Pallid Sturgeon Literature Review

Final Report to the

Platte River Recovery Implementation Program

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INTRODUCTION

Literature on pallid sturgeon (*Scaphirhynchus albus*) has been summarized in several publications and reports (Bailey and Cross 1954; Duffy et al. 1996). In addition a draft of an annotated bibliography (Through 2003) was produced (U.S. Fish and Wildlife Service 2004) as background material for the Research and Assessment Needs for Pallid Sturgeon Recovery in the Missouri River meeting in Bloomington, MN, May 18-20, 2004 (Quist et al. 2004). Since that time a considerable number of studies and their publications have added significantly to the knowledge relevant to the aim of recovering the populations of pallid sturgeon. The literature examined for this review is listed in the literature cited section. In addition we have acquired a set of PDF files of this literature. These files are cross referenced with the literature citations in Appendix 1.

The goal of this review is to organize this expanding information base and to point out the relevance of individual reports and publications to the hypotheses for pallid sturgeon proposed by the Platte River Recovery Implementation Program (PRRIP). In addition, this review notes apparent gaps in the knowledge base for pallid sturgeon and points out several opportunities for studies in the lower Platte River that could interface with on-going or proposed projects elsewhere in the range of the pallid sturgeon.

The three general hypotheses developed by the PRRIP are:

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Specific statements as to how these hypotheses appear to relate to knowledge about pallid sturgeon follow each major section of this review. These statements are presented as starting points for discussion and refinement by the PRRIP. Beyond these general hypotheses the PRRIP has articulated a list of more specific hypotheses (Table 1).

Table 1. A listing of specific Platte River Recovery Implementation Program hypotheses which relate to pallid sturgeon (from the Adaptive Management Plan).

Pallid Sturgeon Hypotheses
Water quality changes as a result of Program water management result in a measurable change in pallid sturgeon reproduction in the lower Platte River.
The net result of retiming due to depletions plans in the upper basin will/will not result in measurable changes in the lower Platte River.
The net result of retiming due to depletions plans in the upper basin will/will not result in measurable changes in channel characteristics in the lower Platte River associated habitat.
The net result of retiming due to depletions plans in the upper basin will/will not result in measurable changes in floodplain connectivity in the lower Platte River associated habitat
The net result of retiming due to depletions plans in the upper basin will/will not result in measurable changes in spring (March-June) peak flows in the lower Platte River associated habitat.
Incidental harvest of pallid sturgeon negates recovery efforts and benefits gained in the lower Platte River.
Pallid stocking efforts will impact ability to investigate other hypotheses.
Competition with non-native species could affect the recovery of the pallid sturgeon.
Changes in flow rate and/or channel characteristics will/will not result in detectable change in patterns/levels of pallid sturgeon use in the lower Platte River.
Program water management and retiming due to depletions plans will/will not result in detectable change in water quality in the lower Platte River.
Pallid sturgeon occurrence in the Platte River is incidental and not because of selection.
Pallid sturgeon do/do not spawn in the Platte River.
Pallid sturgeon use on the lower Platte River is dependent on conditions in the middle Missouri River basin.
Changes in water quality (temp, turbidity, etc) will result in detectable change in patterns/levels of pallid sturgeon use in the lower Platte River.
Program water management and retiming due to depletions plans will/will not result in measurable changes in pallid sturgeon use of the lower Platte River.
The lower Platte River does not provide essential habitat for the pallid sturgeon; rather it receives incidental usage.
The hydrological changes caused by the Program and new depletions plans will not provide measurable changes in the lower Platte River hydrologically, and/or stage changes.
Program flows and sediment management will result in measurable changes on sediment load in the lower Platte River
Increasing pallid sturgeon use in the lower Platte River will increase pallid sturgeon populations.
Different rates of flow in the lower Platte affect pallid sturgeon prey base.
Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River

DISTRIBUTION

As shown in Figure 1, pallid sturgeon are primarily known from the Mississippi River from Louisiana upstream to Keokuk, Iowa (Coker 1930) and in the Missouri River from its confluence with the Mississippi upstream to near Great Falls, Montana (Brown 1971). The earliest record recognized by Bailey and Cross (1954) was referred to by Cope (1879) as a shovelnose sturgeon. For most of the time since the pallid sturgeon was described fishermen and fisheries biologists did not distinguish between shovelnose and pallid sturgeon in their catch (Keenlyne 1989). However, today, historic references to very large individuals (>5kg) of *Scaphirhynchus* spp. are now generally considered to be pallid sturgeon (Bailey and Cross 1954).

Individuals reported prior to 1994 are all assumed to be wild fish because stocking of pallid sturgeon began in 1994 by the State of Missouri. Most hatchery-reared pallid sturgeon were tagged before release, but tag loss is a concern (Krentz et al. 2004).

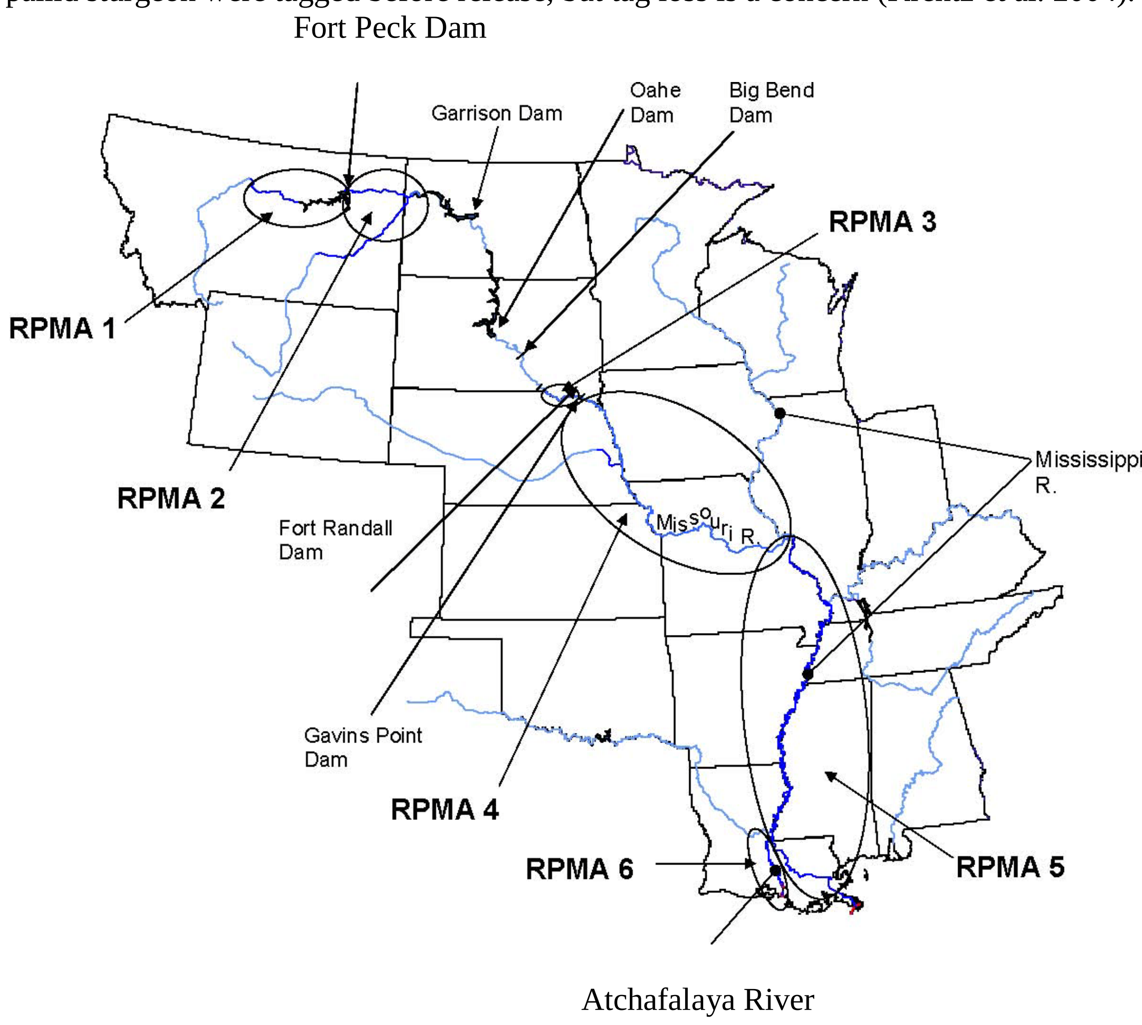

Figure 1. A map of the Mississippi – Missouri river drainage showing the location of the pallid sturgeon Recovery Priority Management Areas (U.S. Fish and Wildlife Service 2007).

Platte River

The earliest documented record of pallid sturgeon in the Platte River is a specimen which was collected near the mouth of the Elkhorn River 10 May 1979. Between 1979 and 2001, a total of 10 pallid sturgeon were captured by anglers and verified by Nebraska Game and Parks Commission personnel (Darrel Feit, Nebraska Game and Parks Commission, personal communication). From 2001 to 2004 researchers captured 15 pallid sturgeon from the Platte River downstream from the mouth of the Elkhorn River (Peters and Parham 2008; Swigle 2003). This was the first and only concerted effort to capture pallid sturgeon in the lower Platte River. Since 2005 at least one pallid sturgeon was captured in the Platte River (Tony Barada, University of Nebraska – Lincoln, personal communication). The presence of tags or markings on some of these specimens, captured between 2001 and 2005, indicates that at least six were hatchery-reared fish.

Missouri River (RPMA 1, 2, 3, and 4)

The Missouri River and a few of its turbid tributaries was probably the core of the pallid sturgeon range (Bailey and Allum 1962; Bailey and Cross 1954; Keenlyne 1989). Prior to dam construction, which began in the 1930's and channelization of the reach from Sioux City to the confluence with the Mississippi River, the whole river's length upstream to the Great Falls in Montana was available to pallid sturgeon. Today, much of the length from Fort Peck reservoir downstream to Gavins Point dam is now a lacustrine environment with short reaches of flowing water habitat. Pallid sturgeon were still caught in the reservoirs for several decades after impoundment (Erickson 1992; Keenlyne 1989; Walburg 1977) but today most of the specimens caught are senescing or nearing their maximum age (U.S. Fish and Wildlife Service 2007). The U.S. Fish and Wildlife Service designated four Recovery Priority Management Areas (RPMA's) within the length of the Missouri River which are defined in the pallid sturgeon recovery plan (U.S. Fish and Wildlife Service 1993). Subsequently, these areas have been refined into 14 monitoring and assessment segments starting at Fort Peck Dam in Montana (Segment 1) and extending downstream to the confluence with the Mississippi River (Segment 14).

RPMA 4

This reach of the Missouri River begins at the Gavins Point Dam and extends downstream to the confluence of the Missouri and Mississippi rivers near St Louis, Missouri. The lower Platte River is in RPMA 4. Within this area there are several distinctive reaches. First, there is the unchannelized reach (also designated as Segment 7) which extends from Gavins Point dam downstream to near Sioux City, Iowa. The James River and the Vermillion River join the Missouri River from the north within this segment. Two early records of pallid sturgeon in South Dakota were taken from this reach shortly after closure of Fort Randall Dam, but none have been recorded from the tributary rivers (Bailey and Allum 1962; Bailey and Cross 1954; Keenlyne 1989). Recent studies have collected numerous pallid sturgeon in this segment and it has been the site of several releases of hatchery reared pallid sturgeon (U.S. Fish and Wildlife Service 2007).

The river segments from Sioux City downstream to the mouth the Missouri River have been channelized for navigation. At Sioux City, the Big Sioux River joins the Missouri from the north. The next major tributary in this reach is the Platte River, south of Omaha, Nebraska. This reach of the Missouri River has been designated as Segment 8. The reach from Omaha, Nebraska to the Kansas River near Kansas City, Kansas has been designated as Segment 9. Sampling in Segment 9 during 2005, 2006, and 2007 captured 77 pallid sturgeon, 56 of which were known to be hatchery reared individuals (Steffensen and Barada 2006; Steffensen and Hamel 2007; Steffensen and Hamel 2008). These same references labeled the confluence of the Platte and Missouri rivers a “hot spot” for pallid sturgeon captures because 20 of the fish captured during the 2005 – 2007 samples came from that area. The Kansas River (Segment 11) has historical records of pallid sturgeon captures, but they are considered extirpated from that system (Cross 1967; Cross and Moss 1987).

In Missouri the river receives additional water from the Grand River, the Osage River and the Gasconade River, but pallid sturgeon are only known from the main stem of the Missouri River (Pflieger and Grace 1987) This portion of the Missouri River includes monitoring and assessment Segments 10, 12, 13 and 14.

The pallid sturgeon population in RPMA 4 has been intensively studied and there are several sites where stocking of hatchery reared fish has taken place. Even though channel alterations and controlled reservoir releases, among other perturbations, have altered the environment, pallid sturgeon can still migrate over the whole of this reach of the river. By way of example, two pallid sturgeon captured in the Platte River had travelled 400 miles (> 660km) from their release location near Boonville, Missouri (Peters and Parham 2008).

RPMA 1, 2, and 3

Upstream along the Missouri River from RPMA 4 are RPMA’s 1, 2, and 3. These sections of flowing water in the Missouri River have been divided by a series of dams and their associated reservoirs which make extensive portions of the overall reach unsuitable for pallid sturgeon. RPMA 1 is the reach of the Missouri River upstream from Fort Peck Reservoir. A 47 pound specimen was taken at Fort Benton, Montana in 1876 (Brown 1955; Brown 1971).

RPMA 2 (Monitoring and Assessment Segments 1, 2, 3 and 4) is the reach from Fort Peck Reservoir to Lake Sakakawea in North Dakota. This reach receives flow from the Yellowstone River. Pallid sturgeon have been collected as far up the Yellowstone River as the mouth of the Tongue River at Miles City, Montana, but today most records come from the area downstream from a diversion dam (Intake) near Glendive, Montana.

From the headwaters of Lake Sakakawea in western North Dakota downstream to Fort Randall Dam on the South Dakota/Nebraska border most of the former riverine habitat for pallid sturgeon has been impounded. After the closure of the Missouri River main stem dams, large individuals of pallid sturgeon were captured in this region (Erickson 1992; Walburg 1977), but today they are virtually absent and none have been collected for several years. The reservoirs also flooded the mouths of Little Missouri, Cheyenne and White rivers which may have been suitable habitat for pallid sturgeon prior to impoundment, although they have never been recorded from these tributaries.

RPMA 3 (Monitoring and Assessment Segments 5 and 6) is an isolated section of river habitat between Fort Randall Dam and Lewis and Clark Reservoir. This reach of the Missouri River receives water from the Niobrara River. Although this reach had habitat which supported pallid sturgeon (Keenlyne 1989), today this section of the Missouri River and the adjoining portion of the lower Niobrara River contains only a stocked population of pallid sturgeon. The population in this reach has been studied intensively (Wanner et al. 2007a; Wanner et al. 2007b)

Mississippi River and tributaries (RPMA 5 and 6)

Downstream from the mouth of the Missouri River (RPMA 4) are RPMA's 5 and 6. Pallid sturgeon are regularly collected in the Mississippi River from its confluence with the Missouri River to near the river's mouth (Hurley et al. 2004b; Sheehan et al. 2000; Sheehan et al. 1998; Sheehan et al. 1999). Pallid sturgeon have also been collected in several small tributaries of the Mississippi (Bailey and Cross 1954; Buchanan 1973; Ross 2001), such as the St. Francis River in Arkansas, the Big Sunflower River in Mississippi, and most notably in the Atchafalaya River in Louisiana (Bailey and Cross 1954; Killgore et al. 2007a). However, pallid sturgeon are not known to use the Ohio River. RPMA 6 is the Atchafalaya River which is separated from the Mississippi River by a river control structure. The river control structure separates pallid sturgeon populations in the Atchafalaya River from those in the rest of the Mississippi River.

LIFE CYCLE STAGES

Definitions of life cycle stages

Wildhaber et al. (2007) developed a conceptual life history model to organize the stages which are important to consider as studies of pallid sturgeon proceed. In addition, in this model, transition probabilities are used to describe the impacts of the spectrum of conditions in the environment which influence the survival of a pallid sturgeon from one life stage to the next. We present information pertaining to major categories included in these transition probabilities (i.e. mortality factors, habitat, water quality) in subsequent sections of this report.

Gametes:

The production of viable gametes by adult fishes is their contribution to the next generation. The eggs and sperm from the adults provide the genetic basis upon which the next generation depends. The fertilized eggs of sturgeon sink and adhere to the substrate (Simpkins and LaBay 2007). These gametes need to be deposited in a suitable environment which allows their development into embryos. The use of egg mats at suspected spawning sites is a valuable sampling technique to detect the presence of spawning (Laustrup et al. 2007; Simpkins and LaBay 2007).

Embryos:

The embryo life stage is divided into two segments (pre and post hatching). Both of these stages are dependent upon the food resources in the yolk for development. Prior to hatching, the embryos adhere to the substrate where the eggs were deposited during spawning. After hatching, the embryos drift downstream with the water currents (Kynard et al. 2002; Kynard et al. 2007). The period of drift may carry them for over 300km downstream from their point of hatching (Kynard et al. 2007). The distance drifted during the post-hatching embryonic phase may be particularly critical in areas where the drift may carry the embryos into reservoirs or lakes where they may be preyed upon by planktivorous fishes (Braaten et al. 2008).

Larvae:

At about the time that sturgeon develop fin rays they also transition to exogenous feeding (Snyder 1999; Snyder 2002) and this defines the transition from the embryo stage to the larval stage. At this critical juncture larval pallid sturgeon enter into competition with other fish larvae for available food resources. During this transition, larval pallid sturgeon also become able to move actively to habitats to avoid the current and to feed. Pallid sturgeon are considered larvae until they lose their fin folds, develop a complete set of caudal fin rays and reach approximately 200mm.

Juveniles:

Pallid sturgeon are considered juveniles until their gonads develop. Age 1 fish consume primarily macroinvertebrates while older juvenile pallid sturgeon switch to consuming fish (Gerrity et al. 2005; Gerrity et al. 2006). Throughout their range benthic minnows, such as sturgeon chubs, sicklefin chubs and other *Macrhybopsis* spp., are the favored prey of pallid sturgeon (Gerrity et al. 2006; Hoover et al. 2007; Wanner et al. 2007b).

Adults:

Pallid sturgeon are considered adults when they become sexually mature. Pallid sturgeon require a long time to become reproductive members of the population. Males may mature at about age 10 but females may not become sexually mature until they reach age 15 (Keenlyne and Jenkins 1993). In addition, females may only spawn every 3 or 4 years (Bajer and Wildhaber 2007; DeLonay et al. 2007b; DeLonay et al. 2007c; Wildhaber and Bryan 2006; Wildhaber et al. 2007; Wildhaber et al. 2005). This compounds the difficulty of locating spawning habitat, because it is only during the years when they are going to spawn that they exhibit spawning migrations to appropriate spawning habitats. Recent studies of the physiology of shovelnose sturgeon have provided insights to non-invasively determine the spawning condition of sturgeon (Papoulias et al. 2007).

Relationship of PRRIP hypotheses to life cycle stages of pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Adult and juvenile pallid sturgeon have been captured in the lower Platte River. In addition, larval (*Scaphirhynchus* spp.) sturgeon have also been collected in the lower Platte River. The presence and abundance of this range of life cycle stages is a significant indicator that the habitats found in the lower Platte River are suitable for pallid sturgeon. Therefore, continued population assessments of pallid sturgeon life stages could be used to evaluate habitat in the lower Platte River.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

The different life stages of pallid sturgeon have different habitat requirements. If water related activities above the Loup River change the flow in the lower Platte River then impacts on the presence of these life stages of pallid sturgeon are likely. The distribution and amount of the habitats needed by different life stages of pallid sturgeon correlated with differences in water supply entering the lower Platte River from above the Loup River confluence would be a promising way to evaluate the impacts of these flows on the quality of the habitat for the different life stages of pallid sturgeon.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

The lower Platte River and the Missouri River are directly connected systems and studies in the Platte River have indicated that the pallid sturgeon populations are directly connected as well. Coordination of study methods between the Missouri River and the lower Platte River would aid in documenting the degree to which Non-Program actions (and program actions) determine the occurrence of pallid sturgeon in the lower Platte River.

TAXONOMY AND IDENTIFICATION

The pallid sturgeon was originally described as *Parascaphirhynchus albus* (Forbes and Richardson 1905) from nine specimens collected in the Mississippi River near the mouth of the Missouri River. In 1911 L.S. Berg (cited in (Bailey and Cross 1954; Keenlyne 1996)) determined that both North American species of river sturgeons *S. platorynchus* and *S. albus* should be placed in the genus *Scaphirhynchus*. From 1951 to 1961 the specific name of the pallid sturgeon was changed to *album*, but since 1961 it was returned to *albus* by action of the International Code of Zoological Nomenclature (Bailey and Allum 1962).

The North American species of the genus *Scaphiryhnchus* have been placed in the sub-family Sacphirhynchinae in the family Acipenseridae. Several species of Asiatic sturgeons are classified in the genus *Pseudoscaphirhynchus*, but recent genetic studies indicate that their similarities are due to convergent evolution and that they are not a monophyletic group with the genus *Scaphiryhnchus* (Birstein et al. 2002; Dillman et al. 2007).

Morphology, meristics, and morphometrics:

In general, pallid sturgeon are similar in appearance to shovelnose sturgeon. The primary differences, noted in the original description, between the two species were the number of ribs (21 to 22 in pallid vs. 10 or 11 in shovelnose), the naked breast and belly in pallid sturgeon and the presence of sub-rhombic plates on the shovelnose sturgeon, and the length of the air bladder to standard length (8 times in pallid sturgeon and 5 times in shovelnose) (Forbes and Richardson 1905).

Subsequent analyses by Bailey and Cross (1954) illuminated other differentiating meristic and morphometric characteristics. This suite of differences between pallid and shovelnose sturgeon led to the development of a number of morphological character indexes (Bailey and Cross 1954; Keenlyne et al. 1994b; Sheehan et al. 1999) designed to aid in species identification. These morphological character indexes have proved useful for field identification of the different sturgeon species. Recent studies have built upon previous work and used several qualitative characters such as the shape of papillae on the barbells and lip lobes and the shape of gill rakers to distinguish pallid sturgeon from shovelnose sturgeon (Kuhajda et al. 2007). One issue with the use of morphological character indexes is how to assign individuals with intermediate meristic and morphometric characters which are suspected to be hybrids between shovelnose and pallid sturgeon (Bailey and Cross 1954; Carlson et al. 1985; Keenlyne et al. 1994a; Murphy et al. 2007a; Murphy et al. 2007b; Sheehan et al. 1999). These assignments have been facilitated by the development of genetic markers.

Genetics

Attempts to use various genetic markers to verify morphologically based identifications have met with varying success. One of the earliest analyses of the genetics of pallid sturgeon found that they were indistinguishable from shovelnose sturgeon (Phelps and Allendorf 1983). Subsequent studies also found difficulty in discriminating between these species (Bischof and Szalanski 2000; Genetic Analyses Inc. 1994). However, the addition of other genetic information, especially from microsatellite loci has facilitated discrimination of pallid sturgeon and shovelnose sturgeon (McQuown et al. 2000; Ray et al. 2007; Schrey et al. 2007; Simons et al. 2001). In addition, applications of these techniques have been able to confirm hybrids (Campton et al. 2000; Schrey 2007; Schrey et al. 2007; Tranah et al. 2004). Most recently, use of genetic tags have made it possible to distinguish captive bred pallid sturgeon from wild individuals (DeHaan et al. 2008).

The ability of researchers, managers and fishers (commercial and sport) to distinguish pallid sturgeon from shovelnose sturgeon is important to recovery of pallid sturgeon in several ways. First, researchers studying aspects of the biology and ecology of sturgeons need to be able to ascribe their results to the correct species. Second, managers will use changes in pallid sturgeon populations to indicate the success or failure of management strategies so an accurate count of each species is critical. Finally, fishers need to be able to identify sturgeon species to avoid “take” (harvesting) of pallid sturgeon since it is an endangered species. Table 2 summarizes the references to studies that have been conducted to facilitate identification of pallid sturgeon in different sections of its range.

In addition, the occurrence of hybrid individuals in the population not only compounds the difficulty of distinguishing between the species, but it may indicate the existence of other problems for the pallid sturgeon. Several authors have pointed out that the presence of hybrid individuals may be the results of habitat modifications in the Mississippi River and Missouri River which have interrupted spawning migrations, and altered temperature regimes and flood pulses needed as reproductive cues by these fish (Keenlyne 1989; Keenlyne 1995; Keenlyne 1996; Mayden and Kuhajda 1997).

Table 2. References that discuss identification (morphology or genetics) for pallid sturgeon by life stage and RPMA area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BOLL-01-1998								
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	SEI-01-2008	Yes							
All	WILD-01-2007	Yes							
Adult	BAIL-01-1954	Yes							
Adult	BAIL-01-1962					Yes			
Adult	CAMP-01-2000		Yes	Yes				Yes	
Adult	CARR-01-2003	Yes							
Adult	DILL-01-2007						Yes	Yes	
Adult	FORB-01-1905					Yes	Yes		
Adult	FORB-01-1920						Yes		
Adult	KEEN-01-1994		Yes	Yes					
Adult	MURP-01-2007						Yes		
Adult	MURP-02-2007						Yes		
Adult	RAYJ-01-2007					Yes	Yes	Yes	
Adult	SCHR-03-2007						Yes		
Adult	SEI-01-2005			Yes	Yes	Yes			
Adult	SHEE-01-1999								
Adult	SIMO-01-2001	Yes							
Adult	TEWS-01-1994			Yes					
Adult	TRAN-01-2001			Yes				Yes	
Adult	TRAN-01-2004		Yes	Yes				Yes	
Juvenile	BAIL-01-1954	Yes							
Juvenile	CARL-01-1985					Yes	Yes		
Juvenile	CARR-01-2003	Yes							
Juvenile	DEHA-01-2008					Yes			
Juvenile	KUHA-01-2007		Yes	Yes					
Juvenile	MURP-01-2007						Yes		
Juvenile	MURP-02-2007								
Juvenile	SEI-01-2005			Yes	Yes	Yes			
Juvenile	SILL-01-2005								
Larvae	SNYD-01-1999	Yes							
Larvae	SNYD-01-2002								
Gametes	DILA-01-2001								
Non-specific	BIRS-01-2002								
Non-specific	BISC-01-2000			Yes			Yes	Yes	
Non-specific	CROS-01-1967					Yes			
Non-specific	GENE-01-1994	Yes							
Non-specific	KEEN-01-1995	Yes							
Non-specific	KEEN-01-1996	Yes							
Non-specific	KEEN-02-1994	Yes				Yes	Yes	Yes	
Non-specific	MCQU-01-2000								
Non-specific	PHEL-01-1983					Yes	Yes		
Non-specific	SCHR-02-2007		Yes			Yes	Yes	Yes	

Relationship of PRRIP hypotheses to Taxonomy and Identification of pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

In order to develop accurate habitat use and suitability models, measurements of habitat variables must be ascribed correctly to pallid sturgeon or shovelnose sturgeon. This will allow an assessment of whether current conditions in the lower Platte River are suitable for adult and juvenile pallid sturgeon. Any future investigations on pallid sturgeon in the lower Platte River should include collection of meristic and mophometric data and tissue samples to confirm the identification of the fish collected.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

If water related activities in the Platte River do affect habitat in the lower Platte River, the ability to correctly identify pallid sturgeon and shovelnose sturgeon will allow an assessment of this impact.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

The ability to correctly identify pallid sturgeon, shovelnose sturgeon, and their hybrids is important to evaluate whether non-target harvest of pallid sturgeon in the recreational shovelnose sturgeon fishery is influencing the occurrence of pallid sturgeon in the lower Platte River. Accurate identification is also basic to developing an understanding of the relative importance of stocking and natural reproduction to individuals using the lower Platte River.

BIOLOGY OF PALLID STURGEON

Feeding and food availability

Feeding and digestive tract analysis:

Fish have been noted as important food items for pallid sturgeon by many studies and these results have been noted in general accounts (Carlson et al. 1985; Coker 1929-30?; Coker 1930; Cross 1967; Keenlyne 1995; Mayden and Kuhajda 1997). Observations of feeding in hatcheries have indicated a strong preference for fish (Bollig 1998; Bollig 2005). Studies of the morphology of the mouth of the pallid sturgeon reveals that they can protrude their mouth towards their prey and close it before retracting it in a way similar to that used by sharks (Carroll and Wainwright 2003).

Several studies have developed and tested the efficacy and safety of techniques to sample food items in the digestive tracts of pallid sturgeon. Shuman and Peters (2007) tested pulsed gastric lavage on shovelnose sturgeon, found it safe for the fish and recommended it for use on pallid sturgeon. Wanner et al. (2007) and Gerrity et al. (2006) used gastric lavage to sample the stomach contents of hatchery-reared pallid sturgeon and both studies found that juvenile pallid sturgeon were piscivorous. Colonic flushing has also been used to safely remove material from pallid sturgeon digestive tracts (Hoover et al. 2007). This technique also found that fish, especially *Macrhybopsis* chubs, made up a large portion of the diet. Comparisons of shovelnose sturgeon and pallid sturgeon food habits have indicated that early in their lives they both feed on invertebrates, especially Ephemeroptera and Chironomids. However, shovelnose sturgeon cannot be used as a surrogate for pallid sturgeon food habits, because they select fish over invertebrates (Gerrity et al. 2006; Hoover et al. 2007; Wanner et al. 2007b). No pallid sturgeon specimens from the Platte River system have been analyzed for their stomach contents. Table 3 lists the studies which have assessed pallid sturgeon food habits across its range.

Prey availability and system productivity:

While pallid sturgeon are piscivorous, several studies have reported that they feed specifically on native minnow species, notably several species of the genus *Macrhybopsis* (Adams et al. 1999; Gerrity et al. 2006; Hoover et al. 2007; Wanner et al. 2007b). Several authors have noted declines in these species in the Missouri River which have been related to alterations in discharge patterns caused by main stem reservoir operations and the loss of connectivity between the Missouri River and its floodplain (NRC 2001, Galat et al. 2005). The distribution and abundance of *Macrhybopsis* spp. has also been related to changes in river habitat conditions in Kansas (Cross and Moss 1987). Four species of chubs (*Macrhybopsis hyostoma, M. storeriana, M. gelida, Platygobio gracilis*) have been collected from the Platte River and all are potential prey items of juvenile and adult pallid sturgeon (Peters and Parham 2008).

Table 3. References that discuss feeding and food availability for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BOLL-01-1998								
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	WILD-01-2007	Yes							
Adult	CARL-01-1985					Yes	Yes		
Adult	CARR-01-2003	Yes							
Adult	HOOV-01-2007						Yes		
Adult	PETE-01-2008								Yes
Juvenile	ADAM-01-1999			Yes					
Juvenile	BOLL-01-2005		Yes			Yes			
Juvenile	CARL-01-1985					Yes	Yes		
Juvenile	GERR-01-2005		Yes						
Juvenile	GERR-01-2006		Yes						
Juvenile	KLUM-01-2005				Yes				
Juvenile	PETE-01-2008								Yes
Juvenile	SHUM-01-2005				Yes				
Juvenile	SPIN-01-2008				Yes				
Juvenile	WANN-01-2006				Yes				
Juvenile	WANN-02-2007				Yes				
Non-specific	COKE-01-1930						Yes		
Non-specific	CROS-01-1967					Yes			
Non-specific	KEEN-01-1995	Yes							
Non-specific	KEEN-01-1996	Yes							
Non-specific	USEP-01-2007	Yes							

Relationship of PRRIP hypotheses to feeding and digestive tract analysis and prey availability:

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Since prey items favored by pallid sturgeon (*Macrhybopsis hyostoma*, *M. storeriana*, *M. gelida*, *Platygobio gracilis*) occur in the lower Platte River, food habits analysis of pallid sturgeon captured from the lower Platte River would be a good test of the suitability of the habitat there.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

Since changes in abundance of small fishes, especially *Macrhybopsis hyostoma*, *M. storeriana*, *M. gelida*, *Platygobio gracilis* have been related to changes in habitat caused by upstream water-use activities, it seems likely that water related activities could have an influence on pallid sturgeon food resources downstream from the mouth of the Loup River. Future studies of pallid sturgeon habitat conditions should include studies of the species which comprise important components of their food resources.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

A comparison of food habits studies between pallid sturgeon collected from Missouri River and Platte River localities could be one way to test this hypothesis. Stable isotope analysis could also provide excellent insights if it does not require sacrifice of whole animals to complete the process.

Competition

There have been no published studies on direct competition between pallid sturgeon and other species, but several publications have discussed this topic (Table 4). However, potential overlaps in diet with other species sympatric with pallid sturgeon are evident especially during the larval and juvenile life stages (Erickson 1992). Studies throughout the range of pallid sturgeon have found a diversity of species which share the habitat (Coker 1930; Fisher 1962; National Research Council 2002; Peters and Parham 2008; Pflieger and Grace 1987).

Native fishes

Pallid sturgeon evolved with a diversity of species which were adapted to the same environment of large, turbid, shifting sand-bed rivers with fluctuating discharges. Changes in the habitat caused by controls of discharge etc. have allowed certain species to expand their populations while other species like pallid sturgeon have been disadvantaged (Cross 1967; Cross and Moss 1987; Pflieger and Grace 1987).

Non-native fishes

The filling of the main stem reservoirs on the Missouri River have created new habitats that has fostered establishment of species which are not native to the system. Some of these species, such as walleye, various salmonid species and lacustrine forage species like smelt were purposely stocked to take advantage of the reservoir habitats (Adams et al. 2003; Beckman and Elrod 1971; Walburg 1977; Walburg et al. 1971). Others, like Asian carps are the result of accidental releases from elsewhere in the Mississippi-Missouri drainage system (National Research Council 2002).

Other species

Besides fish there are no known competitors with sturgeon for food resources at any stage in their life cycle.

Table 4. References that discuss competition by native fishes, non-native fishes, or other animals with pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	WEBB-01-2004		Yes	Yes					
All	WILD-01-2007	Yes							
Adult	TEWS-01-1994			Yes					
Juvenile	ERIC-01-1992			Yes	Yes				
Juvenile	WANN-01-2006				Yes				

Relationship of PRRIP hypotheses to competition between pallid sturgeon and other species in the Platte River

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Current habitat in the lower Platte River supports a diversity of populations of fish and other species which form an interacting community which can support populations of adult and juvenile pallid sturgeon. Some of these interactions may have positive influences while others may have a negative influence on the pallid sturgeon population. Continued assessment of the fish assemblage in the lower Platte River is one approach to determining the relative suitability of this reach for pallid sturgeon.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

Water related activities above the Loup River will likely influence the composition of predator and competitor populations for pallid sturgeon by changing the habitat in the lower Platte River. Actions which increase water clarity will probably benefit fishes which may prey on pallid sturgeon life stages. In addition, increased water clarity would probably reduce the ability of pallid sturgeon to compete with other piscivorous species for the small fish in the lower Platte River.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Non-Program actions such as introductions of invasive species may influence available prey, predator, and competitor populations for pallid sturgeon. The spread and establishment of Asian carp populations is of particular concern since they may feed on drifting sturgeon larvae as well as the larvae of other species important as a food resource for pallid sturgeon.

Age, Growth and Condition

The health of a fish population can be evaluated by examining its age structure, the rate of growth of its members, and their physical robustness (condition). Table 5 summarizes the literature citations on pallid sturgeon which address these topics.

Age

Pallid sturgeon are a long lived species which may attain ages of over 40 years (Keenlyne and Jenkins 1993). The large specimens which are still infrequently collected in some portions of its historic range where there has been no known reproduction for over 35 years bear testimony to their longevity (Keenlyne and Jenkins 1993). Since the skeletons of pallid sturgeon are primarily cartilaginous, ageing specimens is difficult and imprecise. Several studies have attempted to validate the use of sections through pectoral fin rays from known age hatchery-reared fish, but these results have not been encouraging (Hurley 1998; Hurley et al. 2004a).

As the number of hatchery-reared pallid sturgeon in the environment increases researchers will have better information on how long these individuals can live (as long as they retain their tags). Other techniques for aging are being investigated.

Growth

Several studies have estimated growth rates from pallid sturgeon captured in the wild (Carlander 1969; Kallemeyn 1983; Killgore et al. 2007b; Yerk and Baxter 2002). Growth rates of pallid sturgeon have been documented in hatcheries (Bollig 1998; U.S. Fish and Wildlife Service 2007). The recapture of PIT-tagged individuals is providing data for following growth of stocked fish in the wild (Peters and Parham 2008).

Condition

The relationship between length and weight affords fishery biologists a measure of the well-being of individuals and populations of fish. Early studies of pallid sturgeon condition was from specimens captured during reservoir sampling along the Missouri River primarily in South Dakota (Carlander 1969). More recent studies developed length-weight and relative weight (Wr) equations (Keenlyne and Evenson 1993; Keenlyne and Maxwell 1992; Keenlyne and Maxwell 1993). In addition, the development of proportional stock density (PSD) and relative stock density (RSD) criteria should enable more effective analysis of population statistics for pallid sturgeon management (Shuman et al. 2006).

Table 5. References that discuss age, growth, or condition factors for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BOLL-01-1998								
All	USFW-01-1993	Yes							
Adult	CARL-01-1985					Yes	Yes		
Adult	FORB-01-1920						Yes		
Adult	GARD-01-2005		Yes						
Adult	HOOV-01-2007						Yes		
Adult	HURL-01-1998						Yes		
Adult	JAEG-01-2005			Yes					
Adult	KALL-01-1983	Yes							
Adult	KEEN-01-1992			Yes					
Adult	KEEN-01-1993			Yes		Yes	Yes	Yes	
Adult	KEEN-02-1993		Yes	Yes		Yes			
Adult	KEEN-03-1993	Yes							
Adult	KILL-01-2007						Yes		
Adult	PETE-01-2008								Yes
Adult	SHEE-01-2000						Yes		
Adult	SHUM-01-2006		Yes	Yes	Yes				
Adult	TEWS-01-1994			Yes					
Adult	YERK-01-2002			Yes					
Juvenile	ADAM-01-1999			Yes					
Juvenile	CARL-01-1985					Yes	Yes		
Juvenile	GARD-01-2005		Yes						
Juvenile	GERR-01-2005		Yes						
Juvenile	GERR-01-2006		Yes						
Juvenile	HURL-01-2004								
Juvenile	JAEG-01-2005			Yes					
Juvenile	KEEN-03-1993	Yes							
Juvenile	KILL-01-2007						Yes		
Juvenile	KLUM-01-2005				Yes				
Juvenile	PETE-01-2008								Yes
Juvenile	SHUM-01-2005				Yes				
Juvenile	SHUM-01-2006		Yes	Yes	Yes				
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes
Juvenile	STEF-01-2006					Yes			
Juvenile	STEF-01-2007					Yes			Yes
Juvenile	STEF-01-2008					Yes			Yes
Juvenile	WANN-01-2006				Yes				
Larvae	SNYD-01-2002								
Non-specific	BROW-01-1971		Yes	Yes					
Non-specific	CARL-01-1969	Yes							
Non-specific	KEEN-02-1992	Yes	Yes	Yes		Yes	Yes	Yes	
Non-specific	USEP-01-2007	Yes							
Non-specific	USFW-01-2007								
Non-specific	WEBB-01-2007								

Relationship of PRRIP hypotheses to age, growth, and body condition

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Assessments of the age structure, size structure, growth rate, and condition of the pallid sturgeon population can be used to evaluate whether current habitat in the lower Platte River is or is not suitable for adult and juvenile pallid sturgeon. The presence of pallid sturgeon individuals which are living to maturity, growing, and exhibiting healthy body condition should be indicators of habitat suitability in the lower Platte River.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

Correlations of water related activities upstream from the confluence of the Platte and Loup rivers with growth or condition indices of pallid sturgeon would be a useful indicator of the relationships among these factors.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

The pallid sturgeon that use the Platte River also use the Missouri River during their life. Therefore, partitioning growth and condition for individuals captured in the Platte River among the areas used during their lives is problematic.

Movement

Movements and migration

Pallid sturgeon make long distance movements during their life history (DeLonay et al. 2007c; Wildhaber et al. 2007). During their free-embryo and larval life stages pallid sturgeon drift with the current to feeding areas (Kynard et al. 2002; Kynard et al. 2007). Juvenile individuals also move downstream (Kynard et al. 2007). Although there have been no definitive relationships drawn between pallid sturgeon movements and spawning activities, shovelnose sturgeon which are physiologically ready to spawn have exhibited spawning migrations (DeLonay et al. 2007b; DeLonay et al. 2007c; Wildhaber and Bryan 2006; Wildhaber et al. 2007). References which discuss movements and migrations by pallid sturgeon are listed in Table 6.

Movements of pallid sturgeon into and out of the lower Platte River have been observed. Between 2001 and 2004, pallid sturgeon in the Platte River appeared in sampling gears as early as 2 April and the latest date on which one was caught was 25 September. From this group, individuals implanted with radios all exited the Platte River by 9 June (Peters and Parham 2008; Swigle 2003). A pallid sturgeon captured on 3 May 2001 in the Platte River contained visible eggs and moved out of the river at the same time as *Scaphirhynchus* spp. larvae were collected. On 23 May 2002 a pallid sturgeon, which was apparently spent, was captured and it also moved downstream at the same time as other *Scaphirhynchus* spp. larvae were collected(Peters and Parham 2008).

Of 25 hatchery-reared pallid sturgeon juveniles (age 6 and 7) implanted and released in the Platte River during Aprils of 1998 and 1999, six individuals either remained in the Platte throughout the year or returned to the Platte from the Missouri River the spring following their release (Snook 2001).

Swimming ability

Pallid sturgeon are known to use habitats associated with swift currents (Bramblett 1996; Bramblett and White 2001; Hurley 1998; Hurley et al. 2004b; Snook 2001; Snook et al. 2002). In addition, laboratory studies have confirmed their ability to use relatively swift current conditions (Adams et al. 2003; Adams et al. 1999). Most observations of pallid sturgeon indicate that they often swim in contact with the substrate (Adams et al. 2003; Adams et al. 1999), but recent studies using depth indicating tags showed that shovelnose sturgeon spent significant time swimming above the substrate (DeLonay et al. 2007b).

Table 6. References that discuss movement (movement, migration, or swimming ability) for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	WILD-01-2007	Yes							
Adult	BRAA-01-2005			Yes					
Adult	BRAM-01-1996			Yes					
Adult	BRAM-01-2001			Yes					
Adult	DELO-01-2007					Yes			
Adult	DELO-02-2007					Yes			
Adult	ERIC-01-1992			Yes	Yes				
Adult	GARD-01-2005		Yes						
Adult	HURL-01-1998						Yes		
Adult	JAEG-01-2005			Yes					
Adult	KLUN-01-2005			Yes					
Adult	PAPO-01-2007			Yes		Yes			
Adult	PETE-01-2008								Yes
Adult	SHEE-01-1998						Yes		
Adult	SHEE-01-2000						Yes		
Adult	SWIG-01-2003								Yes
Adult	TEWS-01-1994			Yes					
Adult	USGS-01-2008			Yes		Yes			
Juvenile	ADAM-01-1999			Yes					
Juvenile	ADAM-01-2003			Yes					
Juvenile	ERIC-01-1992			Yes	Yes				
Juvenile	GARD-01-2005		Yes						
Juvenile	GERR-01-2005		Yes						
Juvenile	JAEG-01-2005			Yes					
Juvenile	JORD-01-2006				Yes				
Juvenile	KLUN-01-2005			Yes					
Juvenile	KYNA-01-2001								
Juvenile	PETE-01-2008								Yes
Juvenile	SHEE-01-1998						Yes		
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes
Larvae	BRAA-01-2005			Yes					
Larvae	PETE-01-2008								Yes
Free Embryo	USGS-01-2008			Yes		Yes			
Non-specific	CROS-01-1967					Yes			
Non-specific	KYNA-01-2002			Yes					
Non-specific	KYNA-01-2007			Yes					
Non-specific	USEP-01-2007	Yes							

Relationship of PRRIP hypotheses to movement of pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Movements and/or migration of pallid sturgeon into the lower Platte River indicate that the current habitat is suitable for adult and juvenile pallid sturgeon. However, the use of any habitat by a species (in this case pallid sturgeon) depends on their ability to access that habitat. Therefore, the habitats must be connected by suitable corridors before they can be utilized effectively.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

Regular movement and migration of pallid sturgeon into and out of the lower Platte River are indicators of the health of the population and the connectedness of the habitats. If water related activities, from above the Loup River, contribute flows to the lower Platte River they almost certainly would have a positive impact on the use of habitats by pallid sturgeon in the lower Platte River and the connectedness of these habitats.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Since pallid sturgeon apparently move widely through the Missouri River downstream from Gavins Point Dam, it seems likely that a variety of non-program actions may affect their occurrence in the lower Platte River.

Reproduction and artificial propagation

All sturgeons spawn in freshwater and as far as is known all species scatter their eggs over coarse gravel or rocky substrates in shallow areas of rivers (Wildhaber et al. 2007). As a result of the turbid water conditions in large rivers which pallid sturgeon inhabit, researchers have experienced difficulties in studying the spawning habits of pallid sturgeon. Several studies have used endoscopic and ultrasonic examination to evaluate the spawning readiness of sturgeons (Bryan et al. 2007; Wildhaber and Bryan 2006; Wildhaber et al. 2005). Ultrasound alone accurately measured gonad volume and underestimated the fecundity of sturgeon, but in association with endoscopy it was a good way to track gonad development through time (Bryan et al. 2007). In addition, physiological tests have proved useful in the evaluation of sturgeon reproductive stage (DeLonay et al. 2007b; Papoulias et al. 2007). These measures of spawning readiness have allowed studies to select individuals which are ready to spawn so that they can be followed to spawning sites using a variety of telemetry tools (DeLonay et al. 2007a; DeLonay et al. 2007b; DeLonay et al. 2007c). Additionally, these techniques have application to the evaluation of pallid sturgeon in hatcheries because they minimize the need for invasive examination techniques and this decreases the chances for infections in individuals that are being maintained for brood-stock.

Natural Reproduction

There have been no direct observations of natural reproduction of pallid sturgeon, but advances in telemetry technology and techniques for collecting eggs, embryos, and larvae in the field have afforded researchers with many new insights (DeLonay et al. 2007b; Hrabik et al. 2007; Simpkins and LaBay 2007). Radio tagged shovelnose sturgeon that showed gonadal development and physiological characteristics which indicated that they were ready to spawn, moved upstream, spawned, and moved downstream (DeLonay et al. 2007b). Trawl samples at the downstream ends of sand bars in the Mississippi River captured seven pallid sturgeon larvae along with 17 pallid sturgeon x shovelnose sturgeon hybrid larvae and 15 shovelnose sturgeon larvae (Hrabik et al. 2007). In the Missouri River egg mats were used to collect sturgeon eggs from locations where reproductively mature shovelnose sturgeon were tracked using radio telemetry (Simpkins and LaBay 2007).

In the Platte River there have been no observations of pallid sturgeon reproduction, but *Scaphirhynchus* spp. larvae have been collected (Peters and Parham 2008). The dates when *Scaphirhynchus* spp. larvae have been collected in the Platte River range from 15 May to 24 June and in water temperatures that ranged from 13.6 to 27.4^{o}C.

Spawning site selection

All known sturgeon spawning areas occur in freshwater rivers and streams over gravel or rock substrates. This information has been used to indicate where pallid sturgeon might spawn (Laustrup et al. 2007; Simpkins and LaBay 2007; Wildhaber et al. 2007). Knowledge of where pallid sturgeon spawn is further limited by their low population density and the 3 to 4 year time interval between spawning events by an individual female. The advances in non-invasive evaluation of spawning readiness discussed earlier are being used so that researchers can concentrate their efforts on those individuals containing mature gametes (DeLonay et al. 2007b; DeLonay et al. 2007c). In the Platte River two pallid sturgeon implanted with radio transmitters moved downstream into the Missouri River at the same time that sturgeon larvae were collected. One of these pallid sturgeon had eggs when it was implanted and spent nearly a month in the Platte River before moving into the Missouri River at about the same time that *Scaphirhynchus* spp. larvae were collected (Peters and Parham 2008; Swigle 2003).

Fecundity/GSI

The numbers of eggs produced by pallid sturgeon females is important to the development of estimates of their ability to increase their populations to sustainable levels (recovery from their endangered status) (U.S. Fish and Wildlife Service 1993). A challenge to studies of fecundity is that in most cases the fish must be sacrificed to determine the data or the fish must be held in a hatchery environment. A 41 year old pallid sturgeon that weighed 17.1kg with a GSI of 11.4% contained an estimated 170,000 eggs (Keenlyne et al. 1992). In the Gavins Point hatchery, females weighing 18.45kg and

21.86kg produced 133,737 eggs and 150,552 eggs, respectively in 1998 (Bollig 1998). There have been no studies of pallid sturgeon fecundity in the Platte River.

Artificial propagation and stocking

Part of the pallid sturgeon recovery plan (Dryer and Sandvol 1993; U.S. Fish and Wildlife Service 1993) includes stocking of fish from hatcheries to supplement their populations in the wild. Artificial propagation and stocking require careful considerations of the source of the parental stock which are used to provide fish for a specific stocking locale (U.S. Fish and Wildlife Service 2007). This concern is becoming more critical as the truly wild populations of pallid sturgeon in certain RPMA's reach senescence and die from old age (Schrey 2007; Schrey and Heist 2007; Schrey et al. 2007).

Between 1994, when the stocking program began, and 2004 nearly 69,000 pallid sturgeon have been stocked in RPMA 4 (Krentz et al. 2005). As part of this effort 401 tagged pallid sturgeon were stocked in the Platte River in 1997. In 1998 a total of 84 age 6 pallid sturgeon, of which 10 were implanted with radio transmitters, were released in the Platte River. In 1999 15 additional radio implanted pallid sturgeon were released.

Table 7. References that discuss spawning (site selection or behavior) for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BOLL-01-1998								
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	USFW-01-2007	Yes							
All	WEBB-01-2004		Yes	Yes					
All	WILD-01-2007	Yes							
Adult	BAJE-01-2007					Yes			
Adult	BOLL-01-2005		Yes			Yes			
Adult	BRAA-01-2005			Yes					
Adult	BRYA-01-2007					Yes			
Adult	CARL-01-1985					Yes	Yes		
Adult	DELO-01-2007					Yes			
Adult	DELO-02-2007					Yes			
Adult	FORB-01-1920						Yes		
Adult	GARD-01-2005		Yes						
Adult	HOOV-01-2007						Yes		
Adult	HURL-01-1998						Yes		
Adult	JAEG-01-2005			Yes					
Adult	KALL-01-1983	Yes							
Adult	KEEN-01-1992			Yes					
Adult	KEEN-01-1993			Yes		Yes	Yes	Yes	
Adult	KEEN-02-1993		Yes	Yes		Yes			
Adult	KEEN-03-1993	Yes							
Adult	KILL-01-2007						Yes		
Adult	KLUN-01-2005			Yes					
Adult	KREN-01-2005	Yes							
Adult	MURP-01-2007						Yes		
Adult	PAPO-01-2007			Yes		Yes			
Adult	PETE-01-2008								Yes
Adult	SCHW-01-2006					Yes			Yes
Adult	SHEE-01-2000						Yes		

Adult	SHUM-01-2006		Yes	Yes	Yes				
Adult	SIMP-01-2007					Yes			
Adult	STEF-01-2008					Yes			Yes
Adult	TEWS-01-1994			Yes					
Adult	USGS-01-2008			Yes		Yes			
Adult	WILD-01-2005			Yes					
Adult	WILD-01-2006					Yes	Yes		
Adult	YERK-01-2002			Yes					
Juvenile	ADAM-01-1999			Yes					
Juvenile	BAJE-01-2007					Yes			
Juvenile	BOLL-01-2005		Yes			Yes			
Juvenile	CARL-01-1985					Yes	Yes		
Juvenile	DEHA-01-2008					Yes			
Juvenile	GARD-01-2005		Yes						
Juvenile	GERR-01-2005		Yes						
Juvenile	GERR-01-2006		Yes						
Juvenile	GUYC-01-200X		Yes						
Juvenile	HOLM-01-2005			Yes		Yes			
Juvenile	HURL-01-2004								
Juvenile	JAEG-01-2005			Yes					
Juvenile	KEEN-03-1993	Yes							
Juvenile	KILL-01-2007						Yes		
Juvenile	KLUM-01-2005				Yes				
Juvenile	KLUN-01-2005			Yes					
Juvenile	KREN-01-2005	Yes							
Juvenile	MURP-01-2007						Yes		
Juvenile	PETE-01-2008								Yes
Juvenile	SCHW-01-2006					Yes			Yes
Juvenile	SHUM-01-2005				Yes				
Juvenile	SHUM-01-2006		Yes	Yes	Yes				
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes
Juvenile	STEF-01-2006					Yes			
Juvenile	STEF-01-2007					Yes			Yes
Juvenile	STEF-01-2008					Yes			Yes
Juvenile	TONE-01-2005		Yes	Yes					
Juvenile	WANN-01-2006				Yes				
Juvenile	WANN-02-2007				Yes				
Larvae	BAJE-01-2007					Yes			
Larvae	BRAA-01-2005			Yes					
Larvae	HOLM-01-2005			Yes		Yes			
Larvae	HRAB-01-2007						Yes		
Larvae	PETE-01-2008								Yes
Larvae	SIMP-01-2007					Yes			
Larvae	SNYD-01-2002								
Gametes	BRYA-01-2007					Yes			
Gametes	KEEN-01-1992			Yes					
Gametes	SIMP-01-2007					Yes			
Gametes	WILD-01-2005			Yes					
Non-specific	BROW-01-1971		Yes	Yes					
Non-specific	CARL-01-1969	Yes							
Non-specific	KEEN-01-1996	Yes							
Non-specific	KEEN-02-1992	Yes	Yes	Yes		Yes	Yes	Yes	
Non-specific	LAUS-01-2007					Yes			
Non-specific	SCHR-02-2007		Yes			Yes	Yes	Yes	
Non-specific	USEP-01-2007	Yes							
Non-specific	WEBB-01-2007								

Relationship of PRRIP hypotheses to reproduction of pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Sturgeon spawning has occurred in the lower Platte River and a mature female pallid sturgeon has been captured, tagged, and tracked in the lower Platte River. Documenting spawning by pallid sturgeon is the next step. Without this information it is difficult to conclude whether suitable spawning habitat exists. This is a difficult task and therefore continued monitoring of pallid sturgeon populations in the lower Platte River should be coordinated with ongoing efforts in the Missouri River (RPMA 4) that are tracking reproductively mature fish. In addition, by using information gathered from known sturgeon spawning areas, surveys of substrate composition within the lower Platte River should help to focus efforts to document the extent of critical spawning habitats.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

Studies of sturgeon spawning have described spawning cues for sturgeon. Since water temperature and increases in discharge are among the factors most commonly noted, it is likely that water releases in the Platte River upstream from the Loup could have positive effects on the pallid sturgeon spawning in the lower Platte River. After describing the distribution and extent of potential spawning habitat in the Platte River, correlations between water management and this habitat would provide insights to whether water related activities above the Loup River do or do not impact pallid sturgeon spawning habitat.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Since mature pallid sturgeon, captured in the Platte River, spend part or most of their life in the Missouri River it is likely that non-program actions are important to their survival and well-being. In addition, upstream non-program actions such as pesticide use and other impacts on water quantity and quality may influence the ability of sturgeon to reproduce. The relative contributions of naturally reproduced and stocked individuals to the total pallid sturgeon population in the lower Platte River will need to be assessed over the long term to determine one answer to this multi-faceted hypothesis. If the lower Platte River has suitable spawning habitat, then its benefit to the overall pallid sturgeon population may be high.

Mortality Factors

Every life stage of pallid sturgeon is susceptible to a different set of mortality factors. As with most species of fish the impact of an individual mortality factor on a population of pallid sturgeon is difficult to ascertain in a wild population and in most cases the individual factors are grouped together as natural and human caused factors. This difficulty is compounded for endangered species, like pallid sturgeon, because of their low populations (Wildhaber et al. 2007).

Natural mortality factors

There are no published accounts of specific predation on pallid sturgeon by any species of fish or other animal. However, knowledge of the general foods consumed by species associated with pallid sturgeon affords some likely candidates (Table 8). The susceptibility of pallid sturgeon and other native species adapted to turbid water conditions to predation by sight-feeding predators probably increased with clearer water conditions resulting from the dams on the Missouri River (Cross and Moss 1987; Pflieger and Grace 1987; U.S. Fish and Wildlife Service 1993). No studies of natural mortality factors for pallid sturgeon have been done in the Platte River. Tests of these relationships may be most effectively done under laboratory conditions before they are extended into open-river conditions.

Native fishes

The following is a list of potential predators on pallid sturgeon by life-stage.

Gametes: Egg predators, such as a variety of minnow and sucker species that may use shallow water habitats at or downstream from areas of egg deposition.

Embryos: Upon hatching embryos drift (Kynard et al. 2002) and planktivores, such as paddlefish, goldeye, shad species and others might prey on drifting embryos.

Larvae: During the larval stage pallid sturgeon cease drifting and begin to use habitats associated with cover on sand bars and similar low velocity habitats (Hrabik et al. 2007). Predators such as gars, bowfin, goldeye, shad, bass and sauger may be potential predators on larval sturgeon.

Juveniles: During the juvenile stage pallid sturgeon make the change from prey to predator, but large piscivores like gars, bowfin, goldeye, bass, and sauger, may be able to prey upon smaller juveniles (U.S. Fish and Wildlife Service 1993) Predation by other fish seems unlikely as the sturgeon approach adult size.

Adults: Predation by other fish seems unlikely because of the large size of adult pallid sturgeon.

N**on-native fishes**

Several species of fish have either escaped into or been stocked into habitats used by pallid sturgeon. Some of these (such as Asian carps) are from other continents. Others are reservoir or lake species from other parts of North America that have been stocked to populate the conditions created by damming the Missouri River (Walburg 1977; Walburg et al. 1971).

Embryos: Asian carps, smelt, and other species may consume drifting embryos.

Larvae: Asian carps, smelt, and other species may consume drifting larvae.

Juveniles: walleye, salmon, trout, basses, and other predatory species may consume small juveniles, but this is unlikely as the fish approach adult size.

Adults: Predation on adult pallid sturgeon is unlikely because of their size.

Other species (non-fish)

There are no published accounts of predation by non-fish species on pallid sturgeon.

Gametes: Crayfish or other benthic invertebrates may feed on eggs of many fishes.

Embryos: Filter feeding invertebrates may consume drifting embryos.

Larvae: Crayfish, predaceous aquatic insects, and mollusks may consume many species of larvae.

Juveniles: Otters or fish eating birds may consume fish in shallow water, but as juveniles approach adult size it seems unlikely that pallid sturgeon could be captured unless they were confined in isolated shallow pools or side channels.

Adults: Large fish eating birds, such as eagles or ospreys, might be able to capture an adult pallid sturgeon in shallow spawning areas (if that is where they spawn).

Diseases

Pallid sturgeon are probably susceptible to many general infections of fishes. However, Iridovirus has appeared in hatchery environments and in wild populations of pallid sturgeon and is of special concern (U.S. Fish and Wildlife Service 2007). Infections have interrupted plans for stocking some broods from Garrison Dam National Fish Hatchery. This has required testing of all fish entering hatcheries as brood stock since transmission may occur through the eggs. There are concerns that diseases, including iridovirus in wild or stocked populations will have an impact on recovery (Bergman et al. 2008; Quist et al. 2004).

Table 8. References that discuss natural mortality factors (predation or disease) for pallid sturgeon by life stage and area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BERG-01-2008	Yes							
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	WEBB-01-2004		Yes	Yes					
All	WILD-01-2007	Yes							
Juvenile	HOLM-01-2005			Yes		Yes			
Juvenile	TONE-01-2005		Yes	Yes					
Larvae	HOLM-01-2005			Yes		Yes			
Non-specific	USFW-01-2007	Yes							

Relationship of PRRIP hypotheses to natural mortality factors acting on pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

If habitat conditions in the lower Platte River are marginally suitable, then pallid sturgeon may be subjected to increased predation pressure or increased susceptibility to diseases. This will be difficult to document in the short term given the complexity of the interactions involved.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

In general, water related activities that increase water clarity will probably increase predation pressure on pallid sturgeon. Tests of the interactions between potential predators found in the Platte River and pallid sturgeon in laboratory flumes may provide insights into whether water related activities above the Loup River do or do not impact pallid sturgeon habitat as it relates to predation.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Stocking of predatory fishes, the increase in the abundance of Asian carps, and the potential for the introduction of iridovirus in wild populations of pallid sturgeon are likely the most probable non-program activities that may influence natural mortality rates acting on pallid sturgeon in the lower Platte River.

Human caused mortality factors

Human activities of many kinds have been implicated in the decline of pallid sturgeon populations (Kallemeyn 1983). In some cases (fishing or entrainment) fish may be killed directly, while in other cases migration routes may be blocked (damming), or habitats may be altered so that spawning habitat characteristics or the habitats to produce food items is degraded. This section discusses some of the more direct impacts of human activities on pallid sturgeon mortality and the references to these factors are categorized in Table 9.

Fishing

Fishing mortality is a major concern for all species of sturgeon around the world because of their late maturation and the interval between spawning (Bajer and Wildhaber 2007; Colombo et al. 2007). As discussed in the identification section of this review, the difficulty of distinguishing pallid sturgeon from shovelnose sturgeon compounds the problem since shovelnose sturgeon are legal to harvest in some states. Nebraska does not allow commercial harvest of sturgeon, but allows sport anglers to harvest shovelnose sturgeon. Missouri, Illinois, Kentucky, and Tennessee allow both commercial and sport fishing for shovelnose sturgeon in the main stem of the Missouri or Mississippi river segments that flow through their respective states. Arkansas, Mississippi, and Louisiana restrict fishing for shovelnose sturgeon to tributaries of the Mississippi River (U.S. Fish and Wildlife Service 2007).

In the Platte River, angler surveys have identified that shovelnose sturgeon are the specific objective of some sport fishers in the lower Platte River (Holland and Peters 1994). In addition, a targeted creel survey found that anglers who identified themselves as “fishing for sturgeon” were able to distinguish pallid sturgeon from shovelnose sturgeon at a higher rate than those who targeted other species or just anything (Peters and Parham 2008).

Gametes: no likely impact
Embryos: no likely impact
Larvae: no likely impact
Juveniles: Several studies have documented the impacts of fishing on the populations of sturgeons and with their low numbers pallid sturgeon cannot sustain any mortality increases and still survive (Colombo et al. 2007). Anglers and commercial fishers may not be able to discern the differences between pallid and shovelnose sturgeon. In the Platte River study, it was estimated that one or two pallid sturgeon may be accidentally harvested there each year (Peters and Parham 2008).
Adults: Poaching (illegal harvest) for caviar sale is a concern for pallid sturgeon populations (Mayden and Kuhajda 1997; U.S. Fish and Wildlife Service 2007).

Dredging

Removal of sand and silt deposits in navigation channels is a common practice in some sections of the pallid sturgeon range. This is particularly true for the lower Missouri and Mississippi rivers. Dredging removes substrate that supports invertebrate food resources (U.S. Fish and Wildlife Service 1993; U.S. Fish and Wildlife Service 2007) and changes the shape of the river bed thus effecting the hydraulic habitat for sturgeon. In the lower Platte River, dredging for navigation is not a concern, but the timing and extent of other construction activities like bridge repair may have similar impacts.

Gametes: Eggs may be disturbed if dredging occurs during a season when spawning deposits eggs.
Embryos: Embryos may be entrained during the dredging process.
Larvae: Larvae may be entrained during the dredging process and food organisms necessary for their development may be destroyed.
Juveniles: Food organisms including small fish may be destroyed and habitat for juvenile fish may be disturbed.
Adults: Spawning habitats may be destroyed, pathways for movement may be interrupted, and general habitats may be disturbed.

In the lower Platte River dredging for navigation is not a concern, but the timing and extent of other construction activities may have similar impacts.

Boats

Tow boats churn large volumes of water as they pass up and down the navigation channel. Pallid sturgeon may be entrained by the engines or washed onto the shore by the wake of the passing boats. All life stages may be affected, but gametes, embryos, larvae, and juveniles may be most seriously impacted (Wildhaber et al. 2007).

In the Platte River there is no commercial navigation and there has been no indication of problems caused by recreational boating. Disturbance of pallid sturgeon by air boats is possible, but there is no evidence of direct mortality due to impact or wakes.

Entrainment

Drifting young life stages of pallid sturgeon including small juveniles are especially susceptible to entrainment in water intakes for cooling power plants (Kynard et al. 2002; Kynard and Horgan 2001; Kynard et al. 2007). Studies have shown that they can be diverted by the use of baffles on the intake structures (Kynard and Horgan 2001).

In the lower Platte River the only potential entrainment possibilities would be due to pumping directly from the river. The potential impact of this possible factor is unknown.

Reservoir Operation

Adult pallid sturgeon can survive in reservoir habitats, but are unable to reproduce in these environments (Erickson 1992; Keenlyne 1989; Keenlyne 1995). In tail-race environments downstream from large dams, water temperatures may restrict reproduction of pallid sturgeon and other native species (National Research Council 2002). This is especially a problem below dams with hypolimnetic releases at hydroelectric power facilities. There are ongoing efforts to modify reservoir releases to enhance conditions for pallid sturgeon recovery (Braaten and Fuller 2005; Gardner 2005).

Table 9. References that discuss human mortality factors (fishing, dredging, boats, entrainment, reservoir operations, or others) for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BERG-01-2008	Yes							
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	USFW-01-2007	Yes							
All	WEBB-01-2004		Yes	Yes					
All	WILD-01-2007	Yes							
Adult	BAJE-01-2007					Yes			
Adult	BARN-01-1951						Yes		
Adult	BRAA-01-2005			Yes					
Adult	BRAM-01-1996			Yes					
Adult	BRAM-01-2001			Yes					
Adult	BROW-01-1955		Yes	Yes					
Adult	COLO-01-2007						Yes		
Adult	FISH-01-1962					Yes			
Adult	FORB-01-1905					Yes	Yes		
Adult	GARD-01-2005		Yes						
Adult	GASA-01-1970				Yes				
Adult	JAEG-01-2005			Yes					
Adult	KALL-01-1983	Yes							
Adult	KEEN-01-1989	Yes							
Adult	KEEN-03-1993	Yes							
Adult	KILL-01-2007						Yes		
Adult	NRC-01-2002	Yes							
Adult	NRC-01-2005					Yes			Yes
Adult	PETE-01-2008								Yes
Juvenile	BAJE-01-2007					Yes			
Juvenile	COLO-01-2007						Yes		
Juvenile	FISH-01-1962					Yes			
Juvenile	GERR-01-2008			Yes					
Juvenile	JAEG-01-2005			Yes					
Juvenile	KEEN-03-1993	Yes							
Juvenile	KILL-01-2007						Yes		
Juvenile	KYNA-01-2001								
Juvenile	NRC-01-2005					Yes			Yes
Juvenile	PETE-01-2008								Yes
Juvenile	WANN-01-2006				Yes				
Juvenile	WANN-01-2007				Yes				
Larvae	BAJE-01-2007					Yes			
Larvae	BRAA-01-2005			Yes					
Non-specific	COKE-01-1930						Yes		
Non-specific	CROS-01-1967					Yes			
Non-specific	CROS-01-1987					Yes			
Non-specific	KEEN-01-1995	Yes							
Non-specific	KEEN-01-1996	Yes							
Non-specific	KEEN-02-1992	Yes	Yes	Yes		Yes	Yes	Yes	
Non-specific	KYNA-01-2002			Yes					
Non-specific	KYNA-01-2007			Yes					
Non-specific	WALB-01-1977				Yes				

Relationship of PRRIP hypotheses to human caused mortality factors acting on pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Direct mortality or modification of the current habitat in the lower Platte River due to boats is low or unknown. Entrainment by water pumping operations is unknown. Releases of cold water from reservoirs is currently not a problem. Concerns about the effect of hydroelectric peaking power discharges have been expressed, but have not been documented. Fishing is the only documented human caused mortality issue in the lower Platte River and this is unrelated to the current habitat.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

It seems unlikely that water related activities above the Loup River will cause direct mortality (via boats, entrainment, and reservoir operations) on pallid sturgeon in the lower Platte River.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Evaluation of human caused mortality factors (especially fishing, entrainment, and habitat modification due to dredging and boat operations) may provide insights into whether non-program actions determine the occurrence of pallid sturgeon in the lower Platte River. In addition, evaluation of a similar suite of non-program activities in areas upstream from the lower Platte River may elucidate potential human caused mortality factors.

HABITAT USE BY PALLID STURGEON

In general, pallid sturgeon are considered to be a large turbid river species (Bailey and Allum 1962; Bailey and Cross 1954; Brown 1971; Cross 1967; Forbes and Richardson 1905; Forbes and Richardson 1920; Lee 1978; Ross 2001). While most habitat descriptions are based on juvenile or adult life stage animals, the habitat used by different life stages of pallid sturgeon vary widely (Wildhaber et al. 2007). Early descriptions of habitat use depended on where pallid sturgeon specimens were collected during general fishery studies (Bailey and Cross 1954; Barnickol and Starrett 1951; Cross 1967; Kallemeyn 1983; Kallemeyn and Novotny 1977; Keenlyne 1989). Research in Missouri River reservoirs yielded most of the information about pallid sturgeon in the 1950's to the early 1980's (Beckman and Elrod 1971; Gasaway 1970; Walburg 1977; Walburg et al. 1971). Subsequent to the Federal listing of pallid sturgeon as an endangered species, the Recovery Plan (U.S. Fish and Wildlife Service 1993) list of research needs stimulated studies to more quantitatively describe pallid sturgeon habitat needs. Habitat studies can be categorized into groups where general large-scale channel characteristics are noted (macrohabitat studies: see Table 10), where more specific point location characteristics are reported (microhabitat studies: see Table 11), or where water quality parameters are measured (see Table 12).

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Macrohabitat Factors

Channel shape and structure

Historically, most of the rivers which comprised the range of pallid sturgeon were characterized by shallow braided channels with shifting sand bars. While some of this type of river habitat still exists, much of it has been modified by dredging and training with wing dikes and other structures. The lower Platte River still retains this type of habitat over most of its length. Pallid sturgeon in the lower Platte River used areas associated with the downstream ends of sand bars and in deeper channels along the edge of sand bars (Peters and Parham 2008; Snook 2001; Snook et al. 2002; Swigle 2003). In the channelized reaches of the Missouri River (RPMA 4), pallid sturgeon used areas near wing dikes (Jacobson et al. 2007; Jacobson and Laustrup 2000; Laustrup et al. 2007), but channelized sections of the Missouri River have been considered poor habitat for native riverine species including pallid sturgeon (Carlson et al. 1985; Cross and Moss 1987; Mayden and Kuhajda 1997; Pflieger and Grace 1987). In the upper Missouri River and the Yellowstone River, studies found that pallid sturgeon were located most commonly in areas with sand bars and sandy substrate (Bramblett 1996; Bramblett and White 2001; Tews 1994). Studies in the Mississippi River (Hurley 1999; Hurley et al. 2004b; Sheehan et al. 2000; Sheehan et al. 1998) found that pallid sturgeon positively selected for main channel border, downstream island tips, between wing dams, and on wing dam tips. Conversely, these studies found negative selection for main channel, downstream from wing dams and upstream of wing dam habitats even though most of the habitat in their Mississippi River study area was comprised of main channel habitat.

Discharge and flow

River discharge can influence the amount, quality, or accessibility of riverine habitats of pallid sturgeon. In the Platte River, the amount and accessibility of habitat for pallid sturgeon were related to discharge (Peters and Parham 2008). High discharge events produce flow velocities that scour deeper channels and deposit sandbars which create and maintain the habitats favored by pallid sturgeon. In the Missouri River, a number of studies have examined how flow is related to pallid sturgeon habitat (DeLonay et al. 2007a; Jacobson et al. 2007; Jacobson and Laustrup 2000; Laustrup et al. 2007; Wildhaber et al. 2007). In the Mississippi River habitat use by pallid sturgeon was primarily associated with main channel areas during normal flows, but shifted to areas associated with wing dikes during flood flows (Hurley 1999; Hurley et al. 2004b; Sheehan et al. 2000; Sheehan et al. 1998).

Pallid sturgeon habitat can also be affected by the regulation of flows downstream from dams. Dams can change both the seasonal and daily patterns of discharge in a river. Dams are often operated to retain spring flood peaks and then release the water over a longer period. This alters the historic hydrograph and can concomitantly alter the habitat and disrupt spawning behaviors of native fishes (National Research Council 2002; National Research Council 2005). Over the past century damming and water withdrawals have altered the volume and timing of flows in the lower Platte River (Ginting et al. 2008; National Research Council 2005; Parham 2008). An analysis of lower Platte River flows in relation to sturgeon habitat has indicated the need to protect at least a portion of the current flows and the annual discharge pattern to maintain the current habitat (Peters and Parham 2008). An as yet unanswered question about flows in the lower Platte River is that of the effects of peaking power discharges on the ecosystem (Peters and Parham 2008).

In addition to changes in the amount of water discharged, outflows from dams on the Missouri River have clear and cool water from hypolimnetic releases for hydroelectric power generation. As a result, for some distance downstream from a dam the thermal habitat for pallid sturgeon is altered, especially with respect to spawning habitats (Kallemeyn 1983; Keenlyne 1989; Keenlyne 1995; Pflieger and Grace 1987).

Table 10. References that discuss macrohabitat factors for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	WILD-01-2007	Yes							
Adult	BRAM-01-1996			Yes					
Adult	BRAM-01-2001			Yes					
Adult	DELO-01-2007					Yes			
Adult	HURL-01-1998						Yes		
Adult	HURL-02-2004						Yes		
Adult	JACO-01-2000					Yes			
Adult	JACO-01-2007					Yes			
Adult	KALL-01-1977					Yes			
Adult	KALL-01-1983	Yes							
Adult	KEEN-01-1989	Yes							
Adult	NRC-01-2002	Yes							
Adult	NRC-01-2005					Yes			Yes
Adult	PAPO-01-2007			Yes		Yes			
Adult	PETE-01-2008								Yes
Adult	SEI-01-2005			Yes	Yes	Yes			
Adult	SHEE-01-1998						Yes		
Adult	SHEE-01-2000						Yes		
Adult	SIMP-01-2007					Yes			
Adult	SWIG-01-2003								Yes
Adult	TEWS-01-1994			Yes					
Adult	USGS-01-2008			Yes		Yes			
Juvenile	CARL-01-1985					Yes	Yes		
Juvenile	GERR-01-2005		Yes						
Juvenile	GERR-01-2008			Yes					
Juvenile	GUYC-01-200X		Yes						
Juvenile	HURL-02-2004						Yes		
Juvenile	JORD-01-2006				Yes				
Juvenile	NRC-01-2005					Yes			Yes
Juvenile	PETE-01-2008								Yes
Juvenile	SEI-01-2005			Yes	Yes	Yes			
Juvenile	SHEE-01-1998						Yes		
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes
Juvenile	STEF-01-2006					Yes			
Juvenile	STEF-01-2007					Yes			Yes
Juvenile	STEF-01-2008					Yes			Yes
Juvenile	WANN-01-2007				Yes				
Larvae	PETE-01-2008								Yes
Non-specific	BLEV-01-2007					Yes			
Non-specific	CROS-01-1967					Yes			
Non-specific	CROS-01-1987					Yes			
Non-specific	LAUS-01-2007					Yes			
Non-specific	PARH-01-2008								Yes
Non-specific	USEP-01-2007	Yes							

Relationship of PRRIP hypotheses to macrohabitat factors acting on pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

The macrohabitat characteristics of the lower Platte River include the complex of shallow sandbar and swift deeper channel habitats which have been described as preferred conditions for adult and juvenile pallid sturgeon.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

If changes in water related activities above the Loup River can augment the amount and influence the timing and duration of discharge in the lower Platte River, this could affect the macrohabitat channel characteristics there. Increases in discharge and appropriate timing of this discharge could positively impact the extent and quality of pallid sturgeon habitat in the lower Platte River.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

Downstream non-program actions likely have little influence on the macrohabitat channel characteristics of the lower Platte River and thus would have little influence on this aspect of pallid sturgeon occurrence in the lower Platte River. Conversely, upstream non-program actions may have significant impacts on the macrohabitat characteristics of the lower Platte River.

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Microhabitat factors

Microhabitat factors include all those parameters which may vary from one point to another where an individual of a particular species is found. For fishes these factors generally include measurements of depth, velocity, substrate, and cover. Studies which have reported microhabitat factor measurements for pallid sturgeon are summarized in Table 11.

Depth

Depth use by pallid sturgeon in various studies is widely variable. In most studies, pallid sturgeon have been found to use the deepest water available which conforms to other habitat requirements. Pallid sturgeon juveniles in a laboratory flume used deep water habitats (73-93cm) to a greater extent than expected (Allen et al. 2007).

In the Platte River, radio-tagged pallid sturgeon were found to use depths which ranged from 0.33-1.21m for hatchery-reared fish (Snook 2001; Snook et al. 2002) and averaged 1.27m for specimens caught in the Platte River (Peters and Parham 2008; Swigle 2003). Depths at which the fish caught during the 2001-2005 study by trotline, drifted gill net, and drifted trammel net averaged 1.58m (Peters and Parham 2008). These depths were deeper than those generally available in the lower Platte River, indicating that pallid sturgeon were selecting for the deepest water available and avoiding water less than 0.8m deep (Peters and Parham 2008).

In the upper Missouri River and the Yellowstone River (RPMA 1, 2) pallid sturgeon juveniles used depths which averaged 2.3-2.48m (Gerrity et al. 2005; Gerrity et al. 2008). Adults in the upper Missouri River and the Yellowstone River used 0.9-14.5m depths (Bramblett 1996; Bramblett and White 2001). However, depth use in the same area during an earlier study found that adults used depths ranging from 2.1-2.9m (Tews 1994). Pallid sturgeon in Lake Sharp used water depths that averaged 4.65m, which was greater than the average available water depth of 4.07m (Erickson 1992). In RPMA 3 juvenile pallid sturgeon used depths which were more than 3.0m and represented 80-92% of the maximum depth in the area (Jordan et al. 2006). In the Mississippi River pallid sturgeon used depths between 1.8 and 19.2m (Hurley 1999) and in the lower Missouri River they used depths greater than 2.0m (Spindler 2008). Larval pallid sturgeon were captured in trawls from the upper Mississippi River at depths from 2.1-3.6m (Hrabik et al. 2007).

Velocity

Juvenile pallid sturgeon were able to maintain their positions for 30min in a flume (Adams et al. 2003). At 10^{o}C they could maintain a speed of 15.05cm/s while at 20^{o}C they could maintain a speed of 35.93cm/s. When tested for their ability to swim for a duration (8 hours), juvenile pallid sturgeon were able to sustain their position in currents of up to 25cm/s (Adams et al. 1999). These studies found that the test fish generally swam in contact with the bottom of the flume.

Mean column velocity

Mean column velocity is a measurement commonly used for estimation of stream discharge, but as noted above this measurement may not be the velocities experienced by pallid sturgeon as they swim. However, difficulties in measuring bottom velocities in some circumstances (i.e. deep water or flood conditions) may require measurement of mean column velocity.

In the Platte River, mean column velocity at the point of capture of pallid sturgeon by trotline, drifted gill net, and drifted trammel net averaged 0.79m/s (Peters and Parham 2008). During telemetry studies, hatchery-reared pallid sturgeon were located at mean column velocities which ranged from 0.05 to 1.26 m/s (Snook 2001; Snook et al. 2002). Telemetry studies of pallid sturgeon caught from the Platte River (including presumed wild and stocked fish) were located at mean column velocities which ranged from 0.52 to 0.82m/s (Peters and Parham 2008; Swigle 2003). In comparison to available velocities, pallid sturgeon in the lower Platte River appear to avoid waters with mean column velocities slower than 0.7m/s (Peters and Parham 2008).

Bottom velocity

In the Platte River, bottom velocity at the point of capture of pallid sturgeon by trotlines, drifted gill nets, and drifted trammel nets ranged from 0.17 to 0.54m/s and averaged 0.33m/s (Peters and Parham 2008). During telemetry studies, hatchery-reared pallid sturgeon were located at bottom velocities which ranged from 0.03 to 0.88m/s (Snook 2001; Snook et al. 2002). Telemetry studies of pallid sturgeon caught from the Platte River (including presumed wild and stocked fish) were located at bottom velocities which ranged from 0.21 to 0.55m/s (Peters and Parham 2008; Swigle 2003).

In Lake Sharp, South Dakota, small pallid sturgeon (<5kg) used areas with bottom velocities which averaged 0.4m/s while large individuals (>5kg) used areas with bottom velocities averaging 0.18m/s (Erickson 1992). In the Yellowstone River, pallid sturgeon used bottom velocities which ranged from 0.0 to 1.37m/s (Bramblett 1996; Bramblett and White 2001). In the Missouri River (RPMA 3), juvenile pallid sturgeon used bottom velocities between 0.1 and 0.9m/s (Jordan et al. 2006).

Substrate

Many studies have noted the preponderance of use of sand substrate by pallid sturgeon (Bramblett 1996; Bramblett and White 2001; Hurley 1999; Hurley et al. 2004b; Peters and Parham 2008; Snook 2001; Snook et al. 2002; Swigle 2003). One laboratory study (Allen et al. 2007) found that juvenile pallid sturgeon used sand to a greater degree than expected and gravel to a lesser degree than expected. In the Platte River, average percentages of sand, silt, and gravel at pallid sturgeon telemetry contacts were 99.6%, 0.4%, and 0% respectively (Peters and Parham 2008; Snook 2001; Snook et al. 2002; Swigle 2003).

Table 11. References that discuss microhabitat factors for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	MAYD-01-1997	Yes							
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	WILD-01-2007	Yes							
Adult	BRAM-01-1996			Yes					
Adult	BRAM-01-2001			Yes					
Adult	DELO-01-2007					Yes			
Adult	ERIC-01-1992			Yes	Yes				
Adult	FORB-01-1905					Yes	Yes		
Adult	HURL-01-1998						Yes		
Adult	JACO-01-2000					Yes			
Adult	JACO-01-2007					Yes			
Adult	LEED-01-1980	Yes							
Adult	NRC-01-2005					Yes			Yes
Adult	PETE-01-2008								Yes
Adult	SEI-01-2005			Yes	Yes	Yes			
Adult	SHEE-01-1998						Yes		
Adult	SIMP-01-2007					Yes			
Adult	SWIG-01-2003								Yes
Adult	TEWS-01-1994			Yes					
Juvenile	ADAM-01-1999			Yes					
Juvenile	ADAM-01-2003			Yes					
Juvenile	ALLE-01-2007								
Juvenile	ERIC-01-1992			Yes	Yes				
Juvenile	GERR-01-2005		Yes						
Juvenile	GERR-01-2008			Yes					
Juvenile	GUYC-01-200X		Yes						
Juvenile	HURL-02-2004						Yes		
Juvenile	JORD-01-2006				Yes				
Juvenile	LEED-01-1980	Yes							
Juvenile	NRC-01-2005					Yes			Yes
Juvenile	PETE-01-2008								Yes
Juvenile	SEI-01-2005			Yes	Yes	Yes			
Juvenile	SHEE-01-1998						Yes		
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes
Juvenile	SPIN-01-2008				Yes				
Larvae	HRAB-01-2007						Yes		
Larvae	PETE-01-2008								Yes
Non-specific	CROS-01-1987					Yes			
Non-specific	KEEN-01-1996	Yes							
Non-specific	LAUS-01-2007					Yes			
Non-specific	PARH-01-2008								Yes
Non-specific	USEP-01-2007	Yes							

Relationship of PRRIP hypotheses to microhabitat factors acting on pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

> Microhabitat characteristics (depth, velocity, and substrate) of the lower Platte River appear to include the ranges of values preferred by adult and juvenile pallid sturgeon.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

> If water related activities above the Loup River augment discharge and sediment input into the lower Platte River, then it is likely that they will positively affect the microhabitat characteristics (depth, velocity, and substrate) and have a positive impact on pallid sturgeon habitats there.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River.

> Downstream non-program actions likely have little influence on the microhabitat characteristics (depth, velocity, and substrate) of the lower Platte River, and thus would have little influence on this aspect of pallid sturgeon occurrence in the lower Platte River. Upstream non-program actions which influence water depth and velocity via river discharge and sources of sandy sediment may have significant effects on the extent and quality of pallid sturgeon microhabitat characteristics in the lower Platte River.

Water Quality

Throughout the range of pallid sturgeon, water quality data are monitored by several state agencies and the U. S. Geological Survey. Some studies have included water quality measurements as a coordinated part of pallid sturgeon studies e.g. (Blevins et al. 2007; Peters and Parham 2008).

Dissolved Oxygen

Dissolved oxygen requirements for pallid sturgeon have not been specifically defined, but hatchery observations have indicated that early life history stages (embryos and larvae) are "sensitive fish" (Bollig 1998; Bollig 2005; Haukenes et al. 2008).

In the Platte River dissolved oxygen concentrations at the point of capture of pallid sturgeon by trotlines, drifted gill nets, and drifted trammel nets ranged from 7.0 to 15.8mg/L and averaged 11.6mg/L (Peters and Parham 2008). Dissolved oxygen concentrations at radio telemetry locations of hatchery-reared pallid sturgeon in the lower Platte River ranged from 4.87 to 12.83mg/L (Snook 2001; Snook et al. 2002). Telemetry studies of pallid sturgeon caught from the Platte River (including presumed wild and stocked fish) were located at dissolved oxygen concentrations which ranged from 6.71 to 18.41mg/L (Peters and Parham 2008; Swigle 2003).

Temperature

Temperature was a major factor in the critical swimming speed that juvenile pallid sturgeon could maintain for 30min in a flume (Adams et al. 2003). At 10^{o}C they could maintain a speed of 15.05cm/s while at 20^{o}C they could maintain a speed of 35.93cm/s. When tested for their ability to swim for a duration (8 hours), juvenile pallid sturgeon were able to sustain their position in currents of up to 25cm/s (Adams et al. 1999). Hurley (1999) and Hurley et al. (2004b) found difference in the habitats used by pallid sturgeon above vs. below 10^{o}C.

In the Platte River, temperature at the point of capture of pallid sturgeon by trotlines, drifted gill nets, and drifted trammel nets ranged from 9.9 to 24.9^{o}C and averaged 15.0^{o}C (Peters and Parham 2008). Temperatures at radio telemetry locations of hatchery-reared pallid sturgeon in the lower Platte River ranged from 11.4 to 33.7^{o}C (Snook 2001; Snook et al. 2002). Telemetry studies of pallid sturgeon caught from the Platte River (including presumed wild and stocked fish) were located at temperatures which ranged from 3.5 to 24.9^{o}C (Peters and Parham 2008; Swigle 2003).

Although it is not currently a problem on the lower Platte River, outflows from dams on the Missouri River have altered the thermal habitat for native species of fish, including pallid sturgeon. These thermal alterations have interrupted reproductive cycles for these fish and created a competitive advantage for other species (Kallemeyn 1983; Keenlyne 1989; Pflieger and Grace 1987).

Suspended solids / turbidity/ light

In a laboratory flume, juvenile pallid sturgeon used dark (157-273Lux) and very dark (14-156Lux) conditions to a greater extent than expected (Allen et al. 2007) while at the same time avoiding cover. Bailey and Cross (1954) and Erickson (1992) state that pallid sturgeon avoid areas of low turbidity. Studies of the retina of pallid sturgeon indicate adaptation to a turbid environment (Sillman et al. 2005).

In the Platte River, suspended solids concentrations at the point of capture of pallid sturgeon by trotlines, drifted gill nets and drifted trammel nets ranged from 110.5 to 336mg/L and averaged 171.5mg/L (Peters and Parham 2008). Total suspended solids concentrations at telemetry contacts of pallid sturgeon caught from the Platte River (including presumed wild and stocked fish) ranged from 86 to 1,228mg/L and averaged 385mg/L (Peters and Parham 2008; Swigle 2003).

There is one specific instance of the apparent response of radio-tagged pallid sturgeon to turbid water releases from a water treatment facility. Observations noted a milky color to the lower Platte River and at the same time the tagged sturgeon moved out of the Platte River to the Missouri River (Peters and Parham 2008).

Contaminants

Contaminants may affect pallid sturgeon in diverse ways. Studies of most contaminants have concentrated on standard test organisms such as fathead minnows, rainbow trout, etc. Thus far there are no studies which test contaminants on pallid sturgeon, only studies of how they are concentrated by various organs in their bodies, but there are concerns that organochlorine compounds act as endocrine disrupters (Harshbarger et al. 2000).

One study on specimens of pallid sturgeon analyzed from the Missouri River found concentrations of chlorinated hydrocarbons such as PCB's, DDT, Chlordane, and other insecticides (Ruelle and Keenlyne 1993). In addition they noted high concentrations of heavy metals which include mercury, cadmium, and selenium. More recently, a study in the Platte River (Schwarz et al. 2006) evaluated contaminant concentrations in shovelnose sturgeon as a surrogate for pallid sturgeon and also measured their concentrations in the water, food items, and the digesta of shovelnose sturgeon. Contaminants at concentrations that were judged to be a concern included PCB's, selenium, and atrazine. Schwarz et al. (2006) stated that "Pallid sturgeon may be especially at risk to contaminants in the lower Platte River that bioaccumulate and cause reproductive impairment because they have a more piscivorous diet, greater life-span, and a longer reproductive cycle than shovelnose sturgeon."

Table 12. References that discuss water quality factors (dissolved oxygen, pH, temperature, sediment, light, contaminants, or others) for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	BOLL-01-1998								
All	QUIS-01-2004	Yes							
All	USFW-01-1993	Yes							
All	WILD-01-2007	Yes							
Adult	BAIL-01-1954	Yes							
Adult	BOLL-01-2005		Yes			Yes			
Adult	BRAA-01-2005			Yes					
Adult	BRAM-01-2001			Yes					
Adult	DELO-01-2007					Yes			
Adult	ERIC-01-1992			Yes	Yes				
Adult	GASA-01-1970				Yes				
Adult	HARS-01-2000						Yes		
Adult	HURL-01-1998						Yes		
Adult	KEEN-01-1989	Yes							
Adult	KILL-02-2007						Yes	Yes	
Adult	LEED-01-1980	Yes							
Adult	PETE-01-2008								Yes
Adult	RUEL-01-1993			Yes		Yes			
Adult	SCHW-01-2006					Yes			Yes
Adult	SEI-01-2005			Yes	Yes	Yes			
Adult	SHEE-01-1998						Yes		
Adult	SIMP-01-2007					Yes			
Adult	SWIG-01-2003								Yes
Adult	TEWS-01-1994			Yes					
Adult	USGS-01-2008			Yes		Yes			
Adult	YERK-01-2002			Yes					
Juvenile	ADAM-01-1999			Yes					
Juvenile	ADAM-01-2003			Yes					
Juvenile	ALLE-01-2007								
Juvenile	ERIC-01-1992			Yes	Yes				
Juvenile	HAUK-01-2008								
Juvenile	HURL-02-2004						Yes		
Juvenile	KLUM-01-2005				Yes				
Juvenile	LEED-01-1980	Yes							
Juvenile	PETE-01-2008								Yes
Juvenile	SCHW-01-2006					Yes			Yes
Juvenile	SEI-01-2005			Yes	Yes	Yes			
Juvenile	SHEE-01-1998						Yes		
Juvenile	SILL-01-2005								
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes
Juvenile	TONE-01-2005		Yes	Yes					
Juvenile	WANN-01-2006				Yes				
Juvenile	YERK-01-2002			Yes					
Larvae	BRAA-01-2005			Yes					
Larvae	HRAB-01-2007						Yes		

Larvae	PETE-01-2008								Yes
Larvae	YERK-01-2002			Yes					
Free Embryo	USGS-01-2006			Yes					
Non-specific	BLEV-01-2007					Yes			
Non-specific	CROS-01-1987					Yes			
Non-specific	KEEN-01-1995	Yes							
Non-specific	KEEN-01-1996	Yes							
Non-specific	USEP-01-2007	Yes							

Relationship of PRRIP hypotheses to water quality factors acting on pallid sturgeon

PS-1: Current habitat in the lower Platte River is/is not suitable for adult and juvenile pallid sturgeon.

Water quality in the lower Platte River seems to be suitable for pallid sturgeon, but some contaminant levels may have long term consequences for natural reproduction.

PS-2: Water related activities above the Loup River do/do not impact pallid sturgeon habitat.

Water related activities in the Platte River upstream from the Loup River may have impacts on water quality in the lower Platte River.

PS-3: Non-Program actions (e.g., harvest, stocking, Missouri River conditions) determine the occurrence of pallid sturgeon in the lower Platte River

Upstream non-program actions within the drainage basin of the lower Platte River (i.e. the Loup and Elkhorn river drainages) may have impacts on water quality conditions for pallid sturgeon. Downstream non-program actions are not likely to affect water quality in the Platte River, but since pallid sturgeon move between the lower Platte and the Missouri River water quality or contaminants may affect the health of the fish that move back into the Platte River.

SAMPLING GEAR

The study of pallid sturgeon has led to refinements on how to collect and study these rare species in areas which are difficult to sample. Many of these techniques have evolved from collaborations with commercial fishers who, because of their years of experience, have been expert ecological observers. In fact, early workers on pallid sturgeon (Bailey and Cross 1954; Forbes and Richardson 1905) made use of commercial fishermen to collect their specimens and provide habitat data. In some studies, this continues today even though commercial fishing for pallid sturgeon is illegal (Hurley et al. 2004b). Until recently most techniques for sampling pallid sturgeon were not quantitatively evaluated, but now studies are being published which have analyzed the effectiveness of the use of trawls, drifted trammel nets and trotlines (Wanner 2006; Wanner et al. 2007a).

The most recent addition to the techniques used for evaluating the ecology of pallid sturgeon includes radio and sonic telemetry (Hurley et al. 2004b; Peters and Parham 2008; Swigle 2003). These techniques, coupled with tags which are able to record water depth and temperature where fish are located, have given valuable insights to sturgeon biology (DeLonay et al. 2007b). In addition, it may be possible to locate sturgeon using hydrophones to listen for the sounds they produce (Johnston and Phillips 2003). Table 13 lists citations which have used a variety of these tools to study pallid sturgeon biology.

Table 13. References that discuss sampling techniques (drift nets, hoop nets, gill nets, hook & line, trotlines, electrofishing, telemetry, or others) for pallid sturgeon by life stage and study area.

Life Stage	Ref ID	Basin-wide	RPMA 1	RPMA 2	RPMA 3	RPMA 4	RPMA 5	RPMA 6	Platte River
All	SEI-01-2008	Yes							
Adult	BRAA-01-2005			Yes					
Adult	BRAM-01-1996			Yes					
Adult	BRAM-01-2001			Yes					
Adult	CARL-01-1985					Yes	Yes		
Adult	DELO-01-2007					Yes			
Adult	DELO-02-2007					Yes			
Adult	ERIC-01-1992			Yes	Yes				
Adult	FISH-01-1962					Yes			
Adult	FORB-01-1905					Yes	Yes		
Adult	GASA-01-1970				Yes				
Adult	JOHN-01-2003						Yes		
Adult	KALL-01-1977					Yes			
Adult	KILL-02-2007						Yes	Yes	
Adult	MURP-02-2007						Yes		
Adult	PAPO-01-2007			Yes		Yes			
Adult	PETE-01-2008								Yes
Adult	SEI-01-2004			Yes	Yes	Yes			
Adult	SEI-01-2005			Yes	Yes	Yes			
Adult	SHEE-01-1998						Yes		
Adult	SWIG-01-2003								Yes
Adult	TEWS-01-1994			Yes					
Adult	USFW-01-2005		Yes	Yes					
Adult	YERK-01-2002			Yes					
Juvenile	ERIC-01-1992			Yes	Yes				
Juvenile	GERR-01-2005		Yes						
Juvenile	GUYC-01-200X		Yes						
Juvenile	HURL-02-2004						Yes		
Juvenile	JORD-01-2006				Yes				
Juvenile	KLUN-01-2005			Yes					
Juvenile	MURP-02-2007								
Juvenile	PETE-01-2008								Yes
Juvenile	SEI-01-2004			Yes	Yes	Yes			
Juvenile	SEI-01-2005			Yes	Yes	Yes			
Juvenile	SHEE-01-1998						Yes		
Juvenile	SHUM-01-2005				Yes				
Juvenile	SNOO-01-2001					Yes			Yes
Juvenile	SNOO-01-2002					Yes			Yes

Juvenile	STEF-01-2006					Yes			
Juvenile	STEF-01-2007					Yes			Yes
Juvenile	STEF-01-2008					Yes			Yes
Juvenile	USFW-01-2005		Yes	Yes					
Juvenile	WANN-01-2006				Yes				
Juvenile	WANN-01-2007				Yes				
Juvenile	YERK-01-2002			Yes					
Larvae	BRAA-01-2005			Yes					
Larvae	PETE-01-2008								Yes
Larvae	YERK-01-2002			Yes					
Non-specific	WALB-01-1977				Yes				

Although these techniques do not directly impact the hypotheses articulated by the PRRIP, we think that this information may be useful in future evaluations of research protocols that the program may receive from specific requests for proposals.

CURRENT AND PROPOSED RESEARCH EFFORTS

In 1993, the pallid sturgeon recovery plan (U.S. Fish and Wildlife Service 1993) articulated what was known about pallid sturgeon and identified a recovery plan which included the categories of research needed for survival and recovery of the pallid sturgeon.

In 2004, a group of scientists and managers was assembled in Bloomington, MN to examine research and assessment needs for pallid sturgeon recovery in the Missouri River (Quist et al. 2004). At about the same time the pallid sturgeon assessment program in the upper basin was being evaluated (Sustainable Ecosystems Institute 2004; Sustainable Ecosystems Institute 2005; Webb et al. 2004).

In 2007, a similar group of scientists and managers from throughout the range of pallid sturgeon was assembled in St Louis, MO to evaluate research needs and management alternatives for pallid sturgeon recovery (Bergman et al. 2008). This meeting had the benefit of two major documents; the pallid sturgeon summary and review (U.S. Fish and Wildlife Service 2007) and a conceptual life history model (Wildhaber et al. 2007) both of which provided a framework for discussions. Again the upper basin program was reviewed as a separate unit (Sustainable Ecosystems Institute 2008). All of these reviews have made recommendations on research and management needs for pallid sturgeon recovery. Annual meetings of the Upper Basin Pallid Sturgeon Recovery Work Group receive reports from researchers and managers who have conducted studies in RPMA 1 and 2 e.g. (Bollig 2005; Braaten and Fuller 2005; Gardner 2005; Gerrity et al. 2005; Jaeger et al. 2005; Klungle and Baxter 2005; Shuman et al. 2005; Toner 2005; U.S. Fish and Wildlife Service 2005). From these reports, work plans are developed e.g. (Upper Basin Pallid Sturgeon Workgroup 2005).

RPMA 4

In 2008 the Middle Basin Pallid Sturgeon Workgroup (RPMA 4) ranked the ten highest research priorities that were outlined in the William D. Ruckelshaus Institute of Environment and Natural Resources Report (Bergman et al. 2008). These ten highest research priorities are listed here.

1. Examine habitat requirements and use by pallid sturgeon age 1+ and determine which habitats are used, suitable and limiting. Long term.
2. Examine habitat requirements and use by larvae and age 0 juveniles and determine which habitats are used, suitable, and limiting. Long term.
3. Determine parameters that best characterize spawning habitat in the Middle Basin and create common range-wide approaches on how to characterize that habitat. Long term.
4. Describe environmental factors that influence maturation and spawning movements, including homing. Long term.
5. Describe food habits and determine ontogenetic diet shifts of larvae and age 0 juveniles. Ongoing.
6. Describe food habits and determine ontogenetic diet shifts for age 1+. Short term.
7. Describe the role of shallow water habitats for juvenile pallid sturgeon. Long term.
8. Evaluate the Middle Basin pallid sturgeon stocking program. Short term.
9. Develop population viability models. Ongoing.
10. Determine existing populations of adult pallid sturgeon in the Middle Missouri River Basin. Ongoing.

Because the lower Platte is directly connected to the middle Missouri River, it seems that coordination of research efforts between the basins is prudent.

RPMA 5

Studies in the middle Mississippi River have concentrated on habitat, movement, and demographics of the pallid sturgeon and the following objectives have been completed (Robert Hrabik, Missouri Department of Conservation, personal communication):

- Quantify available adult non-reproductive habitat
- Determine preference for adult habitat
- Assess seasonal movement of adults in the context of reproduction
- Estimate population growth, size and age structure, and mortality rate
- Develop genetic tools for identifying hybridization and separation between species
- Assess the impact of other human-induced factors such as harvest and pollution
- Generate strategies for mitigating human effects (e.g., identify habitat characteristics to be emulated in the MMR; reduce harvest of sensitive individuals) and develop techniques to quantify benefits to species.

A report from this work to the US Army Corps of Engineers includes chapters on:

* A comparison of sampling techniques for capturing sturgeon species in the middle Mississippi River
*Sizes and Relative Abundance of Sturgeon in the Free-Flowing Mississippi River
*Habitat Selection and Movement

*Morphomeristics
*Genetic Discrimination and Stock Structure
*Demographics and Adult Mortality
*Gonadal Development of Sturgeon
*Diets of Wild-Caught Pallid Sturgeon
*Embryological Development
*Aging Precision.

Remaining work still in progress includes a preliminary assessment of sturgeon reproduction in the middle Mississippi River includes the following objectives:

* Using Ultrasonic Telemetry to Identify Potential Spawning Aggregations of Sturgeon in the middle Mississippi River
* Early-Life History of Naturally Occurring Sturgeon in the middle Mississippi River.

LITERATURE CITED

Adams, S. R., G. L. Adams, and G. R. Parsons. 2003. Critical swimming speed and behavior of juvenile shovelnose sturgeon and pallid sturgeon. Transactions of the American Fisheries Society 132(2):392-397.

Adams, S. R., J. J. Hoover, and K. J. Killgore. 1999. Swimming endurance of juvenile pallid sturgeon S*caphirhynchus albus*. Copeia 3:802-807.

Allen, T. C., Q. E. Phelps, R. D. Davinroy, and D. M. Lamm. 2007. A laboratory examination of substrate, water depth, and light use at two water velocity levels by individual juvenile pallid (*Scaphirhynchus albus*) and shovelnose (*Scaphirhynchus platorynchus*) sturgeon. Journal of Applied Ichthyology 23:375-381.

Bailey, R. M., and M. O. Allum. 1962. Fishes of South Dakota. University of MIchigan Museum of Zoology. Miscellanous Publication No. 119, Ann Arbor, Michigan.

Bailey, R. M., and F. B. Cross. 1954. River sturgeons of the American genus *Scaphirhynchus*: characters, distribution, and synonymy. Michigan Academy of Science, Arts, and Letters 39:169-208.

Bajer, P. G., and M. L. Wildhaber. 2007. Population viability analysis of lower Missouri River shovelnose sturgeon with initial application to the pallid sturgeon. Journal of Applied Ichthyology 23:457-464.

Barnickol, P. G., and W. C. Starrett. 1951. Commercial and sport fishes of the Mississippi River between Caruthersville, Missouri, and Dubuque, Iowa. Bulletin of the Illinois Natural History Survey 25(5):266-350.

Beckman, L. G., and J. H. Elrod. 1971. Apparent abundance and distribution of young-of year fishes in Lake Oahe, 1965-69. Pages 333-347 *in* G. E. Hall, editor. Reservoir Fisheries and Limnology. Special Publication No. 8. American Fisheries Society, Washington, D.C.

Bergman, H. L., and coauthors. 2008. Research needs and management strategies for pallid sturgeon recovery. Proceedings of a workshop held July 31-August 2, 2007, St Louis, Missouri. William D. Ruckelshaus Institute of Environmental and Natural Resources, University of Wyoming, Final Report, Laramie, Wyoming.

Birstein, V. J., P. Doukakis, and R. DeSalle. 2002. Molecular phylogeny of Acipenseridae: Nonmonophyly of Scaphirhynchinae. Copeia 2002(2):287-301.

Bischof, R., and A. L. Szalanski. 2000. Mitochondrial-DNA variation in pallid and shovelnose sturgeons, *Scaphirhynchus* (Pisces: Acipenseridae). Transactions of the Nebraska Academy of Sciences 26:19-21.

Blevins, D. W., and coauthors. 2007. Water quality and hydrology. Pages 256-279 *in* C. E. Korschgen, editor. Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. U.S. Geological Survey, Reston, Virginia.

Bollig, H. 1998. Fiscal year 1998 sturgeon activities and accomplishments. Gavins Point National Fish Hatchery, Yankton, South Dakota.

Bollig, H. 2005. Fiscal year 2004 sturgeon activities and accomplishments. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Braaten, P. J., and D. B. Fuller. 2005. Fort Peck flow modification biological data collection plan summary of 2004 activities. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Braaten, P. J., and coauthors. 2008. Drift dynamics of larval pallid sturgeon and shovelnose sturgeon in a natural side channel of the upper Missouri River, Montana. North American Journal of Fisheries Management 28:808-826.

Bramblett, R. G. 1996. Habitats and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers, Montana and North Dakota. Doctoral dissertation. Montana State University-Bozeman, Bozeman, Montana.

Bramblett, R. G., and R. G. White. 2001. Habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130(6):1006-1025.

Brown, C. J. D. 1955. A record-size pallid sturgeon, *Scaphirhynchus album*, from Montana. Copeia 1955(1):55.

Brown, C. J. D. 1971. Fishes of Montana. Big Sky Books, Montana State University, Bozeman, Montana.

Bryan, J. L., and coauthors. 2007. Estimation of gonad volume, fecundity, and reproductive stage of shovelnose sturgeon using sonography and endoscopy with application to the endangered pallid sturgeon. Journal of Applied Ichthyology 23:411-419.

Buchanan, T. M. 1973. Key to the Fishes of Arkansas. Arkansas Game and Fish Commission, Little Rock, Arkansas.

Campton, D. E., A. L. Bass, F. A. Chapman, and B. W. Bowen. 2000. Genetic distinction of pallid, shovelnose, and Alabama sturgeon: emerging species and the US Endangered Species Act. Conservation Genetics 1:17-32.

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Iowa State University Press, Ames, Iowa.

Carlson, D. M., W. L. Pfieger, L. Trial, and P. S. Haverland. 1985. Distribution, biology and hybridization of *Scaphirhynchus albus* and *S. platorynchus* in the Missouri and Mississippi Rivers. Environmental Biology of Fishes 14(1):51-59.

Carroll, A. M., and P. C. Wainwright. 2003. Functional morphology of prey capture in the sturgeon, *Scaphirhynchus albus*. Journal of Morphology 256:270-284.

Coker, R. E. 1930. Studies of common fishes of the Mississippi River at Keokuk. U.S. Bureau of Fisheries Bulletin 45 Fisheries Document No.1072, Washington, D.C.

Colombo, R. E., and coauthors. 2007. Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse? Journal of Applied Ichthyology 23:444-451.

Cross, F. B. 1967. Handbook of fishes of Kansas. University of Kansas Museum of Natural History, Lawrence, Kansas.

Cross, F. B., and R. E. Moss. 1987. Historic changes in fish communitites and aquatic habitats in plains streams of Kansas. Pages 155-165 *in* W. J. Matthews, and D. C. Heins, editors. Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma.

DeHaan, P. W., G. R. Jordan, and W. R. Ardren. 2008. Use of genetic tags to identify captive-bred pallid sturgeon (Scaphirhynchus albus) in the wild: improving abundance estimates for an endangered species. Conservation Genetics 9:691-697.

DeLonay, A. J., and coauthors. 2007a. Project overview. Pages 3-23 *in* C. E. Korschgen, editor. Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. U.S. Geological Survey, Reston, Virginia.

DeLonay, A. J., and coauthors. 2007b. Use of behavioral and physiological indicators to evaluate *Scaphirhynchus* sturgeon spawning success. Journal of Applied Ichthyology 23:428-435.

DeLonay, A. J., and coauthors. 2007c. Movement, habitat use, and reproductive behavior of shovelnose sturgeon and pallid sturgeon in the lower Missouri River. Pages 23-107 *in* C. E. Korschgen, editor. Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. U.S. Geological Survey, Reston, Virginia.

Dillman, C. B., and coauthors. 2007. Molecular systematics of Scaphirynchinae: an assessment of North American and Central Asian freshwater sturgeon species. Journal of Applied Ichthyology 23:290-296.

Dryer, M. P., and A. J. Sandvol. 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*) See USFW- 01-1993.

Duffy, W. G., C. R. Berry, and K. D. Keenlyne. 1996. The pallid sturgeon biology and annotated bibliography through 1994. South Dakota Cooperative Fish and Wildlife Research Unit, Brookings, South Dakota.

Erickson, J. D. 1992. Habitat selection and movement of pallid sturgeon in Lake Sharpe, South Dakota. Master's Thesis. South Dakota State University, Brookings, South Dakota.

Fisher, H. J. 1962. Some fishes of the lower Missouri River. American Midland Naturalist 68(2):424-429.

Forbes, S. A., and R. E. Richardson. 1905. On a new shovelnose sturgeon from the Mississippi River. Bulletin of the Illinois State Laboratory of Natural History 7:37-44.

Forbes, S. A., and R. E. Richardson. 1920. Fishes of Illinois, 2nd edition. Illinois Natural History Survey, Danville, Illinois.

Gardner, B. 2005. 2004 Pallid sturgeon recovery efforts in the upper Missouri River, Montana (RPMA #1). Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Gasaway, C. R. 1970. Changes in the fish population in Lake Francis Case in South Dakota in the first 16 years of impoundment. Fish and Wildlife Service, Techinical paper No. 56, Washington, D.C.

Genetic Analyses Inc. 1994. Genetic studies of *Scaphirynchus* spp. US Army Corps of Engineers, Contract # DACW45-92-C-0064, Omaha, Nebraska.

Gerrity, P. C., C. S. Guy, and W. M. Gardner. 2005. Habitat use, diet, and growth of hatchery-reared juvenile pallid sturgeon and indigenous shovelnose sturgeon in the Missouri River above Fort Peck Reservoir, Montana. Upper Basis Pallid Sturgeon, 2004 Annual Report, Helena, Montana.

Gerrity, P. C., C. S. Guy, and W. M. Gardner. 2006. Juvenile pallid sturgeon are piscivorous: a call for conserving native cyprinids. Transactions of the American Fisheries Society 135:604-609.

Gerrity, P. C., C. S. Guy, and W. M. Gardner. 2008. Habitat use of juvenile pallid sturgeon and shovelnose sturgeon with implications for water-level management in a downstream reservoir. North American Journal of Fisheries Management 28:832-843.

Ginting, D., B. R. Zelt, and I. J. Linard. 2008. Temporal differences in the hydrologic regime of the Lower Platte River, Nebraska, 1895-2006. U.S. Geological Survey, Scientific Investigations Report 2007-5267, Reston, Virginia.

Harshbarger, J. C., M. J. Coffey, and M. Y. Young. 2000. Intersexes in Mississippi River shovelnose sturgeon sampled below Saint Louis, Missouri, USA. Marine Environmental Research 50:247-250.

Haukenes, A. H., B. A. Barton, and H. Bollig. 2008. Cortisol responses of pallid sturgeon and yellow perch following challenge with lipopolysaccharide. Journal of Fish Biology 72:780-784.

Holland, R. S., and E. J. Peters. 1994. Biological and economic analyses of the fish communities in the Platte River: creel survey of fishing pressure along the lower Platte River. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Hoover, J. J., S. G. George, and K. J. Killgore. 2007. Diet of shovelnose sturgeon and pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23:494-499.

Hrabik, R. A., D. P. Herzog, D. E. Ostendorf, and M. D. Petersen. 2007. Larvae provide first evidence of successful reproduction by pallid sturgeon, *Scaphirhynchus albus*, in the Mississippi River. Journal of Applied Ichthyology 23:436-443.

Hurley, K. L. 1998. Habitat use, selection, and movements of middle Mississippi River pallid sturgeon and validity of pallid sturgeon age estimates from pectoral fin rays. Master's thesis. Southern Illinois University at Carbondale, Carbondale, Illinois.

Hurley, K. L. 1999. Habitat use, selection, and movements of middle Mississippi River pallid sturgeon and validity of pallid sturgeon age estimates from pectoral fin rays. Master's thesis. Southern Illinois University at Carbondale, Carbondale, Illinois.

Hurley, K. L., R. J. Sheehan, and R. C. Heidinger. 2004a. Accuracy and precision of age estimates for pallid sturgeon from pectoral fin rays. North American Journal of Fisheries Management 24(2):715-718.

Hurley, K. L., R. J. Sheehan, R. C. Heidinger, P. S. Wills, and B. Clevenstine. 2004b. Habitat use by middle Mississippi River pallid sturgeon. Transactions of the American Fisheries Society 133(4):1033-1041.

Jacobson, R. B., H. E. Johnson, J. M. Reuter, and C. M. Elliott. 2007. The roles of physical habitat in reproduction and survival of pallid sturgeon and shovelnose sturgeon in the lower Missouri River, progress 2005-06. Pages 143-217 *in* C. E. Korschgen, editor. Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. U.S. Geological Survey, Reston, Virginia.

Jacobson, R. B., and M. S. Laustrup. 2000. Habitat assessment for pallid sturgeon overwintering surveys, lower Missouri River. U.S. Geological Survey, Columbia, Missouri.

Jaeger, M., G. Jordan, and S. Camp. 2005. Assessment of the suitability of the Yellowstone River for pallid sturgeon restoration efforts: annual report for 2004. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Johnston, C. E., and C. T. Phillips. 2003. Sound production in sturgeon *Scaphirhycus albus* and *S. platorynchus* (Acipenseridae). Environmental Biology of Fishes 68:59-64.

Jordan, G. R., R. A. Klumb, G. A. Wanner, and W. J. Stancill. 2006. Poststocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. Transactions of the American Fisheries Society 135(6):1499-1511.

Kallemeyn, L. W. 1983. Status of the pallid sturgeon. Fisheries 8(1):3-9.

Kallemeyn, L. W., and J. F. Novotny. 1977. Fish and fish food organisms in various habitats of the Missouri River in South Dakota, Nebraska, and Iowa. U.S. Fish and Wildlife Service, FWS/OBS-77/25, Columbia, Missouri.

Keenlyne, K. D. 1989. A report on the pallid sturgeon. U.S. Fish and Wildlife Service, Pierre, South Dakota.

Keenlyne, K. D. 1995. Recent North American studies on pallid sturgeon, *Scaphirhynchus albus* (Forbes and Richardson). Pages 225-234 *in* A. D. Gershanovich, and T. I. J. Smith, editors. International Symposium on Sturgeons. VNIRO Publishing, Moscow, Russia.

Keenlyne, K. D. 1996. Validity of the pallid sturgeon as a species - an issue paper prepared for the Pallid Sturgeon Recovery Team. U.S. Fish and Wildlife Service, Pierre, South Dakota.

Keenlyne, K. D., and P. D. Evenson. 1993. Standard and relative weight for the pallid sturgeon, *Scaphirhynchus albus*. Proceedings of the South Dakota Academy of Science 72:41-49.

Keenlyne, K. D., L. K. Graham, and B. C. Reed. 1994a. Hybridization between the pallid and shovelnose sturgeons. Proceedings of the South Dakota Academy of Science 73:59-66.

Keenlyne, K. D., E. M. Grossman, and L. G. Jenkins. 1992. Fecundity of the pallid sturgeon. Transactions of the American Fisheries Society 121:139-140.

Keenlyne, K. D., C. J. Henry, A. Tews, and P. Clancey. 1994b. Morphometric comparisons of upper Missouri River sturgeons. Transactions of the American Fisheries Society 123(5):779-785.

Keenlyne, K. D., and L. G. Jenkins. 1993. Age at sexual maturity of the pallid sturgeon. Transactions of the American Fisheries Society 122:393-396.

Keenlyne, K. D., and S. J. Maxwell. 1992. Ponderal index studies on the pallid sturgeon (*Scaphirhynchus albus*). U.S. Fish and Wildlife Service, Pierre, South Dakota.

Keenlyne, K. D., and S. J. Maxwell. 1993. Length conversions and length-weight relations for pallid sturgeon. North American Journal of Fisheries Management 13(2):395-397.

Killgore, K. J., and coauthors. 2007a. Distribution, relative abundance and movements of pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23:476-483.

Killgore, K. J., and coauthors. 2007b. Age and growth of pallid sturgeon in the free-flowing Mississippi River. Journal of Applied Ichthyology 23:452-456.

Klungle, M. M., and M. W. Baxter. 2005. Lower Missouri and Yellowstone Rivers pallid sturgeon study 2004 report. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Krentz, S., and coauthors. 2005. Pallid sturgeon spawning and stocking summary report 1992 - 2004. U.S. Fish and Wildlife Service, Bismarck, North Dakota.

Kuhajda, B. R., R. L. Mayden, and R. M. Wood. 2007. Morphologic comparisons of hatchery-reared specimens of *Scaphirhynchus albus*, *Scaphirhynchus platorynchus,* and *S. albus* x *S. platorynchus* hybrids (Acipenseriformes: Acipenseridae). Journal of Applied Ichthyology 23:324-347.

Kynard, B., E. Henyey, and M. Horgan. 2002. Ontogenetic behavior, migration, and social behavior of pallid sturgeon, *Scaphirhynchus albus*, and shovelnose sturgeon, *S. platorynchus*, with notes on the adaptive significance of body color. Environmental Biology of Fishes 63:389-403.

Kynard, B., and M. Horgan. 2001. Guidance of yearling shortnose and pallid sturgeon using vertical bar rack and louver arrays. North American Journal of Fisheries Management 21(3):561-570.

Kynard, B., E. Parker, D. Pugh, and T. Parker. 2007. Use of laboratory studies to develop a dispersal model for Missouri River pallid sturgeon early life intervals. Journal of Applied Ichthyology 23:365-374.

Laustrup, M. S., R. B. Jacobson, and D. G. Simpkins. 2007. Distribution of potential spawning habitat for sturgeon in the lower Missouri River. U.S. Geological Survey, Open-File Report 2007-1192, Reston, Virginia.

Lee, D. S. 1978. *Scaphirhynchus albus* (Forbes and Richardson). Pages 43 *in* D. S. Lee, and coeditors, editors. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Publication 1980-12, Raleigh, North Carolina.

Mayden, R. L., and B. R. Kuhajda. 1997. Threatened fishes of the world: *Scaphirhynchus albus* (Forbes & Richardson, 1905) (Acipenseridae). Environmental Biology of Fishes 48:420-421.

McQuown, E. C., and coauthors. 2000. Microsatellite analysis of genetic variation in sturgeon: new primer sequences for *Scaphirhynchus* and *Acipenser*. Transactions of the American Fisheries Society 129(6):1380-1388.

Murphy, C. E., J. J. Hoover, S. G. George, and K. J. Killgore. 2007a. Morphometric variation among river sturgeons (*Scaphirhynchus* spp.) of the middle and lower Mississippi River. Journal of Applied Ichthyology 23:313-323.

Murphy, C. E., J. J. Hoover, S. G. George, B. R. Lewis, and K. J. Killgore. 2007b. Types and occurrence of morphological anomalies in *Scaphirhynchus* spp. of the middle and lower Mississippi River. Journal of Applied Ichthyology 23:354-358.

National Research Council. 2002. The Missouri River ecosystem: exploring the prospects for recovery. National Academy Press, Washington, D.C.

National Research Council. 2005. Endangered and threatened species of the Platte River. National Academy Press, Washington, D.C.

Papoulias, D. M., M. L. Annis, A. J. DeLonay, and D. E. Tillitt. 2007. Reproductive physiology of Missouri River gravid pallid sturgeon and shovelnose sturgeon during the 2005 and 2006 spawning seasons. Pages 107-143 *in* C. E. Korschgen, editor. Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. U.S. Geological Survey, Reston, Virginia.

Parham, J. E. 2008. Hydrologic analysis of the lower Platte River from 1954 - 2004, with special emphasis on habitats of the endangered least tern, piping plover, and pallid sturgeon. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Peters, E. J., and J. E. Parham. 2008. Ecology and management of sturgeon in the lower Platte River, Nebraska. Nebraska Game and Parks Commission, Nebraska Technical Series No. 18, Lincoln, Nebraska.

Pflieger, W. L., and T. B. Grace. 1987. Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-177 *in* W. J. Matthews, and D. C. Heins, editors. Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman Oklahoma.

Phelps, S. R., and F. W. Allendorf. 1983. Genetic identity of pallid and shovelnose sturgeon (*Scaphirhynchus albus* and *S. platorynchus*). Copeia 3:696-700.

Quist, M. C., and coauthors. 2004. Research and assessment needs for pallid sturgeon recovery in the Missouri River. Proceedings of a conference held on May 18-20, 2004, Bloomington, MN. William D. Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Final Report, Laramie, Wyoming.

Ray, J. M., C. B. Dillman, R. M. Wood, B. R. Kuhajda, and R. L. Mayden. 2007. Microsatellite variation among river sturgeons of the genus *Scaphirhynchus* (Actinopterygii: Acipenseridae): a preliminary assessment of hybridization. Journal of Applied Ichthyology 23:304-312.

Ross, S. T. 2001. The inland fishes of Mississippi. University Press of Mississippi, Jackson, Mississippi.

Ruelle, R., and K. D. Keenlyne. 1993. Contaminants in Missouri River pallid sturgeon. Bulletin of Environmental Contamination and Toxicology 50:898-906.

Schrey, A. W. 2007. Discriminating pallid sturgeon (*Scaphirhynchus albus*) and shovelnose sturgeon (*S. platorhynchus*) and intraspecific geographic variation based on genetic and morphological characters. Doctoral dissertation. Southern Illinois University, Carbondale, Illinois.

Schrey, A. W., and E. J. Heist. 2007. Stock structure of pallid sturgeon analyzed with microsatellite loci. Journal of Applied Ichthyology 23:297-303.

Schrey, A. W., B. L. Sloss, R. J. Sheehan, R. C. Heidinger, and E. J. Heist. 2007. Genetics discrimination of middle Mississippi River *Scaphirhynchus* sturgeon into pallid, shovelnose, and putative hybrids with multiple microsatellite loci. Conservation Genetics 8:683-693.

Schwarz, M. S., C. D. Lydick, D. E. Tillitt, D. M. Papoulias, and T. S. Gross. 2006. A health risk evaluation for pallid sturgeon (*Scaphirhynchus albus*) in the lower Platte River using shovelnose sturgeon (*Scaphirhynchus platorynchus*) as a surrogate. U.S. Fish and Wildlife Service, Division of Environmental Quality, Region 6, Final Report, Grand Island, Nebraska.

Sheehan, R. J., R. C. Heidinger, K. L. Hurley, P. S. Wills, and M. Nuevo. 2000. Middle Mississippi River pallid sturgeon habitat use project. Fisheries Research Laboratory, Southern Illinois University, Annual Progress Report - Year 4, Carbondale, Illinois.

Sheehan, R. J., R. C. Heidinger, K. L. Hurley, P. S. Wills, and M. A. Schmidt. 1998. Middle Mississippi River pallid sturgeon habitat use project. Fisheries Research Laboratory, Southern Illinois University, Annual Progress Report - Year 3, Carbondale, Illinois.

Sheehan, R. J., and coauthors. 1999. Guide to the pallid sturgeon shovelnose sturgeon character index (CI) and morphometric character index (mCI). Fisheries Research Laboratory, Southern Illinois University, SIUC Fisheries Bulletin No.14, Carbondale, Illinois.

Shuman, D. A., R. A. Klumb, and S. T. McAlpin. 2005. Pallid sturgeon population assessment and associated fish community monitoring for the Missouri River: segments 5 and 6. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Shuman, D. A., D. W. Willis, and S. C. Krentz. 2006. Application of a length-categorization system for pallid sturgeon (*Scaphirhynchus albus*). Journal of Freshwater Ecology 21(1):71-76.

Sillman, A. J., A. K. Beach, D. A. Dahlin, and E. R. Loew. 2005. Photoreceptors and visual pigments in the retina of the fully anadromous green sturgeon (*Acipenser medirosturs*) and the potamodromous sturgeon (*Scaphirynchus albus*). Journal of Comparative Physiology A 191:799-811.

Simons, A. M., R. M. Wood, L. S. Heath, B. R. Kuhajda, and R. L. Mayden. 2001. Phylogenetics of *Scaphirhynchus* based on mitochondrial DNA sequences. Transactions of the American Fisheries Society 130:359-366.

Simpkins, D. G., and S. R. LaBay. 2007. Site-specific assessment of spawning behavior and habitat use. Pages 217-255 *in* C. E. Korschgen, editor. Factors Affecting the Reproduction, Recruitment, Habitat, and Population Dynamics of Pallid Sturgeon and Shovelnose Sturgeon in the Missouri River. U.S. Geological Survey, Reston, Virginia.

Snook, V. A. 2001. Movements and habitat use by hatchery-reared pallid sturgeon in the lower Platte River, Nebraska. Master's thesis. University of Nebraska-Lincoln, Lincoln, Nebraska.

Snook, V. A., E. J. Peters, and L. J. Young. 2002. Movements and habitat use by hatchery-reared pallid sturgeon in the lower Platte River, Nebraska. Pages 161-173 *in* Webster Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, management, and protection of North American sturgeon American Fisheries Society, Bethesda, Maryland.

Snyder, D. E. 1999. Pallid and shovelnose sturgeon larvae-morphological development and identification. Department of Fishery and Wildlife Biology, Larval Fish Laboratory, Colorado State University, Contribution No. 106, Fort Collins, Colorado.

Snyder, D. E. 2002. Pallid and shovelnose sturgeon larvae-morphological description and identification. Journal of Applied Ichthyology 18:240-265.

Spindler, B. D. 2008. Modeling spatial distribution and habitat associations for juvenile pallid sturgeon (*Scaphirhynchus albus*) in the Missouri River. Master's thesis. South Dakota State University, Brookings, South Dakota.

Steffensen, K. D., and T. Barada. 2006. 2005 Annual Report, Pallid sturgeon population assessment project and associated fish community monitoring for the Missouri River: segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D., and M. J. Hamel. 2007. 2006 Annual Report, Pallid sturgeon population assessment project and associated fish community monitoring for the Missouri River: segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Steffensen, K. D., and M. J. Hamel. 2008. 2007 Annual Report, Pallid sturgeon population assessment project and associated fish community monitoring for the Missouri River: segment 9. Nebraska Game and Parks Commission, Lincoln, Nebraska.

Sustainable Ecosystems Institute. 2004. Power to detect trends in pallid and shovelnose sturgeon populations in the Missouri River. Sustainable Ecosystems Institute, Portland, Oregon.

Sustainable Ecosystems Institute. 2005. Independent science review of the pallid sturgeon assessment program: Final report. Sustainable Ecosystems Institute, Portland, Oregon.

Sustainable Ecosystems Institute. 2008. Review of comprehensive sturgeon research program. Sustainable Ecosystems Institute, Portland, Oregon.

Swigle, B. D. 2003. Movements and habitat use by shovelnose and pallid sturgeon in the lower Platte River, Nebraska. Master's thesis. University of Nebraska-Lincoln, Lincoln, Nebraska.

Tews, A. 1994. Pallid sturgeon and shovelnose sturgeon in the Missouri River from Fort Peck Dam to Lake Sakakawea and in the Yellowstone from intake to its mouth. Montana Department of Fish, Wildlife, and Parks, Helena, Montana.

Toner, M. 2005. Pallid sturgeon annual report 2004. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

Tranah, G. J., D. E. Campton, and B. May. 2004. Genetic evidence for hybridization of pallid and shovelnose sturgeon. Journal of Heredity 95(6):474-480.

U.S. Fish and Wildlife Service. 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*). U.S. Fish and Wildlife Service, Bismarck, North Dakota.

U.S. Fish and Wildlife Service. 2004. The pallid sturgeon : draft annotated bibliography through 2003, Bismarck, North Dakota.

U.S. Fish and Wildlife Service. 2005. Draft 2004 progress report: Post spawn pallid sturgeon telemetry report. Upper Basin Pallid Sturgeon Workgroup, 2004 Annual Report, Helena, Montana.

U.S. Fish and Wildlife Service. 2007. Pallid sturgeon (*Scaphirhynchus albus*) 5-year review summary and evaluation. U.S. Fish and Wildlife Service, Billings, Montana.

Upper Basin Pallid Sturgeon Workgroup. 2005. Upper basin pallid sturgeon recovery workgroup, 2004 annual report. Montana Fish, Wildlife and Parks, Helena, Montana.

Walburg, C. H. 1977. Lake Francis Case, a Missouri River reservoir: changes in the fish population in 1954-75, and suggestions for management. U.S. Fish and Wildlife Service, Technical paper No. 95, Washington, D.C.

Walburg, C. H., G. L. Kaiser, and P. L. Hudson. 1971. Lewis and Clark Lake tailwater biota and some relations of the tailwater and reservoir fish populations. Pages 449-467 *in* G. E. Hall, editor. Reservoir Fisheries and Limnology. Special Publication No. 8. American Fisheries Society, Washington, D.C.

Wanner, G. A. 2006. Sampling techniques for juvenile pallid sturgeon and the condition and food habits of sturgeon in the Missouri River below Fort Randall Dam, South Dakota. Master's thesis. South Dakota State University, Brookings, South Dakota.

Wanner, G. A., D. A. Shuman, M. L. Brown, and D. W. Willis. 2007a. An initial assessment of sampling procedures for juvenile pallid sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska. Journal of Applied Ichthyology 23:529-538.

Wanner, G. A., D. A. Shuman, and D. W. Willis. 2007b. Food habits of juvenile pallid sturgeon and adult shovelnose sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota. Journal of Freshwater Ecology 22(1):81-92.

Webb, M. A. H., J. E. Williams, and L. R. Hildebrand. 2004. Review of the recovery program for the endangered pallid sturgeon in the upper Missouri River basin. Department of Fish and Wildlife, Corvallis Oregon.

Wildhaber, M. L., and J. L. Bryan. 2006. Ultrasonic and endoscopic examination of lower Missouri and lower Mississippi pallid sturgeon to determine sex and 2006 broodstock potential. U.S. Geological Survey, Columbia, Missouri.

Wildhaber, M. L., and coauthors. 2007. A conceptual life-history model for pallid and shovelnose sturgeon. U.S. Geological Survey, Circular 1315, Reston, Virginia.

Wildhaber, M. L., and coauthors. 2005. Gender identification of shovelnose sturgeon using ultrasonic and endoscopic imagery and the application of the method to the pallid sturgeon. Journal of Fish Biology 67:114-132.

Yerk, D. B., and M. W. Baxter. 2002. Lower Missouri and Yellowstone Rivers pallid sturgeon study 2001 annual report. Montana Fish, Wildlife and Parks, Fort Peck, Montana.