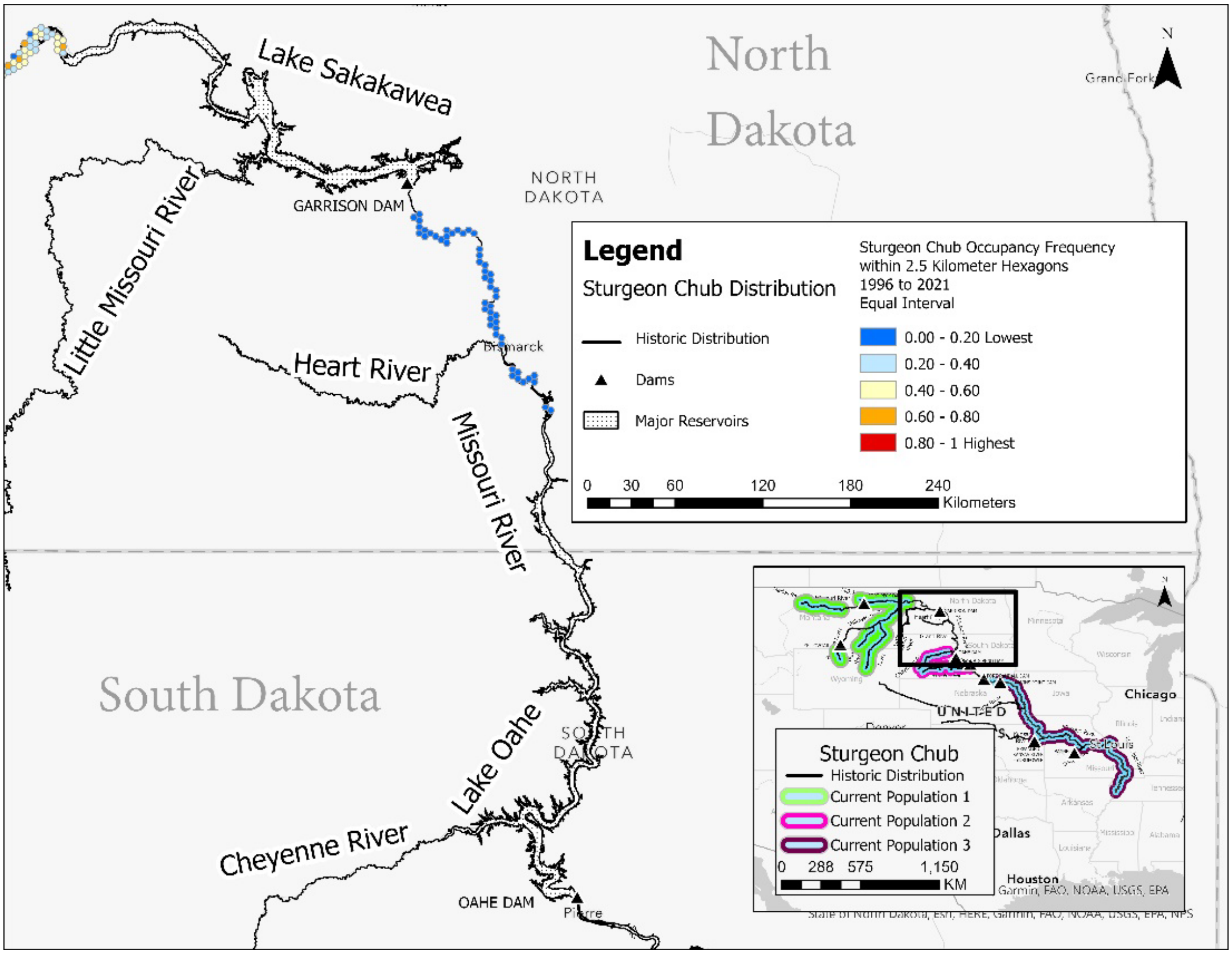

Figure 24. Sturgeon Chub Occupancy Frequency Change Equal Interval 1996-2021, Population 1.

Table 179. Master list of stressors that were considered for current condition. The most relevant stressors were discussed in current condition.

Factor	Source	Type	Stressor
A- Present or threatened destruction, modification, or curtailment of habitat or range	**Dams**	hydroelectric lowhead	Fragmentation Water Management/Reservoir Operations Impingement/Entrainment Larval settling
	Power intakes		Impingement/Entrainment
	Channel modification	maintenance	Bank stabilization
		dredging	Channelization
		dredging	Dredge material disposal
		mining	gravel harvest
	Climate change/Drought/Extreme weather		Air temperatures Extreme variability temps/flows Water depletions Fragmentation/Connectivity to refugia
	Transportation	Road culverts/crossings	Fragmentation
	Coal bed methane production		Water depletions
B- Overutilization for commercial, recreational, scientific or educational purposes	**Exploitation**		Baitfish collections

C- Disease or predation	**Disease**		Disease
	Predators	Nonnatives Pallid sturgeon	Competition/predation predation
D- Inadequate regulatory mechanisms	**Inadequate regulatory mechanisms**		
E- Other natural or manmade factors affecting the continued existence	**Presence of hybridizing species**	speckled chub	Hybridization
	Anthropogenic substances	endocrine disrupting compounds sugar beet factory discharge selenium neonictinoids 6PPD from tires plastic microbeads heavy metals baseline contaminants	Pollution/contamination
	Invasive/Nonnative species		Competition/Predation
	Barge traffic		Pressure waves fleeting entrainment
	Hydrokinetic facilities		entrainment/impingement

Table 1810. Data set in Occupancy Analysis.

Data Source (Project Name)	Years	Number of Sampling Events
Lower Mississippi River 2000's	2005-2008	139
Lower Mississippi River 2010's	2010, 2014, 2021	51
Benthic Fishes	1996-1998	1,037
Chub Genetics	2020	20
Chute Study Mitigation Project	2005-2008	2,373
Habitat Assessment Project	2005-2009, 2014-2021	38,642
Lake Sturgeon Reproduction Project	2015	35
Larval Study	2014-2016	644
Pallid Study	2017-2020	994
Pallid Sturgeon Population Assessment Program	2003-2021	42,932
Sapphire Targets Project	2014, 2017-2019	26
State of Montana Data	1998, 1999, 2001-2017	1,929