

CRYSTAL DARTER STATUS ASSESSMENT REPORT

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DISCLAIMER

This document is a compilation of biological data and a description of past, present, and likely future threats to the crystal darter, *Crystallaria asprella* (Jordan). It does not represent a decision by the U.S. Fish and Wildlife Service (Service) on whether this taxon should be designated as a candidate species for listing as threatened or endangered under the Federal Endangered Species Act. That decision will be made by the Service after reviewing this document; other relevant biological and threat data not included herein; and all relevant laws, regulations, and policies. The result of the decision will be posted on the Service's Region 3 Web site (refer to: http://midwest.fws.gov/eco_serv/endangrd/lists/concern.html). If designated as a candidate species, the taxon will subsequently be added to the Service's candidate species list that is periodically published in the Federal Register and posted on the World Wide Web (refer to: <http://endangered.fws.gov/wildlife.html>). Even if the taxon does not warrant candidate status it should benefit from the conservation recommendations that are contained in this document.

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SYSTEMATICS

Common Name(s): crystal darter

Scientific Name

Crystallaria asprella (Jordan)

Taxonomy

The crystal darter was first described by Jordan (1878) as *Pleurolepis asprellus*, the rough sand darter. Since its first description (Jordan 1878), the crystal darter has undergone several nomenclatural changes. *Pleurolepis* Putnam 1863 was preoccupied by *Pleurolepis* Wuenstedt 1852 (a fossil fish) and, as a junior homonym, was unavailable (Eschmeyer 1990). Jordan and Gilbert (1882) assigned the crystal darter to the genus *Ammocrypta*. Later, *A. asprellus* was moved to the monotypic genus *Crystallaria* (Jordan 1885) based on the presence of nonprotrusible premaxillae and a high number of dorsal fin spines and rays relative to other members of the genus *Ammocrypta*. Gilbert (1888) created a monogeneric classification for the darters, *Etheostoma*, which persisted until Jordan and Evermann (1896) created 15 genera in an attempt to reestablish the darter relational history. The number of genera was later increased to 31 (Jordan et al. 1930).

Bailey et al. (1954) devised a trigenic nomenclature that is widely accepted today. The genus *Percina* includes darters with modified midventral scales. Both *Ammocrypta* and *Crystallaria* were reassigned subgeneric ranking in the genus *Ammocrypta* based on their elongated shape, single anal spine, translucent flesh, and their peculiar behavior of burying themselves in the sand. All remaining darters were placed in the genus *Etheostoma*.

Simons (1991) provided evidence that the morphological characteristics common to *Ammocrypta* and *Crystallaria*, as described by Bailey et al. (1954), are a result of convergence rather than homology. Simons (1991) suggested a modified trigenic nomenclature that preserves both *Percina* and *Etheostoma* (now inclusive of the subgenus *Ammocrypta*) but elevates *Crystallaria* to generic status based on its monotypic origin. Simons (1991) asserted that the genus *Ammocrypta* is polyphyletic and that its members are more closely related to the *Boleosoma* group of the genus *Etheostoma* than to *C. asprella*. Recent descriptions of *Ammocrypta* and *Crystallaria* early life stages by Simon et al. (1992) support the elevation of *Crystallaria* to generic status, as suggested by Simons (1991). Treating *Crystallaria* as a genus was supported by the larval study conducted by Simon et al. (1992), and has broad support from North American ichthyologists. Simons' (1991) suggested synonymy of *Ammocrypta* (subgenus *Ammocrypta*) with genus *Etheostoma* was neither supported nor firmly rejected by Simon et al. (1992). *Ammocrypta* will presumably continue to be used as the generic name for the smaller sand darters in the forthcoming list of common and scientific names of North American fishes (J.S. Nelson, chairperson, Names Committee, North American Society of Ichthyologists and Herpetologists / American Fisheries Society, pers. comm. with coauthor D. Etnier).

Wood and Raley (2000) evaluated the genetic variation of existing crystal darter populations by sequencing the mitochondrially encoded cytochrome *b* gene. In four of the five populations analyzed, individuals differed from each other by an average sequence divergence of no more than 0.64 percent. Sequence divergence between populations ranged from 1.4 percent between

the Pearl River (Louisiana) and Cahaba River (Alabama) populations to an average of 11 percent between the Elk River (West Virginia) population and each of the other populations. This high divergence of the Elk River population is among the highest intraspecific divergence values reported for a fish species and is more typical of interspecific or intergeneric divergence (Wood and Raley 2000). Morrison et al. (*in press*) later verified these results by examining two unlinked loci and comparing body shape and size measurements between the same populations studied by Wood and Raley (2000). These studies indicate that dispersal barriers have been an effective isolating mechanism for the Elk River population and have likely existed for a long period of time. Wood and Raley (2000) suggest that these results warrant the consideration of each known population as an evolutionary significant unit and that *C. asprella* likely represents more than one species given the degree of genetic divergence between populations, and the amount of internal cohesion with respect to genetic divergence within the populations. Wood and Raley (2000) also speculated that Elk River specimens are most likely an undescribed species rather than a crystal darter population.

PHYSICAL DESCRIPTION AND CHARACTERISTICS

The crystal darter is a member of the Perch family (Percidae) which contains such common game species as walleye (*Stizostedion vitreum*), sauger (*Stizostedion canadense*), and yellow perch (*Perca flavescens*). The family Percidae is a group of freshwater fishes characterized by the presence of a dorsal fin separated into two parts, one spiny and the other soft (Kuehne and Barbour 1983). The darters differ from their larger relatives in being much smaller and having a more slender shape. Darters have small jaw, palatine, and prevomerine teeth, and the absence or reduction of the swim bladder reduces buoyancy, allowing them to remain near the bottom substrate with little effort (Kuehne and Barbour 1983).

The crystal darter, is a slender, cigar shaped fish with a distinctly forked tail and pronounced snout (see Figure 1 in Appendix 1- sketch by Samuel Eddy). As one of the largest darters, it reaches up to an average of 130 millimeters (mm) standard length (SL) (Kuehne and Barbour 1983, Page 1983). The largest specimen on record is 166 mm total length (TL) (Lutterbie 1979). Unlike many of its colorful darter relatives, the crystal darter is mostly translucent, although some cryptic coloration is present. The dorsal surface is yellowish and crossed by four darkened "saddles" that are concave anteriorly and extend laterally to the midlateral stripe. Dark brown mottling is often present in the areas between the saddles or, if the saddles are absent, on the entire dorsal half of the body (Page 1983). The ventral surface is generally white or silvery, giving it a colorless appearance. Crystal darter coloration varies geographically, with specimens collected in the northern extent of its distribution often lacking the characteristic translucence (Katula 2003). Darker specimens display a yellow-green coloration on the gill cover (opercle) and cheek region (Katula 2003). The top of the flattened head is darkened with a dark brown stripe and around the snout, extending between the eyes to the upper lip. The fins are typically colorless, although the second dorsal and pectoral fins may be slightly darkened by concentric rows of brown stipples. The caudal fin is colorless except along the posterior margin which may also have darkened bands of pigment. Anal, pelvic, and pectoral rays are clear.

Superficially, the crystal darter resembles the eastern sand darter (*Ammocrypta pellucida*) but has more lateral-line scales and dorsal-fin rays in addition to the dark saddles across the dorsum

(Stauffer et al. 1995). A morphological comparison between the crystal and eastern sand darter is provided in Table 1. The crystal darter's cheek and opercle are partly scaled. The breast may have embedded scales between the pelvic fins but may also be unscaled. Similarly, the belly contains scattered, partially embedded scales. The nape is also scaled.

Table 1. Morphological comparison between crystal and eastern sand darters (data from Page 1983).

Trait	<i>C. asprella</i>	<i>A. pellucida</i>
lateral scales	81-93	62-84
scales above lateral line	7-8	0-7
scales below lateral line	9-15	2-10
transverse scales	19-26	3-18
scales around caudal peduncle	25-30	22-26
dorsal spines	12-15	7-12
dorsal rays	12-15	8-12
pectoral rays	15-17	12-16
anal spines	1	1
anal rays	12-15	7-11
branchiostegal rays	6	6
vertebrae	45-48	42-45

In a detailed study of early-life-stage morphology, Simon et al. (1992) documented the hatchling size of *C. asprella* at 7 mm TL. Upon hatching, protolarvae have well developed jaws, pectoral fins, spherical and pigmented eyes, a single midventral vitellin vein, and the head is not deflected over the yolk sac. The yolk sac is small (23 percent of TL) with 23 to 25 preanal myomeres and 19 to 24 postanal myomeres. Breast pigmentation begins to develop at 9 to 11 mm TL. Yolk absorption was complete between 10 and 11 mm TL. The beginning of the mesolarval stage is marked by the development of caudal-fin rays at 11 mm TL. George et al. (1996) found that young of year males grow faster than females of the same age, although the maximum adult SL was similar for both sexes.

BIOLOGY AND NATURAL HISTORY

Darters get their name because of their habit of swimming short distances in rapid bursts along the stream bottom (Winn 1958a, 1958b). As with darters in the genus *Ammocrypta*, the crystal darter buries itself in sandy substrates with only its eyes protruding, and can be observed darting out of the sand to pursue passing prey (Kuehne and Barbour 1983, Page 1983). In addition to the prey-capturing hypothesis, there are alternative hypotheses for the burying behavior in the crystal darter and darters in the genus *Ammocrypta*. These include predator avoidance and energy conservation (Williams 1975). In a series of experiments investigating the burying behavior in *Ammocrypta pellucida*, Daniels (1989) found no evidence for the prey-capturing or

predator avoidance hypotheses. The energy conservation hypothesis (Williams 1975) could not be rejected, although Daniels (1989) suggests that it may be incomplete since a negative rather than positive relationship between current velocity and burying was detected. The conclusion reached by Daniels (1989) suggests that *A. pellucida* buries itself in sandy substrates to stabilize its immediate environment in response to changing current velocity and turbulence. Similar proximate cues likely influence the burying behavior in *C. asprella*.

Crystal darter habitat is described by Page (1983) as comprised of large creeks and rivers with extensive clean sand and gravel raceways. Individuals generally inhabit waters deeper than 60 centimeters (cm) with strong currents (Page 1983). Rarely are crystal darters collected when current velocities are lower than 32 cm/second (George et al. 1996). George et al. (1996) collected crystal darters in water from 114 to 148 cm deep with current velocities between 46 and 90 cm/second in stretches with a predominantly gravel substratum with some small cobble and patches of sand. Hatch (1998) collected specimens in channel-margin areas of the Mississippi River where the substrata was comprised of coarse sand and gravel with some embedded cobble and boulder. Whereas other studies have captured crystal darters in association with wing dams along the Mississippi River (e.g. Schmidt 1995), all the specimens detected by Hatch (1998) were downstream from wing dams at depths greater than 180 cm. Page (1983) suggests that substrate composition is the most restrictive habitat characteristic for darters in general. However, it is often difficult to distinguish between substrate composition, current velocity, and water depth since they are so interrelated (Page 1983). Hatch (1998) hypothesized that crystal darters may occupy habitats that can not be effectively sampled, thereby resulting in conservative estimates of population size and mentioned that those specimens encountered during sampling are juveniles occupying less desirable habitat.

Forbes (1880) examined the stomach contents of three crystal darter specimens and found that midge larvae comprised most of their diet along with small diptera and mayfly larvae. Similarly, Hatch (1998) provides a description of crystal darter food habits in the Mississippi River. Of 19 stomachs examined, a total of 314 food items, including 11 taxa of insects, 2 taxa of microcrustaceans, and one water mite taxon, were identified. The number of food items found in crystal darter stomachs sampled from the Mississippi River ranged from 0 to 80, with an average of 16 food items. Microcrustaceans appeared to be an important component of the juvenile diet both in terms of biomass and numbers consumed (Hatch 1998). Older specimens contained more midge (Chironomidae) and caddisfly (Hydropsychidae: *Hydropsyche* and *Potomyia*) larvae. Water mites contributed little to the overall biomass consumed (Hatch 1998).

Investigating the breeding biology of the crystal darter in the Saline River of Arkansas, George et al. (1996) observed that spawning occurs from January through mid-April. This early reproductive season, followed by rapid growth of the young of year, resulted in individuals from the Saline population maturing before age 1. As a consequence, *C. asprella* most likely spawn during the season immediately after hatch (George et al. 1996). Females become sexually mature by 50 mm TL (George et al. 1996). Page (1983) notes that most darter species reach sexual maturity at one year of age, although northern populations may take longer. Simon et al. (1992), working with Tallapoosa River (Alabama) specimens, observed the onset of spawning behavior in late February and breeding seemed to last for approximately one week. The reason for such disparity in breeding season timing and length is uncertain, although Hubbs (1985) discovered latitudinal differences in reproductive timing among darter populations. Geographic

variation in morphology has been observed (George et al. 1996) and geography could have an influence on other aspects of the crystal darter's biology and natural history. For example, differing environmental conditions such as flow regimes, photoperiod, and temperature may play a role in body size differences between northern and southern populations observed by George et al. (1996). Monthly ovum diameter was the smallest between May and September with noticeable increases occurring in October and November, and continuing through January and into March (George et al. 1996). Multiple oocyte size classes were observed in the same female, indicating the possibility of multiple clutches within a single season (George et al. 1996). According to Page (1983), all eggs are not necessarily laid in one season. Clutch sizes averaged 195 ova and a positive correlation was found between standard length and clutch size (George et al. 1996).

In a study of *C. asprella* in Minnesota, Hatch (1998) observed rapid growth rates by the end of the first growing season based on TL (80 to 100 mm) and weight (3 to 5 grams) measurements. Young-of-the-year in Minnesota were considerably larger and longer lived than those sampled in other studies (George et al. 1996) although small sample sizes prevented statistical comparisons between studies. Despite small sample size, Hatch (1998) suggests that the difference in longevity, growth rate, and size in northern populations may be a reflection of phenotypic plasticity or genetic divergence. Males grow at a faster rate than females, a disparity that could be a result of the energy allocated to reproduction by females (George et al. 1996). George et al. (1996) described initial maturation of crystal darter testes in September with enlargement occurring by October. Breeding males develop tubercles on the rays of the anal and pelvic fins (Kuehne and Barbour 1983, Page 1983). George et al. (1996) observed tubercle development in late October and an absence of tubercles during May through August. George et al. (1996) also report the discovery of minute breeding tubercles on female *C. asprella*, which are thought to facilitate contact between the sexes when spawning (Collette 1965). It is difficult, however, to extrapolate from these regionally localized studies to populations across the entire crystal darter distribution because of differences in seasonal photo-periodicity and temperature (Hatch 1998).

Females select sites for egg deposition (Page 1983). Stationary females are mounted by one to several males and eggs are subsequently deposited beneath the substrate where they become attached to sand particles (Simon et al. 1992). Life expectancy for crystal darters has been estimated at two (George et al. 1996) or three (Lutterbie 1979) years.

RANGE

Historical Distribution

Historically, the crystal darter was found within the Mississippi River basin from Wisconsin and Minnesota east to Ohio and south to Oklahoma, Louisiana, and Florida (Page 1983) and on the Gulf slope in the Escambia, Mobile Bay, and Pearl River drainages (Page and Burr 1991), see Figure 2 in Appendix 1. Though at one time widespread, the crystal darter was most likely rare throughout its historical range (Page and Burr 1991). Although biologists generally agree that populations have declined throughout its range, the status of crystal darter populations in most streams remains uncertain.

Occurrence records prior to 1970 exist for the Alabama (1928), Cahaba (1954), Coosa (1889), Tallapoosa (1959), and upper and lower Tombigbee (1968) rivers in Alabama (Smith-Vaniz 1968); the eastern Saline River (1969) and War Eagle Creek (1968) in Arkansas (Robison and Buchanan 1988; Brian Wagner, Arkansas Game & Fish Commission, pers. comm.); the Escambia River (1972) in Florida (Gilbert 1992); the upper Mississippi (1878), Rock (pre 1900), Little Wabash (pre 1900), and Wabash (pre 1900) rivers in Illinois (Smith 1979); Laughery Creek (1887), and the Ohio (pre 1892) and Wabash (1888) rivers in Indiana (Jordan 1890, Evermann and Jenkins 1892); the Green (1890) and Ohio (1899) rivers in Kentucky (Woolman 1892, Burr and Warren 1986); the Bogue Chitto (1968) and Pearl (1968) rivers in Louisiana (Douglas 1974); the Mississippi (1955) and Zumbro (1961) rivers in Minnesota (Eddy and Underhill 1974, Hatch 1998); the Buttahatchie (1964), Pearl (1939), and Tombigbee (1939) rivers and Trim Cane Creek (1931) in Mississippi (Cook 1959, Ross 2001); the Big (1963), Black (1947), Gasconade (1937), Little (1964), Meramec (1947), and St. Francis (1937) rivers and Ditch No. 1 (1940), and No. 290 (1940) in Missouri (Pflieger 1971, 1975); the Muskingum (1888) and Ohio (1899) rivers in Ohio (Trautman 1981); and the Cumberland (1870) and Roaring (1939) rivers in Tennessee (Etnier and Starnes 1993); the Mississippi (1935) and Wisconsin (1962) rivers in Wisconsin (Becker 1983).

Current Distribution

The crystal darter has not been collected since 1899 in Indiana and Ohio, 1929 in Kentucky, and 1939 in Tennessee (Hatch 1998). Information obtained from personal communication with scientific professionals within the crystal darter's historic range was used to provide additional detail on the current distribution (see Appendix 2 for Contact Information). Summaries of these personal communications follow.

Alabama: Michael Barbour (Alabama Natural Heritage Program, pers. comm.) reported that crystal darters are currently restricted to larger rivers within the Mobile Bay drainage and the lower courses of their major tributaries. Jeff Powell (US Fish & Wildlife Service, pers. comm.) noted that crystal darter surveys were recently conducted on the Alabama, Conecuh and Tombigbee Rivers in 1998 - 1999 and on the Cahaba River from 1996 through 1999 (Shepard et al. 1999). Occurrence records since 1970 exist for Baldwin County - Alabama River (1973, 1999); Bibb County - Cahaba River (1978, 1984, 1985, 1996); Clarke County - Tombigbee River (1983) and Alabama River (1999); Dallas County - Alabama River (1999), Cahaba River (1984, 1985, 1989, 1993, 1996, 1997), and Cedar Creek (1980); Elmore County Alabama River (1999); Escambia County - Conecuh River (1981, 1998) with an additional record from 1993 cited in Mettee et al. 1996; Greene County - Tombigbee River (no specific dates); Macon County -

Uphapee Creek (1979); Monroe County - Alabama River (1980, 1998); Perry County - Cahaba River (1978, 1984, 1985, 1996, 1997); Pickens County - Big Creek (no specific dates) and Tombigbee River (1972, also several records with no specific date); Sumter County - Tombigbee River (no specific dates); Wilcox County - Alabama River (1970 through 1981, 1990) and Cedar Creek (1974). Many of these rivers are included in the Alabama Rivers Discovery Expedition (ALRDE), an initiative of the Alabama Department of Conservation and Natural Resources.

Arkansas: Cindy Osborne (Arkansas Natural Heritage Commission, pers. comm.) provided a distribution map of crystal darter occurrence in Arkansas (Figure 3 in Appendix 1). Crystal darters have been recently detected in the Little Missouri (1991), Ouachita (1993), and Saline (1993) rivers and Moro Creek (1985) in south-central Arkansas, the Black River (1980) in eastern Arkansas, and the Strawberry River (1976) in north central Arkansas. A 1971 record exists for Indian Bayou as well.

Florida: Gilbert (1992) described the collection of a single crystal darter specimen from the Escambia River in 1972. The most recent occurrences were reported by Yerger and Beecher (1975) and Beecher et al. (1977). However, Dr. Stephen Walsh (USGS - Florida Caribbean Science Center, pers. comm.) reported that he was unable to find any specimens in extensive surveying efforts in the Escambia River during 2001 and 2002.

Illinois: Dr. Brooks M. Burr (Southern Illinois University, pers. comm.) cited the lone record of crystal darter occurrence in Illinois waters taken in the Mississippi River near Cottonwood Island downstream of Grand Tower (Perry County) in 1998. Previously, crystal darters had not been seen or collected since 1901 in the state (Hatch 1998).

Indiana: Brant Fisher (Indiana Department of Natural Resources, pers. comm.) provided the following account concerning crystal darter distribution in Indiana waters: "There are no recent records (post 1900) for crystal darter in Indiana. Historical records indicate that it inhabited the lower portion of the Wabash River from at least Knox to Posey counties and Laughery Creek and the Ohio River in southeastern Indiana. Presumably it inhabited the entire length of the Ohio River along the southern border of Indiana, although there are no further records to substantiate this claim."

Iowa: John Olson (Iowa Department of Natural Resources, pers. comm.) indicated that several isolated locations bordering Clayton County in the Mississippi River and the lower reaches of the Turkey River currently support crystal darter populations. Historically, one record exists for the Mississippi River across from the mouth of the Turkey River near Grant County, Wisconsin. Other than the occasional occurrence in waters adjacent to Minnesota and Wisconsin, no records exist between 1930 and 1990 for Iowa waters. Bowler (2001), however, reported a single 1995 collection from the Mississippi River, Pool 11 during a Iowa Department of Natural Resources (IDNR) catfish study. Additionally, Olson (pers. comm.) reported that IDNR fisheries biologists collected a single specimen in 2001, above the mouth of the Turkey River along the Iowa shoreline. In 2002, another specimen was collected from the Turkey River near Elkader. J. Olson (pers. comm.) suggests that the crystal darter is more common in the Upper Mississippi River basin than originally believed, although high quality habitat for the species remains scarce. Whether these recent detections indicate higher abundances relative to historical records or reflect improved sampling techniques remains uncertain.

Kentucky: Ron Cicerello (Kentucky State Nature Preserves Commission, pers. comm.) reported that biologists have re-sampled historical collection sites with apparently suitable habitat without success. The crystal darter is considered extirpated in Kentucky and has not been collected in Kentucky since 1929 (Burr and Warren 1986).

Louisiana: Ines Maxit (Louisiana Natural Heritage Program, pers. comm.) provided documentation of recent crystal darter occurrence in Morehouse Parish - Bayou Bartholomew (1980); Ouachita Parish - Ouachita River (1979, 1980); St. Tammany Parish - Bogue Chitto River (1998) and Evens Creek (1975); Union Parish - Ouachita River (1980); Washington Parish - Bogue Chitto River (1971, 1974). Maxit (pers. comm.) reported that the crystal darter had not been collected from the Red River until a recent (2002) fish inventory by Dr. Frank Pezold, of the University of Louisiana at Monroe, detected one specimen in Bossier Parish.

Minnesota: Rich Baker (Minnesota Department of Natural Resources, Natural Heritage and Nongame Research Program, pers. comm.) noted that the crystal darter reaches the northern limit of its range in the Mississippi River in Minnesota. According to Hatch (1998), recent occurrence records exist for Wabasha County - Mississippi River, Pool 4 (1994) and Pool 5A (1980, 1995), and Zumbro River (1984, 1985); and St. Croix County - St. Croix River (1982). Konrad Schmidt (Minnesota Department of Natural Resources, pers. comm.) provided additional occurrence records for Wabasha County - Zumbro River (1993); Chisago - St. Croix River (1998); and Houston County - Root River (1998).

Mississippi: Alison Sherman (Mississippi Natural Heritage Program, pers. comm.) reported that the crystal darter was once abundant in the Tombigbee River but has not been collected there since 1981, shortly after the completion of the Tenn-Tom Waterway. It is likely that the crystal darter is extirpated from the Tombigbee system with the possible exception of the Buttahatchee River. Recent occurrence records exist for Clairborne County - Bayou Pierre (1974, 1976, 1978, 1986); Copiah County - Bayou Pierre (1970, 1972, 1975, 1976) and Foster (1976) and White Oak (1972) creeks; Franklin County - Homochitto River (1973); Hancock County - Pearl River (1980); Itawamba County - Buttahatchie (1972) and Tombigbee (1972, 1979) rivers and Bull Mountain Creek (1979, 1981); Lawrence County - Pearl River (1974, 1976, 1977, 1979, 1980, 1981); Lowndes County - Bayou Pierre (1976), Buttahatchie (1971, 1972, 1974), Pearl (1973, 1978), and Tombigbee (1971, 1972, 1976) rivers and Yellow Creek (1973); Marion County - Pearl River (1976); and Monroe County - Buttahatchie (1971, 1972, 1980) and Tombigbee (1972) rivers.

Missouri: Matt Winston (Missouri Department of Conservation, pers. comm.) contributed occurrence records for Butler County - Black River (1947, 1964, 1992, 1995, 1999, 2000) and St. Francis River (1941 and 1964); Dunklin County - Ditch No.1 (1940) and St. Francis River (1941 and 1963); Franklin County - Meramec River (1947, 1999, 2000); Gasconade County - Gasconade River (1963, 1980, 1989, 2000); Jefferson County - Big River (1963) and Meramec River (2000); Maries County - Gasconade River (1997); New Madrid County - Ditch No. 1 (1962 and 1964) and Little River (1964); Osage County - Gasconade River (1947); Pemiscot County - Ditch No.290 (1941 and 1964); Phelps County - Gasconade River (1961 and 1997); St. Louis County - Meramec River (1947, 1954, 2000); Wayne County - St. Francis River (1937, 1941, 1947).

Ohio: Dr. Ted Cavender (Ohio State University, pers. comm.) and Randy Sanders (Ohio Department of Natural Resources, pers. comm.) reported that despite historic occurrences in Ohio waters, crystal darters have not been collected since 1899. At the time of collection, navigation dams were low lift wicket dams; much different from the high lift dams currently in place. Current water levels are much deeper and beyond the reach of seine nets. In addition, day and night shoreline electrofishing efforts have failed to detect crystal darters.

Oklahoma: Jeff Kelly (Oklahoma Natural Heritage Inventory, pers. comm.) provided occurrence information from McCurtain County - Little River (1974, 1975, 1984, 1990); Pushmataha County - Kiamichi River (1990, 1991).

West Virginia: Dan Cincotta (West Virginia Department of Natural Resources, pers. comm.) described crystal darter occurrence in West Virginia, beginning with its first collection from the Elk River of the lower Kanawha drainage near Mink Shoals in 1980. The darter was not detected again until 1991, approximately 18 miles upstream near the town of Clendenin. To date, only eight specimens have been collected in the state. All specimens have come from Kanawha County - Elk River (1980, 1991).

Wisconsin: John Lyons (Wisconsin Department of Natural Resources, pers. comm.) reported the occurrence of crystal darters in Grant County - Mississippi River, Pool 11 (2001) and Wisconsin River (1998, 1999, 2001, 2002); Pepin County - Chippewa River (1989, 1997); Polk and St. Croix County - St. Croix River (1978, 1982, 1998). K. Schmidt (pers. comm.) provided additional records for Dunn County - Chippewa River (1994, 1995, 1996).

POPULATION ESTIMATES AND TRENDS

The crystal darter has never been considered common or abundant. It is thought that the species has undergone population declines over much of its current distribution; given survey data indicating that it is extirpated from much of its historical range, including all of Ohio, Indiana, Illinois, Tennessee, and Kentucky (Page 1983, Etnier and Starnes 1993). For example, Wood and Raley (2000) have concluded that "...the species is in serious decline,...the likelihood of its recovery may be remote, and...we may be observing a species approaching extinction." Unfortunately, due to the relative rarity of crystal darters across their current range, thorough quantitative evaluations of population trends are lacking. For example, only eight specimens, thought to be the single extant population in West Virginia, have been collected in the Elk River in West Virginia (D. Cincotta, pers. comm.). As a result, many fisheries biologists are forced to designate the population status as unknown. Although quantitative abundance data for the crystal darter is rare, generalized relative abundance was documented for some populations. Information gathered from published literature, and through contact with individuals at universities and state resource management agencies is presented, by river, below.

Alabama River. The Alabama River drains an area of 5,956 square miles stretching approximately 300 miles from its confluence with the Tombigbee River upstream to the Coosa and Tallapoosa Rivers (Figure 4 in Appendix 1). The greatest number of occurrence records for the state of Alabama come from the Alabama River between mile markers 108 and 166 (M. Barbour, pers. comm.). The recent surveys of this river in 1998 and 1999 yielded 59 specimens,

from 9 of 37 stations sampled with approximately six hours of aggregate collection effort at these nine stations (Shepard et al. 1999). Shepard et al. (1999) noted that the sand bars that yielded *C. asprella* were all aged and possessed stable substrate. They speculated that given the reclusive nature and nocturnal habits of the crystal darter, combined with the inherent difficulties of sampling a large river, it is likely that *C. asprella* is more widely distributed in this river than their survey results indicate.

Bayou Pierre. The average number of crystal darter detections during surveys conducted in the main channel of Bayou Pierre in Mississippi between 1970 and 1988 are shown in Figure 5 of Appendix 1 (A. Sherman, pers. comm.). Surveys were distributed among Copiah, Claiborne, and Lowndes counties, Mississippi.

Big River. The Big River originates in northern Iron County, in east-central Missouri. Surveys conducted between 1942 and 1990 have detected only 1 specimen in 1963 and that comprised 0.3 percent of the total catch for that year (M. Winston, pers. comm.). Insufficient data precludes estimation of population trends.

Black River. The Black River originates in Iron County, Missouri. The river flows southeast through the Mark Twain National Forest, ending in Arkansas where it joins the Current River in Randolph County. Surveys conducted at three sites in Missouri's Black River between 1937 and 2000 detected 6, 4, 8, 15, 11 and 1 crystal darters, comprising 0.2, 0.4, 1.1, 1.4, 0.2 and 0.2 percent of the total catch, respectively for survey years 1947, 1964, 1992, 1995, 1999 and 2000 (M. Winston, pers. comm.). The population trend is uncertain.

Bogue Chitto. Bogue Chitto flows from Mississippi into Louisiana, eventually joining the Pearl River system just south of Bogalusa, Louisiana. Although no information on catch per unit effort is provided, element occurrence records indicate the collection of 25 crystal darter specimens in 1968 and 2 specimens in 1998 (I. Maxit, pers. comm.). Care should be taken in extrapolating these minimal data to discern population trends.

Buttahatchie River. The Buttahatchie River is one of the main tributaries of the Tombigbee River in Mississippi. According to Stewart (1992), if crystal darter populations persist in the Tombigbee River system, they will be found in the Buttahatchie River. Indeed, Pierson, et al. (1986) detected 53 crystal darter specimens during surveys conducted between 1968 and 1981. Occurrence data for the Buttahatchie River summarized as the average number of specimens collected per year are presented in Figure 6 of Appendix 1 (data provided by A. Sherman, pers. comm.). Note however, that surveys are distributed among unknown sampling locations and the catch per unit effort is unavailable.

Cahaba River. The third largest tributary to the Alabama River in the Mobile basin, the Cahaba River drainage is approximately 1,818 square miles. It extends about 190 miles from its headwaters northeast of Birmingham to its confluence with the Alabama southwest of Selma. Crystal darter populations from the Cahaba River are considered by state biologists as "stable but vulnerable" although historical population declines due to habitat alteration have been suggested (M. Barbour, pers. comm.). Stewart (1992) reported that state biologists had observed the crystal darter in the main channel of the Cahaba River between 1987 and 1991 and therefore considered the population stable. Shepard et al. (1999) recently surveyed 49 stations and 32

crystal darters were collected with approximately eight aggregate hours of collection effort at 11 of these stations. They speculated that their collections would have been enhanced by night sampling efforts and use of a larger seine.

Chippewa River. There are five flowages in Chippewa River created by dams owned by the Northern States Power Company for hydropower generation. Sixty-one miles of free flowing river between Dells Dam to the Mississippi River confluence represent some of the last unimpounded riverine habitat in the Upper Midwest. Crystal darters were first discovered in small numbers in the Chippewa River near Durand, Wisconsin in the mid 1970s (J. Lyons, pers. comm.). Subsequent sampling visits attempting to catch crystal darters at a variety of sites using seine nets and boomshockers yielded 2 in 1989, 0 in 1994, and 2 in 1997. K. Schmidt (pers. comm.) reported that surveys conducted along the river in Dunn County in 1994, 1995, and 1996 yielded 2, 4, and 2 specimens, respectively.

Coosa River. In Alabama, the Coosa River extends approximately 240 miles from its confluence with the Tallapoosa River upstream to the Georgia state line (Figure 7 in Appendix 1). Smith-Vaniz (1968) indicates that the crystal darter has been detected in the Coosa River system from Choccolocco Creek on a single occasion in 1889. M. Barbour (pers. comm.) reported that the crystal darter has been extirpated from the Coosa River. However, Stewart (1992) reported that the Alabama Department of Conservation and Natural Resources collected the crystal darter in the Coosa River near Wetumpka, Alabama in 1991. Shepard et al. (1999) identified the Coosa River in a proposed study plan for future surveys.

Conecuh River. The Conecuh River arises near Union Springs, Alabama and flows approximately 240 miles south to Escambia Bay, an arm of Pensacola Bay, in Florida. It drains an area of about 3,850 square miles. A small isolated crystal darter population currently exists in the Conecuh River (M. Barbour, pers. comm.). According to Stewart (1992), four specimens were collected in the Conecuh River by Dr. Werner Wieland in 1981. A recent survey by Shepard et al. (1999) produced five crystal darters from approximately 2.25 hours aggregate sampling effort, at 3 of the 23 stations sampled. They considered these results to be rather poor given that the habitat appeared to be excellent and that night sampling efforts were included.

Elk River. The crystal darter was first collected in 1980 from the Elk River of the lower Kanawha drainage near Mink Shoals, West Virginia (Cincotta and Hoeft 1987). It was not detected again until 1991, approximately 18 miles upstream near the town of Clendenin (D. Cincotta, pers. comm.). An assessment of the genetic variation between crystal darter specimens in five locations determined that the Elk River population had the greatest amount of genetic divergence when sampled populations were compared (Wood and Raley 2000). The degree of divergence witnessed in the Elk River population is one of the highest intraspecific divergence values reported for a fish species and is, according to Wood and Raley (2000), more indicative of interspecific or intergeneric divergence. Only 5 specimens have been collected in the Elk River since 1987 despite considerable sampling effort, leading Wood and Raley (2000) to recommend that the Elk River population be considered a distinct evolutionary unit and protected under the U.S. Endangered Species Act.

Escambia River. The Escambia River has been identified as one of the highest priority basins for conservation within the state of Florida based on the high level of fish species richness and

the river's ecological impairment (Walsh et al. 2003). Gilbert (1992) describes the collection of a single crystal darter specimen from the Escambia River in 1972. The most recent occurrences were reported by Yerger and Beecher (1975) and Beecher et al. (1977). However, Stephen Walsh (USGS - Florida Caribbean Science Center, pers. comm.) was unable to find any specimens in extensive surveying efforts in the Escambia River during 2001 and 2002. This has led Walsh et al. (2003) to conclude that it is "unlikely that a stable, resident breeding population occurs in the state." Whether this species was more common historically is uncertain and, furthermore, resident breeding populations may now be extirpated from the state (Walsh et al. 2003).

Gasconade River. The Gasconade River is located within the Ozark Plateau of the Ozark Interior Highlands, flowing northeast to join the Missouri River. Surveys conducted in the lower Gasconade River watershed between 1942 and 2000 detected 2, 3, 2, 2, 5, 2 and 1 crystal darters, comprising < 0.05, <0.05, 0.8, 0.2, 0.7, 0.6 and 0.1 percent of the total catch, respectively for survey years 1947, 1961, 1963, 1980, 1989, 1997 and 2000 (M. Winston, pers. comm.). The population trend is uncertain.

Green River. The Green River arises in south central Kentucky and flows east to west until it meets the Ohio River at Evansville, Indiana. The crystal darter has only been collected six times in Kentucky, three of which originate from the Green River. The most recent collection from the Green River occurred in 1929 (R. Cicerello, pers. comm.). Efforts to re-sample historical collection sites and other locations with suitable looking habitat have been unsuccessful and the crystal darter is now thought to be extirpated from this river (R. Cicerello, pers. comm.).

Kiamichi River. The Kiamichi River arises in southeastern Oklahoma, flowing southwest to its confluence with the Red River. Taylor et al. (1993) describe the discovery of crystal darters at two locations in the Kiamichi River, one in 1990 and four in 1991. Crystal darters were not known in this river previously (Taylor et al. 1993).

Little Missouri River. Stewart (1992) describes the collection of 24 specimens at 2 stations along the Little Missouri River in 1977 and 43 specimens at 5 stations in 1983 from the lower reaches of the river where the crystal darter was considered common. In addition, 7 specimens were collected in 1991 by an ichthyology class from Southern Arkansas University (Stewart 1992).

Little River. Located in southeastern Oklahoma, the Little River arises in the Kiamichi Mountains and flows in a southwestern direction across the Arkansas state line. Four occurrence records exist for the Little River in Oklahoma. Single darter specimens were collected in 1971, 1975, 1984, and 1990 (J. Kelly, pers. comm.). Records for the Little River are so few (less than 16 total records) that they preclude any reliable estimation of population trends.

Meramec River. Located in the northeast region of the Ozark Highlands, the Meramec River and tributaries drain 2,149 square miles. Surveys in three reaches of the river from 1942 to 2000 detected 11, 2, 1, and 13 specimens, comprising <0.05, 6.5, 0.1 and 0.2 percent of the total catch, respectively, for survey years 1947, 1954, 1999 and 2000 (M. Winston, pers. comm.). It is difficult to discern a trend from these data.

Mississippi River. Eddy and Underhill (1974) consider the crystal darter to be the rarest of all the Minnesota darters although the species may be more common than once thought. Schmidt (1995) conducted surveys, both diurnal and nocturnal, at 31 sites in four Minnesota and three Wisconsin counties in 1994. One crystal darter was detected at each of 2 sites, comprising 0.1 percent of the total catch. R. Baker (pers. comm.) believes the crystal darter to be relatively rare in Minnesota as it reaches the northern limit of its range in the Mississippi River.

The first crystal darters detected in the state of Wisconsin were collected in the 1920s from Pool 11 of the Mississippi River near Cassville, Wisconsin. Surveys in 1978 and 1996 to 1998 did not detect crystal darters, but J. Lyons (pers. comm.) captured an additional specimen there in 2001.

As previously mentioned, J. Olson (pers. comm.) agrees with the assertion of Eddy and Underhill (1974) that the crystal darter may be more common than originally believed in the upper Mississippi River basin. The occurrence of recent records, including the Turkey River (an interior Iowa stream) and Pool 11 of the Mississippi River, suggest that the species is at least as common today as it was during mid-century (J. Olson, pers. comm.). Olson states that Iowa populations are “stable but localized” and “very rare.” However, occurrence records are too few to speculate on population trends (Bowler 2001).

Populations in Illinois waters were thought to be extirpated until a recent collection in 1998 in the Mississippi River from Cottonwood Island downstream of Grand Tower, Perry County (B. Burr, pers. comm.). Records suggest that the crystal darter was extirpated from northwestern Illinois between 1900 and 1960 (Mike Retzer - Illinois Natural History Survey, pers. comm.).

Ohio River. No recent records (post 1900) of occurrence have been documented in Indiana. However, the crystal darter is thought to have once inhabited the entire length of the Ohio River along the south border of Indiana, although there are no records to substantiate the claim (B. Fisher, pers. comm.). R. Sanders (pers. comm.) reported that the crystal darter had not been collected in the Ohio portion of the Ohio River since 1899.

Ouachita River. The Ouachita flows through Louisiana and Arkansas, originating in the Ouachita Mountains near Eagleton, Arkansas. Although abundance data is lacking for the Ouachita River, I. Maxit (pers. comm.) reported that Louisiana biologists estimate the statewide crystal darter abundance between 1,000 and 10,000 individuals. Occurrence element records from the Arkansas Game and Fish Commission (B. Wagner, pers. comm.) indicate that surveys in 1975, 1982, and 1993 yielded 1, 2, and 1 specimens respectively. Stewart (1992) describes the collection of 15 specimens at 3 stations below the Rammel Dam in 1975, whereas no specimens were collected above the dam in 1977 or 1986.

Pearl River. Located in the eastern portion of Louisiana, the Pearl River basin is bounded by the state of Mississippi in the north and east and the Lake Pontchartrain basin in the west. In 1968, 10 crystal darter specimens were collected from the Pearl River by Louisiana biologists (I. Maxit, pers. comm.). However, no indication of follow up surveys is given so estimating population trends is impossible. Although occurrence records for 61 crystal darters exist for various points along the Pearl River in Mississippi between 1939 and 1981, populations across Mississippi are thought to be declining (A. Sherman, pers. comm.). Data summarized as the

average number of specimens collected per year are presented in Figure 8 (Appendix 1). Note that survey locations among samples are not consistent and that catch per unit effort is not reported.

Red River. The Red River flows nearly 1,400 miles from the Texas panhandle, along the Texas/Oklahoma border and into Louisiana where a U.S. Army Corps of Engineers structure diverts it into the Atchafalaya River. A collection of a single individual from the Red River in Louisiana was recently (2002) reported by biologists from the University of Louisiana at Monroe (F. Pezold, pers. comm.). This is the first and only collection from the Red River to date.

Saline River. Located in southwest Arkansas, the Saline River is one of the last unimpounded streams in the Ouachita Mountain drainage. Faunal surveys of the Saline River in south-central Arkansas conducted by Reynolds (1971) and Stackhouse (1982) reported “moderate” numbers of crystal darters in the lower reaches of the river. Reynolds (1971) reported collecting 349 specimens at 7 stations while Stackhouse (1982) collected 656 specimens at 10 stations. George et al. (1996) conducted similar efforts in 1992 and 1993, collecting 184 specimens. It must be noted, however, that the primary purpose of the efforts of George et al. (1996) was not to estimate population size, but rather document life history traits of this darter species. All female specimens exhibited evidence of ripened eggs and clutch sizes of 11 crystal darters ranged from 106 in smaller specimens to 576 in larger specimens (George et al. 1996). Robison and Buchanan (1988) suggested that Arkansas may support more stable populations than any other state, although the crystal darter is rarely abundant at any locality. Occurrence records for various locations along the Saline River are summarized in Table 2 (records provided by B. Wagner, pers. comm.).

Table 2. Saline River collections at various locations. Number of specimens calculated as the total number collected during the year indicated.

Location	Collection Year	Number of Specimens
Ozment's Bluff	1969	86
	1970	2
	1992	15
	1993	7
6 miles south of Johnsville	1970	158
	1971	19
	1974	4
End of HWY 172	1969	68
	1972	2
	1974	4
HWY 115 bridge	1974	6
	1976	3

St. Croix River. Fago and Hatch (1993) suggest that strong streamflow, high permeability of glacial tills, extensive degree of vegetative cover, and the prevalence of wetlands along the St. Croix River have minimized catastrophic flooding and streambank erosion, thereby maintaining water quality while reducing the runoff of pollutants from the surrounding watershed to the benefit of fish populations in the river. Lyons et al. (2000) state that the distribution and abundance of the crystal darter in Wisconsin is stable and that all reaches with confirmed occurrences by Becker (1983) yielded specimens in surveys conducted in the 1990s. Two specimens were found at two stations in the St. Croix River in 1978 and 1982, and additional specimens were taken during 1989 and 1990 (Fago 1986, Fago and Hatch 1993). A 1998 survey conducted downstream of Taylors Falls in Chisago County, MN yielded 2 specimens (K. Schmidt, pers. comm.).

St. Francis River. The St. Francis River originates in southeast Missouri in Iron County, flowing 225 miles to the Missouri/Arkansas border. Surveys from 1931 to 1964 detected 35, 11, 6, 2 and 1 specimens, comprising 0.4, 2.8, 1.6, 1.1 and 0.25 percent of the total catch, respectively, for years 1947, 1963, 1941, 1964 and 1937 (M. Winston, pers. comm.). Crystal darters have not been detected in 11 surveys of this river since 1964, including recent efforts in 2001 (M. Winston, pers. comm.).

Tallapoosa River. The Tallapoosa River extends approximately 200 miles from the Coosa River upstream to the Georgia state line (Figure 9 in Appendix 1). M. Barbour (pers. comm.) reported that crystal darter populations in the Tallapoosa are “stable but vulnerable”. As with the Cahaba

River, crystal darters were once considered abundant; however, their current status is uncertain (M. Barbour, pers. comm.). Stewart (1992) reported that numerous specimens were observed between 1987 and 1991, indicating population stability in the river. Shepard et al. (1999) identified the Tallapoosa River in a proposed study plan for future surveys.

Tombigbee River. The Tombigbee River system drains an area of about 20,000 square miles in western Alabama and eastern Mississippi. It flows approximately 280 miles from the Alabama River to the Mississippi state line (Figure 10 in Appendix 1). Element occurrence records provided by M. Barbour (pers. comm.) show that 288 specimens were from various locations between 1964 and 1983, with notations indicating that inundation of these locations occurred in 1978 by the creation of the Gainesville Pool. Crystal darters in the Tombigbee River are now considered extirpated (Stewart 1992). Recent data support this conclusion as no *C. asprella* specimens were collected from 27 stations during a 1999 survey effort (Shepard et al. 1999).

Wisconsin River. The lower Wisconsin River basin in south central and southwestern Wisconsin drains approximately 5,000 square miles of the state with the Wisconsin River itself emptying into the Mississippi River near Prairie du Chien, Wisconsin. Six crystal darters were taken in the lower Wisconsin River near Muscoda, Wisconsin in 1963, but they were not detected in comprehensive surveys in 1977 (J. Lyons, pers. comm.). Although thought to be extirpated from the lower Wisconsin River (Fago 1986), crystal darters were detected in 1998 and 1999 (Lyons et al. 2000). Subsequent surveys of this area yielded 0 in 2000, 2 in 2001, and 2 in 2002 (J. Lyons, pers. comm.).

Zumbro River. Flowing through southeastern Minnesota, the Zumbro River and its tributaries have been identified as a “critical landscape” by the Minnesota Land Trust (2002). Eddy and Underhill (1974) reported that since 1960, “several” specimens have been collected from the Zumbro River near Kellog, Minnesota. Minnesota Department of Natural Resources biologists collected one specimen from the Zumbro River in 1984 (Hatch 1998). In subsequent surveys, the Zumbro produced no specimens (Hatch 1998). However, K. Schmidt (pers. comm.) reported that 3 specimens were collected by the Minnesota Department of Natural Resources in 1993.

SUMMARY OF THREATS

The information available in the published literature concerning threats to crystal darter populations lacks detail on the response of these populations to hypothesized threats. In a multi-species assessment of threats, Deacon et al. (1979) found that of 251 fish taxa surveyed, 98 percent (%) were threatened by habitat modification, 37% by natural or artificial factors, 16% by range restriction, 3% by overexploitation, and 2% by disease. As a result, generalized responses of fish populations to these threats are discussed within the context of crystal darter susceptibility. Personal communications with natural resource managers and conservation specialists aided the establishment of a comprehensive list of purported threats to crystal darters, organized by state (Table 3). The most commonly cited threat to crystal darter persistence is the destruction and degradation of important habitat as a result of impoundment, channelization, dredging activities, and siltation. The abundance of “unknown” entries for many of the tabulated categories below strongly indicates that there is insufficient quantification of populations and therefore, a diminished ability to ascribe population declines to potential threats.

Table 3. Potential threats to crystal darter populations in various states.

State	Habitat Impacts	Overutilization	Disease or Predation	Other Factors
Alabama	gravel mining	unknown	unknown	pollution
Arkansas	impoundment; channelization; dredging	unknown	unknown	none reported
Florida	unknown	unknown	unknown	none reported
Illinois	unknown	unknown	unknown	pollution
Indiana	impoundment; sedimentation	unknown	unknown	none reported
Iowa	unknown	unknown	unknown	none reported
Kentucky	unknown	unknown	unknown	none reported
Louisiana	unknown	unknown	unknown	none reported
Minnesota	impoundment; siltation; channelization; dredging	unknown	predation and/or competition with introduced species	pollution
Mississippi	siltation; channelization	unknown	unknown	agricultural runoff
Missouri	impoundment; siltation; channelization; dredging	unknown	unknown	agricultural development
Ohio	siltation	unknown	unknown	none reported
Oklahoma	impoundment	unknown	unknown	municipal water use; timber harvest; recreation
Tennessee	impoundment	unknown	unknown	none reported
West Virginia	impoundment; sedimentation (from timber harvest, coal mining, and oil/gas exploration)	scientific research and educational programs	unknown	pollution (from industrial and domestic water discharge)
Wisconsin	unknown	unknown	unknown	none reported

Information supplied by J. Kelly - Oklahoma Natural Heritage Inventory; B. Burr - Southern Illinois University; M. Retzer - Illinois Natural History Survey; B. Fisher - Indiana Department of Natural Resources; D. Howell - Iowa Department of Natural Resources; R. Baker - Minnesota Department of Natural Resources; J. Hatch - University of Minnesota; M. Winston - Missouri Department of Conservation; T. Cavender - Ohio State University; R. Sanders - Ohio Department of Natural Resources; J. Lyons - Wisconsin Department of Natural Resources; M. Barbour - Alabama Natural Heritage Program; C. Osborne - Arkansas Natural Heritage Commission; R. Cicerello - Kentucky State Nature Preserves Commission; I. Maxit - Louisiana Heritage Program; A. Sherman - Mississippi Natural Heritage Program; J. (Bo) Baxter - Tennessee Valley Authority; D. Cincotta - West Virginia Department of Natural Resources.

A. Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range.

According to Warren et al. (2000), the most significant threat to fishes in the southern United States is landscape degradation and habitat alteration resulting in the reduction and fragmentation of suitable habitat. In a survey of 251 North American fishes, Deacon et al. (1979) found that 98 percent were threatened by habitat modification. An estimated 28 percent of southern freshwater fishes are considered extinct, endangered, threatened, or vulnerable with the number of imperiled species increasing 125 percent over the past 20 years (Warren et al. 2000). Due to the geographically restricted distribution of species such as the crystal darter, southern fishes are highly susceptible to extirpation from localized habitat degradation through water impoundment, siltation, and stream flow modification (Warren et al. 2000). Extensive human disturbance over the past 100 years has contributed to the extirpation of the crystal darter from much of its former range including Ohio, Indiana, Illinois, Tennessee, Kentucky, and Iowa (Etnier and Starnes 1993). It is likely that these large-scale declines in species richness reflect the degradation of southern watersheds under the stress of the growing human population in the region. Deacon et al. (1979) suggest that protection of suitable habitat and restoration of degraded habitat could slow population declines, though they admit that little has been done to address the loss of habitat and more effort is needed. Warren et al. (2000) add that the crystal darter is a vulnerable species which may become imperiled by seemingly minor habitat disturbance and should therefore receive careful monitoring to assess population status and provide protection for population persistence.

Siltation

It has long been recognized that siltation alters aquatic habitats by reducing light penetration, changing heat radiation, covering the stream bottom, and retaining organic material and other debris (Ellis 1936). This translates into the disruption of reproductive behavior and alteration of food resources utilized by stream fish communities (Ellis 1936). Investigating the effects of siltation on fish communities in Missouri streams, Berkman and Rabeni (1987) found that as siltation increased, the distinction among riffle, run, and pool communities decreased and that the feeding guilds most impacted by siltation were those feeding from the substratum. The crystal darter's feeding activities primarily occur in the substratum. Bhowmik and Adams (1989) provide an example of how sediment deposition has altered aquatic habitat in the Upper Mississippi River system where the construction of locks and dams has resulted in a successional shift from open water to habitats dominated by submergent and emergent vegetation. This successional process is not likely to favor species such as the crystal darter, which rely on extensive clean sand and gravel raceways for population persistence (Page 1983). For example, the crystal darter was broadly distributed in tributaries of the Ohio River until high silt loading and the subsequent smothering of sandy substrates occurred (Trautman 1981). In the Upper Mississippi River, the relative rarity of crystal darters has been hypothesized as a response to silt deposition over sand and gravel substrates (Hatch 1998). Similarly, in November 1999, roughly 80 miles of the Cahaba River were added to Alabama's list of impaired waters with siltation and excessive nutrient loading identified as the primary stressors affecting water quality declines. Listing of the Cahaba was based on U.S. Fish and Wildlife Service guidelines for protection of endangered aquatic species thought to be impacted by these stressors. Waters (1995) extensively discussed the sources and influences of sediment deposition on cold and warm-water fish habitats, and concluded that the two most deleterious effects were the filling of interstitial spaces of riffles and reductions in overall water depth. A recent report by Powell (1999) concluded that although a key factor like crop-land density influences many water quality and fish habitat

variables, fish community composition is primarily influenced by the cumulative effects of sedimentation.

Impoundment

Impoundment and channelization are thought to have caused the extirpation of crystal darter populations from the Tombigbee River, a part of the Mobile River system (Stewart 1992). Artificial impoundments drown riffles and reduce flow, thereby increasing the amount of siltation which causes changes in substrate composition (see previous section). After the construction of dams on the North Fork of the Vermilion River and the middle Embarras River in Illinois, loss of riffle habitat and silt deposition resulted in the disappearance of the greenside darter, northern hog sucker, brindled madtom, blackside darter, and fantail darter (Smith 1968). According to Etnier and Starnes (1993), impoundments at Lake Cumberland, Cordell Hull, and Dale Hollow reservoirs in Tennessee have caused the apparent extirpation of the crystal darter by altering big-river habitat in the region. Impoundments also fragment stream habitat, blocking immigration and emigration between populations and preventing recolonization from source populations. Permanent refugia and transitory habitats providing connectivity and dispersal routes can be rendered inaccessible (Minckley 1995). As a result, recolonization is unable to counter local extinctions caused by demographic or environmental stochasticity. Small, isolated populations are more susceptible to environmental perturbation and demographic stochasticity, both of which may lead to local extinction (Lande 1988). Warren et al. (2000) point out that the range restriction in southern fishes, including the crystal darter, emphasizes the significant threat of range fragmentation and isolation to their persistence.

Stream Flow Modification

Schmidt (1995 and pers. comm.) lists dredging for commercial navigation as the greatest threat to crystal darter populations in the Mississippi River. On the other hand, Schmidt (1995) also notes that collections made in a pool designated as a dredge disposal site may provide suitable substrates to accommodate the crystal darter's burying behavior. The positive and negative impacts have yet to be fully sorted out. However, as much of the Mississippi River has been modified to facilitate materials transport and to control flooding, anthropogenic structures such as dam tailwaters, wing dikes, bridge pilings, and rip-rapped shorelines have become common features. Madejczyk et al. (1998) examined the artificial and natural habitats concurrently to assess habitat preferences and species assemblages. Fish assemblages were highly influenced by the dominant types of artificial habitat present (Madejczyk et al. 1998). Although too few crystal darters were sampled to draw definite conclusions, the study found that bare-shore sites contained smaller fish species (including crystal darters) than sites with structural modifications; although modified sites displayed higher taxa richness (Madejczyk et al. 1998). Further modifications of the Mississippi River or other waters containing crystal darter populations may result in a shift in species assemblage, favoring larger species as habitats are altered by the addition of artificial structures. Both dredging and channelization result in the reduction of habitat variability, which has subsequent implications for fish species diversity (Smith 1968). Hatch (1998) suggests that the rarity of crystal darters in the Upper Mississippi River could be a result of the velocity reduction and particle deposition associated with navigation controls. However, Schmidt (1995) notes that crystal darters have been repeatedly detected in association with wing dam structures, which are abundant throughout the Mississippi River system.

Etnier (1972) found fish community assemblage changes in Middle Creek, a tributary to the East Fork of the Little Pigeon River in Sevier County, Tennessee, after a flood control project

widened and straightened the channel. Some species declined or disappeared from the stream after rechannelization, while others maintained stable population levels from an influx of upstream migrants. Dominance shifted, and the changes were attributed to substrate instability and decreased variation in the habitat structure which effectively decreased invertebrate fauna.

Water Quality

Percid species are sensitive to anthropogenic disturbance (Leonard and Orth 1986) as most are restricted to clear, fast-flowing water with clean substrate (Page 1983). Specific association with clean gravel and sand substrates makes the crystal darter especially sensitive to changes in a stream's chemical and physical characteristics. Maitland (1995) cites water pollution as "the single most significant factor in causing major declines in the populations of many fish species." The fact that freshwater fish populations are geographically confined to discrete freshwater systems with significant water movement and, therefore, vulnerable to the effects of pollution, argues the importance of multiple populations to ensure overall persistence (Maitland 1995). Pollutants can cause direct mortality to sensitive species and, at sublethal levels, can increase susceptibility to other threats (Maitland 1995). The issue of pollution is closely linked to habitat alteration and land use practices within the watershed. Major sources of aquatic pollutants include domestic wastes, agricultural runoff, and industrial chemicals. Reash and Berra (1987) conducted a comparison between clean-water and polluted streams in Ohio. Polluted sites generally supported habitat and diet generalists that were able to tolerate degraded habitats, while species with more specific preferences were absent (Reash and Berra 1987). There is also some evidence from Florida suggesting that water quality improvements during the 1960s to mid 1980s coincided with the recovery of fish assemblages to stable levels, although questions remain as to whether or not improved water quality has resulted in the maintenance of healthy fish populations (Walsh et al. 2003).

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes.

Although the crystal darter has no commercial value, live specimens may be collected for the aquarium trade (Walsh et al. 2003). In addition, the small number of individuals comprising the ecologically significant population in the Elk River may make it vulnerable to over-collection for scientific research or educational programs. However, K. Schmidt (pers. comm.) asserted that current inefficiencies in collection techniques precludes overutilization from becoming a major threat to crystal darter populations. Deacon et al. (1979) asserted that, despite elaborate regulations to protect fish populations from over-harvesting, little has been done to address habitat loss. The authors also suggested that collection for scientific purposes should not be restricted since it provides managers with crucial information for habitat and species management.

C. Disease and Predation.

No known threats due to disease and/or predation were found in peer reviewed literature or state agency reports; however, some natural predation by piscivorous fish and wildlife likely occurs (Page 1983). Newly introduced species may act as predators and/or competitors of native fish species.

D. Inadequacy of Existing Regulatory Mechanisms.

Contaminated Sediment Guidelines

The U.S. Environmental Protection Agency (EPA) has prepared technical guidance to address the exposure of sediment-dwelling organisms to contaminants that tend to partition into aquatic

sediments (U.S. EPA 2000 a, b, c, and d). The crystal darter's unusual behavior of burrowing into sediments coupled with its tendency to feed on sediment-dwelling benthic organisms potentially doubles its probability of exposure to sediment-borne contaminants; i.e. the burrowing activity establishes a direct exposure route and the ingestion of sediment-dwelling organisms establishes an indirect exposure route. The most recent EPA document on contaminated sediment acknowledges that the equilibrium partitioning sediment guidelines do not protect against synergistic or antagonistic effects of contaminants or bioaccumulative effects to benthos, and that they are not protective of wildlife health endpoints (U.S. EPA 2002-draft).

Other Legislation

Legal protection afforded freshwater fishes is generally applied within the context of fish as an exploitable resource (Maitland 1995). Maitland (1995) describes the 'no net habitat loss' policy of the Canadian Department of Fisheries and Oceans which requires developers to ensure that habitat loss will not result from the proposed action and if so, alter the proposal accordingly or provide for remediation. The Clean Water Act of 1964 includes similar provisions for protecting the United States' water resources, although enforcement is often criticized as a significant problem for fish conservation (D. Cincotta, pers. comm.). D. Cincotta (pers. comm.) stressed the fact that stronger legislation to regulate oil and gas exploration/extraction will be necessary to allow for crystal darter persistence in West Virginia locations where these activities pose a threat.

E. Other Natural or Manmade Factors Affecting its Continued Existence.

Genetic Variation

Loss of genetic variation through population bottlenecks, genetic drift, and inbreeding can result in increased homozygosity, loss of additive variance, and increased expression of deleterious recessive alleles (Meffe 1986). Through these processes, loss of genetic variance leads to a decrease in fitness. Small and increasingly isolated crystal darter populations may continue to suffer from decreasing within-population diversity as inbreeding among close relatives, which can lead to problems such as reduced fertility and fitness, increases in likelihood (Noss and Cooperrider 1994). Similarly, the random loss of adaptive genes through genetic drift may function to limit the ability of crystal darters to respond to changes in their environment (Noss and Cooperrider 1994). Small population sizes and inhibited gene flow between crystal darter populations caused by habitat fragmentation may increase the likelihood of local extinction (Gilpin and Soulé 1986). Unique genetic lines such as those from the Elk River population in West Virginia (Wood and Raley 2000) are of great importance for the long term goals of maintaining genetic diversity and allowing future adaptation to changing conditions (Meffe 1986). These unique gene pools allow for the maintenance of between-population variance and can be sources of genetic stock for future management efforts (Meffe 1986) and adaptive potential in response to environmental change (Meffe 1987). Recently, steps have been taken to determine how genetic variation is distributed within and among crystal darter populations (Wood and Raley 2000, Morrison et al. *in press*). Understanding these genetic issues is an important step for crystal darter conservation.

CURRENT PROTECTIVE STATUS

The level of effort dedicated to documenting crystal darter occurrence and monitoring population status is generally minimal throughout its range and variable on a state-by-state basis. Each state has therefore established a specific level of protection (or lack thereof) for the crystal darter as

deemed necessary. Table 4 lists the crystal darter’s protective status and Natural Heritage ranking by state, as well as its global and federal protective status designation. Note that “special concern” designation generally offers little or no legal protection for species or populations. In Minnesota, for example, only “threatened” and “endangered” designations allow for protection under the state endangered species statute.

Table 4. Crystal darter protective status at the global, federal, and state level.

Governmental Level	Protective Status	Heritage Status Rank
Global	none	G3
Federal (U.S.)	none	N3
Alabama	state protected	S3
Arkansas	special concern	S2?
Florida	threatened	S1
Illinois	none	SX
Indiana	special concern	SX
Iowa	none	S1
Kentucky	endangered	SX
Louisiana	none	S2S3
Minnesota	special concern	S3
Mississippi	endangered	S1
Missouri	state endangered	S1
Ohio	none	SX
Oklahoma	threatened	S1
Tennessee	none	SX
West Virginia	special concern	S1
Wisconsin	endangered	S1

G3 = vulnerable globally; N3 = nationally vulnerable; SX = presumed extirpated; S1 = critically imperiled; S2? = imperiled but status uncertain; S2S3 = imperiled to vulnerable; S3 = vulnerable. Information obtained from NatureServe Explorer 2002; J. Kelly - Oklahoma Natural Heritage Inventory; B. Burr - Southern Illinois University; M. Retzer - Illinois Natural History Survey; B. Fisher - Indiana Department of Natural Resources; D. Howell - Iowa Department of Natural Resources; R. Baker - Minnesota Department of Natural Resources; J. Hatch - University of Minnesota; M. Winston - Missouri Department of Conservation; T. Cavender - Ohio State University; R. Sanders - Ohio Department of Natural Resources; J. Lyons - Wisconsin Department of Natural Resources; M. Barbour - Alabama Natural Heritage Program; C. Osborne - Arkansas Natural Heritage Commission; R. Cicerello - Kentucky State Nature Preserves Commission; I. Maxit - Louisiana Heritage Program; A. Sherman - Mississippi Natural Heritage Program; J. (Bo) Baxter - Tennessee Valley Authority; D. Cincotta - West Virginia Department of Natural Resources.

Currently, the crystal darter is designated as “state protected” in Alabama. However, Ramsey (1976) recommended that the darter be given threatened status based on limited habitat in the Alabama, lower Cahaba, Mobile, lower Tallapoosa, and Tombigbee rivers. In Alabama waters, the Alabama Department of Conservation and Natural Resources has established a new rule, effective 19 April 2003, stating:

It shall be unlawful to intentionally stock or release any fish, mussel, snail, crayfish or their embryos including bait fish into the public waters of Alabama under the jurisdiction of the Division of Wildlife and Freshwater Fisheries as provided in Rule 220-2-.42 except those waters from which it came without the written permission of a designated employee of the Department of Conservation and Natural Resources authorized by the Director of the Division of Wildlife and

Freshwater Fisheries to issue such permit. The provisions of this rule shall not apply to the incidental release of bait into the water during the normal process of fishing.

This rule, if effectively enforced, could bolster protection of crystal darters and other imperiled biota which may be negatively impacted from the release of non-native species (see THREATS section).

Bauer and Clemmer (1983) describe that the crystal darter was given an “undetermined” status in Arkansas due to the lack of information on current distribution and abundance in the state. Currently, the darter is designated as a species of “special concern” (Table 4).

According to Gilbert (1992), the crystal darter was initially designated as “endangered of extirpation” in Florida. The rationale for this designation was based on the crystal darter’s restriction to major water courses which have been heavily altered by human activity as well as the fact that the species now occurs in a mere fraction of its historical range in the state (see POPULATION section). However, it was decided that if the crystal darter was afforded endangered status, that action would draw attention away from other truly endangered Florida fishes nearing extinction. As a result, the crystal darter is now designated as “threatened” in Florida. Walsh et al. (2003) conclude, however, that the crystal darter should be given endangered status based on updated biological and distributional information.

The Illinois Natural Heritage policy is not to list extirpated species despite the recent occurrence records for the state (see POPULATION section) (B. Burr, pers. comm.). It should be noted that the specimen recently collected in Illinois’ waters did not exhibit any indication of recent spawning (B. Burr, pers. comm.) and may therefore be a transient individual.

There is no formal protection afforded the crystal darter in Indiana although it is currently on Indiana’s list of special concern species (B. Fisher, pers. comm.). The state’s Fish Technical Committee has recently recommended that the crystal darter be added to the Indiana list of extirpated species (B. Fisher, pers. comm.).

Although not currently listed as threatened or endangered in Iowa, the crystal darter will be considered for listing when the state fish species list is next reviewed (D. Howell, pers. comm.).

Schmidt (1995) does not believe the crystal darter should be elevated to threatened status in Minnesota because: (1) it is at its geographic periphery, (2) most of the occurrences have been documented since 1991, (3) surveys produce consistent results, (4) it has a wider distribution in the state than surveys in 1983 indicated, and (5) it has shown the ability to adapt to artificial structures in the Mississippi River, such as wing dams, which are abundant in the system. However, Hatch (1998) did not see this association with wing dams in surveys conducted in 1994 and 1995. K. Schmidt (pers. comm.) suggested that there is insufficient information to determine the population status of crystal darters.

As early as 1975 biologists were recommending “endangered” status for the crystal darter in Mississippi (Clemmer et al. 1975). The designation of “state endangered” in Missouri ensures that the crystal darter is not collected without a permit from the Missouri Department of Conservation (M. Winston, pers. comm.).

Etnier and Starnes (1993) reported the extirpation of the crystal darter in Tennessee waters, but recommended its designation as “deemed in need of management” in the event that populations were discovered at a later date.

Although listed as a species of special concern by the West Virginia Department of Natural Resources, state law provides little true protection for the crystal darter (Cincotta and Hoeft 1987).

LAND OWNERSHIP

There is no comprehensive database or publication containing specific occurrence records that are thoroughly cross-referenced with site-specific ownership documentation for the entire geographic distribution of the crystal darter. In general, most streams are managed as state and/or federal navigable waters. However, land ownership within each watershed is variable and land use decisions on property within a watershed will likely have impacts on fish populations within individual streams. Warren et al. (2000) reported that only 11 percent of the 212 million acres of forested watersheds, which support the most ecologically significant streams and rivers in the southern United States, are publicly owned. What follows is a description of the available information concerning land ownership surrounding the streams where the crystal darter is known to occur.

Cahaba River. The Nature Conservancy manages three preserves covering nearly 500 acres of the Cahaba watershed, the Barton’s Beach Preserve (125 acres) in Perry County, the Pratt’s Ferry Preserve (12 acres) in Bibb County, and the Kathy Stiles Freeland Bibb Preserve (330 acres) also in Bibb County. As an important recreational resource, the Cahaba receives the heaviest use of any free-flowing river in Alabama and was proposed for designation as a National Wild and Scenic River as a result. Although designation did not occur, plans are currently underway to establish a National Wildlife Refuge along a 3.5 mile stretch of the river in Bibb County, protecting an estimated 1,285 acres of land. In 2001, land acquisition money was appropriated and land was purchased with official refuge establishment on 13 May 2002. Roughly 65% of the land within the Cahaba River basin is dedicated to forestry with 15% designated as urban and nearly 13% used for pasture.

Chippewa River. Much of the riparian zone immediately adjacent to the Chippewa River is owned by the state of Wisconsin (Wisconsin Department of Natural Resources 2001). For example, the 1,225 acre Brunet Island State Park, delimited by the Chippewa and Fisher rivers, is located near Cornell, Wisconsin. The Lake Wissota State Park, encompassing 1,062 acres, is located near Chippewa Falls, Wisconsin. In addition, the Old Abe State Trail stretches along the Chippewa River between Lake Wissota and Cornell, connecting the two state parks. A few state natural areas and wildlife areas also line the river. For example, Putnam Park, a 105 acre preserve on the University of Eau Claire campus, consists of natural forest land. Outside of the riparian corridor, much of the land ownership falls under private management. The river itself flows through two major cities, Chippewa Falls (population 13,000) and Eau Claire, which has seen an increase in population from 38,000 to 63,000 between 1960 and 1999 (Wisconsin Department of Natural Resources 2001). The Wisconsin Department of Natural Resources (2001) stated that approximately 60% of the Chippewa River basin is in cropland and pasture with a 1% prairie component (down from a pre-settlement 13%). Figure 11 (Appendix 1) identifies general ownership classes within the basin and along the riparian corridor of the Chippewa River.

Elk River. The Elk River basin, in West Virginia, contains industries associated with coal, oil, gas, and sandstone extraction as well as Sutton Lake, a 600 ha impoundment managed by the U.S. Army Corps of Engineers. The basin also contains timber resources of commercial quality and agricultural activity dominated by livestock production. Approximately 95% of the Elk River watershed is privately owned, especially in the lower reaches where the crystal darter occurs. The U.S. Forest Service manages lands in the Monongahela National Forest and the state controls land in the Holly River State Forest.

Red River. The state of Louisiana Department of Wildlife and Fisheries manages the Red River Wildlife Management Area, encompassing nearly 36,000 acres of mixed bottomland hardwood forest. An additional 12,000 acres is managed by the U.S. Army Corps of Engineers.

Wisconsin River. According to the Wisconsin Department of Natural Resources (2002), land cover within the lower Wisconsin River basin is split between forest (39 %) and agriculture (37 %), with less than 1% percent of the basin consisting of developed land cover.

Zumbro River. According to the Minnesota Land Trust (2002), the Zumbro River region has begun to attract developers from nearby cities, namely Rochester, Minnesota. One development in particular was chosen as an example of ecologically informed development by the Minnesota Land Trust. The development, named Evergreen Acres, is a 464 acre subdivision with 10 homes clustered on 20 acres of land. The adjacent green space, including wetland and forest patches, is jointly owned and approximately 364 acres are protected by an easement held by the Minnesota Land Trust.

BENEFICIAL CONSERVATION ACTIVITIES

Chippewa River. Intense development along lakes, rivers, and streams within the Chippewa River basin have led to grassroots efforts to promote buffer establishment along sensitive streambanks in the basin (Wisconsin Department of Natural Resources 2001). The Lower Chippewa River Basin Partnership Team proposes to work with local landowners utilizing the Conservation Reserve Program (CRP). In addition, residents of Colfax, Wisconsin, voted to remove a dam in 1998, restoring 3,200 feet of fish habitat (Wisconsin Department of Natural Resources 2001). Similar efforts could be aimed at protecting and restoring existing crystal darter habitat and create additional habitat within the species' natural range.

Wisconsin River. In 1989, the Wisconsin Legislature created the lower Wisconsin Riverway, which includes a 92 mile free flowing river section from Prairie du Sac dam to the river's confluence with the Mississippi River (Wisconsin Department of Natural Resources 2002). The riverway covers nearly 80,000 acres, with 44,000 acres owned by the state and 2,800 acres with easements for habitat protection (Figure 12 in Appendix 1). One of the primary purposes of this endeavor is to maintain and enhance wildlife habitat and populations. Under this framework, the lower Wisconsin Riverway Project could help with crystal darter recovery.

MANAGEMENT ACTION AND RESEARCH NEEDS

A. Taxonomic, Ecological, and Distributional Status

Confusion over the taxonomic designations used for the crystal darter warrants an ongoing discussion as to the relationships between closely related species, as well as conspecific

populations across the crystal darter's geographic distribution. Biologists are still uncertain about the ecology of the species and its response to human alteration of stream habitat (see THREATS section) as well as the distribution of the crystal darter (Gilbert 1992). For example, B. Burr (pers. comm.) suggests that, in light of the recent occurrence record from Cottonwood Island in Illinois (where the crystal darter was thought to be extirpated), research should evaluate the role of Mississippi River islands in providing possible habitat for the species. Fundamental information deficiencies call for conducting more research on the crystal darter (R. Baker, pers. comm.). The resulting information and data would aid future management efforts.

B. Habitat Protection and Restoration

Habitat protection and restoration will allow for the long-term success of conservation for freshwater fishes (Maitland 1995). Reinstating spawning areas and ensuring the maintenance of clean sand and gravel raceways for crystal darter populations is likely to allow for population persistence if conducted in concert with pollution control and abatement programs within the species' range. For example, a sandbar constructed in 1988 in a cut-off of the Tenn-Tom Waterway has yielded 17 crystal darter specimens, suggesting that the sandbar may provide suitable habitat to support a small population (Kuhajda 2000). Tactics for restoring habitat, such as tax incentives to control sedimentation, have been suggested (B. Burr, pers. comm.). However, management priorities should be given to high quality habitat areas currently supporting crystal darter populations, rather than heavily impacted areas, since the costs of restoring degraded habitats is high. Walsh et al. (2003) stress the need for surveys aimed at identifying suitable habitat as potential sources for translocation efforts (see below). In addition, the Missouri Department of Conservation (2000) recommends that best management practices include restoration, in addition to stream protection from impoundment within the darter's range, and that the riparian corridors along streams should not be removed or altered. Biologists from the Minnesota Natural Heritage and Nongame Research Program (R. Baker, pers. comm.) suggest that beneficial management practices should include limiting the alteration of stream bed characteristics and reducing siltation and nutrient loading from agricultural sources.

C. Translocation

Translocation should be considered before a species becomes critically imperiled (Poly 2003). Williams et al. (1988) provide criteria for the planning of fish translocations. It is critical that transplantation occur within the species' native range since ecological interactions within its natural distribution are likely to have fewer negative consequences than would introduction to a novel environment (Williams et al. 1988, Minckley 1995). Transplant sites should be afforded some degree of protection from habitat degradation (Williams et al. 1988), contain sufficient natural resources to support self-sustaining populations, and be large enough to sustain the range of natural variability needed to maintain local and regional diversity (Moyle and Sato 1991). Maitland (1995) emphasizes that translocation should pose no threat to the parent stock from which propagules are selected and that consideration be given to the genetic composition of the introduced stock so as to maintain genetic variation within and between populations. Other considerations include the potential for introduction of disease or parasites (Williams et al. 1988) and hybridization with closely related species (Williams et al. 1988, Minckley 1995). Post-introduction monitoring should be implemented to determine survival, recruitment, and population persistence (Williams et al. 1988). The unintentional cultivation of crystal darters by the Arkansas Game and Fish Commission in 1981 (Robison and Buchanan 1988) suggests that cultivated stock could be used as a source for translocation efforts. K. Schmidt (pers. comm.)

believes that captive propagation should be further evaluated.

Precedent for the translocation of imperiled darter species has been set by efforts to reestablish snail darter (*Percina tanasi*; Hickman and Fitz 1978), duskytail darter (*Etheostoma percnurum*) and fringed darter (*Etheostoma crossopterum*; Poly 2003) populations. Poly (2003) stresses that the number of individuals released should be substantial and consist of multiple age classes, and that individuals be released into suitable habitat. Other factors to consider include the sex ratio of individuals being introduced, their fecundity, and their potential interactions with other species in the new locale (Poly 2003). Fringed darters displayed normal breeding activity after translocation and both juveniles and adults were present in following years, along with an increase in the number of nests discovered in subsequent years (Poly 2003). Efforts to move individuals at the beginning of their natural breeding season seem most effective at increasing the chances of locating a mate in the new habitat prior to dispersal (e.g. Poly 2003). Similar steps could be taken to evaluate the potential for crystal darter translocation if deemed necessary. However, Poly (2003) suggests that a closely related species be used as a surrogate for initial investigation into the efficacy of translocation, for imperiled species.

D. Monitoring

Walsh et al. (2003) cite a report by Hoehn (1998) which notes that routine sampling and population monitoring has declined or been discontinued altogether in recent years in the state of Florida. This is an alarming trend given the importance of population monitoring efforts for providing baseline information and population trend data. In fact, the necessity for adequate monitoring of extant populations to determine the present distribution and confirm or deny the effectiveness of measures to mitigate the effects of human activities in inhabited stream reaches was emphasized by nearly every state official contacted. All management actions should involve adequate monitoring to evaluate success and guide future efforts to protect imperiled species. Long-term population monitoring should be initiated immediately to ensure that future decisions are made within the context of future population trends (R. Baker, pers. comm.), and re-sampling of historic occurrence sites should be conducted to establish historic trend information (B. Burr, pers. comm.). Monitoring efforts should be standardized across geographic and political boundaries to facilitate comparisons in both space and time (Maitland 1995). Schmidt (1995) conducted a survey of the effectiveness of specific sampling techniques for monitoring crystal darter populations in Minnesota waters. According to Schmidt (1995 and pers. comm.), monitoring efforts should include: (1) surveys in areas where the species has not been reported, (2) at least one voucher specimen at each new occurrence locality, (3) seines deep enough to sample depths of six to nine feet, (4) selective boom shocking, (5) deepwater trawls in scour holes below lock and dams, wing and closing dams, and tributary mouths, (6) nocturnal sampling, (7) sampling during low flows, and (8) repeated monitoring with SCUBA equipment to document abundance data and evaluate sampling techniques. Although some have reported that crystal darters are more amenable to nocturnal sampling (e.g., Kuehne and Barbour 1983), George et al. (1996) collected the majority of their specimens during the day, just before sundown (i.e., 1500 to 1900). Later sampling produced fewer specimens (George et al. 1996).

E. Watershed Management

Efforts should be made to address watershed-scale stressors to crystal darter populations and/or habitat in order to address multiple stressors that may or may not originate in close proximity to extant populations (see THREATS section) and build consensus among stakeholders from a

diverse assemblage of interest groups within the watershed. For example, the Cahaba River Basin Clean Water Partnership (www.cahabariver.com) was formed in 2002. The partnership is comprised of representatives from various interest groups within the basin and is tasked with identifying environmental problems within the basin and discussing improvement measures. Using comparative risk assessment, the partnership has prioritized ecological stressors to incorporate the effects of environmental impacts, the feasibility of improvement measures, and associated consequences of watershed protection strategies. Recommendations and policy measures can then be identified and action can be taken to protect important stretches of the river. In general, efforts to reduce siltation and channel modification within watersheds should be of high priority (A. Sherman, pers. comm.).

LITERATURE CITED

- Bailey, R.M., H.E. Winn, and C.L. Smith. 1954. Fishes from the Escambia River, Alabama and Florida, with ecologic and taxonomic notes. Proceedings of the Academy of Natural Science, Philadelphia, NJ.
- Bauer, B.H. and G.H. Clemmer. 1983. A status report on the crystal darter *Ammocrypta asprella* (Jordan). Federal Aid Report to the U.S. Fish and Wildlife Service. Atlanta, GA. 31pp.
- Becker, G.C. 1983. *Fishes of Wisconsin*. University of Wisconsin Press, Madison, WI.
- Beecher, H.A., W.C. Hixson, and T.S. Hopkins. 1977. Fishes of Florida oxbow lake and its parent river. Florida Scientist 40:140-148.
- Berkman, H.E. and C.F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18:285-294.
- Bhowmik, N.G. and J.R. Adams. 1989. Successional changes in habitat caused by sedimentation in navigation pools. Hydrobiologia 176/177:17-27.
- Bowler, M.C. 2001. Recent observations of the distribution and status of Bluntnose darters and Crystal darters in Iowa. Journal of Iowa Academy of Science 107:15-18.
- Burr, B.M. and M.L. Warren, Jr. 1986. *A Distributional Atlas of Kentucky Fishes*. Kentucky Nature Preserves Commission, Scientific and Technical Series No. 4.
- Cincotta, D.A. and M.E. Hoeft. 1987. Rediscovery of the Crystal Darter, *Ammocrypta asprella*, in the Ohio River Basin. Brimleyana 13:133-136.
- Clemmer, G.H., R.D. Suttkus, and J.S. Ramsey. 1975. *A Preliminary List of Rare and Threatened Vertebrates in Mississippi*. Mississippi Game and Fish Committee, Jackson, MS.
- Collette, B.B. 1965. Systematic significance of breeding tubercles in fishes of the family Percidae. Proceedings of the United States National Museum 117:567-614.
- Cook, F.A. 1959. *Freshwater Fishes in Mississippi*. Mississippi Fish and Game Commission, Jackson, MS.
- Daniels, R.A. 1989. Significance of burying in *Ammocrypta pellucida*. Copeia 1989:29-34.
- Deacon, J.E., G. Kobetich, J.D. Williams, and S. Contreras. 1979. Fishes of North America endangered, threatened, or of special concern: 1979. Fisheries 4:29-44.
- Douglas, N.H. 1974. *Freshwater Fishes of Louisiana*. Claitor's Publishing, Baton Rouge, LA.
- Eddy, S. and J.C. Underhill. 1974. *Northern Fishes: With Special Reference to the Upper*

Mississippi Valley, 3rd edition. University of Minnesota Press, Minneapolis.

Ellis, M.M. 1936. Erosion silt as a factor in aquatic environments. *Ecology* 17:29-42.

Eschmeyer, W.N. 1990. *Catalog of the Genera of Recent Fishes*. California Academy of Sciences, San Francisco, CA.

Etnier, D.A. 1972. The effect of annual rechanneling on a stream fish population. *Trans. Amer. Fish. Soc.* 1972:372-375.

Etnier, D.A. and W.C. Starnes. 1993. *The Fishes of Tennessee*. University of Tennessee Press, Knoxville.

Evermann, B.W. and O.P. Jenkins. 1892. Notes on Indiana Fishes. *Biennial Report of the State Fish Commissioner*, 1892: 108-127.

Fago, D. 1986. Distribution and relative abundance of fishes in Wisconsin. Technical Bulletin No. 159. Department of Natural Resources, Madison, WI.

Fago, D. and J. Hatch. 1993. Aquatic resources of the St. Croix River basin. Pp. 23-56 in L.W. Hesse, C.B. Stalnaker, N.G. Benson, and J.R. Zuboy (eds.). *Restoration Planning for the Rivers of the Mississippi River Ecosystem*. National Biological Survey, Technical Report Series. Biological Report 19.

Forbes, S.A. 1880. The food of the darters. *American Naturalist* 14:697-703.

George, S.G., W.T. Slack, and N.H. Douglas. 1996. Demography, habitat, reproduction, and sexual dimorphism of the Crystal Darter, *Crystallaria asprella* (Jordan), from south-central Arkansas. *Copeia* 1996:68-78.

Gilbert, C.H. 1888. Description of new and little known Etheostomoids. *Proc. U.S. Nat. Mus.* 10:47-64.

Gilbert, C.R. 1992. Crystal darter, *Crystallaria asprella*. Pp. 79-83 in: C.R. Gilbert (ed.). *Rare and Endangered Biota of Florida*. University Press of Florida, Gainesville, FL.

Gilpin, M.E. and M.E. Soulé. 1986. Minimum viable populations: the processes of species extinction. Pages 13-34 in *Conservation Biology: The Science of Scarcity and Diversity*, M.E. Soulé (ed.). Sinaur Associates, Sunderland, Mass.

Hatch, J. T. 1998. Resource utilization and life history of the crystal darter, *Crystallaria asprella* (Jordan), in the Lower Mississippi River, Minnesota. Minnesota Natural Heritage and Nongame Wildlife Research Technical Report: 1-22.

Hickman, G.D. and R.B. Fitz. 1978. A report on the ecology and conservation of the snail darter (*Percina tanasi* Etnier): 1975-1977. Technical Note B28. Tennessee Valley Authority, Norris, Tennessee.

Hoehn, T. 1998. Rare and imperiled fish species of Florida: a watershed perspective. Office of Environmental Services, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Hubbs, C. 1985. Darter reproductive seasons. *Copeia* 1985:56-68.

Jordan, D.S. 1878. A catalogue of the fishes of Illinois. *Bull. Illinois St. Lab. Nat. Hist.* 1:38-70.

Jordan, D.S. 1885. A catalogue of the fishes known to inhabit the waters of North America, north of the Tropic of Cancer, with notes on the species discovered in 1883 and 1884. *Ann. Rep. Comm. Fish and Fish.* 13:789-973.

Jordan, D.S. 1890. Report of explorations made during the summer and autumn of 1888, in the Alleghany region of Virginia, North Carolina and Tennessee, and in western Indiana, with an account of the fishes found in each of the river basins of those regions. *Bulletin of the United States Fish Commission* 1888. 8: 97-173.

Jordan, D.S. and C.H. Gilbert. 1882. Synopsis of the fishes of North America. *Bull. U.S. Nat. Mus.* 16:1-1018.

Jordan, D.S. and B.W. Evermann. 1896. The fishes of North and Middle America: a descriptive catalogue of the species of fish like vertebrates found in the waters of North America, north of the Isthmus of Panama. *Bull. U.S. Nat. Mus.* 47:1-1240.

Jordan, D.S., B.W. Evermann, and H.W. Clark. 1930. Checklist of the fish and fishlike vertebrates of North and Middle America north of the boundary of Venezuela and Colombia. *Rep. U.S. Comm. Fish.* 1928.

Katula, R. 2003. Crystal clear: observations on the crystal darter (*Crystallaria asprella*). http://www.nativefish.org/Articles/Crystal_clear.htm.

Kuehne, R.A. and R.W. Barbour. 1983. *The American Darters*. University Press of Kentucky, Lexington, KY.

Kuhajda, B. 2000. Report of Region 4- South Central. Proceedings of the Southeastern Fishes Council .

Lande, R. 1988. Genetics and demography in biological conservation. *Science* 241:1455-1461.

Leonard, P.M. and D.J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. *Transactions of the American Fisheries Society* 115:401-414.

Lutterbie, G.W. 1979. Reproduction and age and growth in Wisconsin darters (Osteichthyes: Percidae). *Univ. Wisc., Stevens Point, Mus. Nat. Hist. Fauna Flora Wisc. Rept.* 15:1-44.

Lyons, J., P.A. Cochran, and D. Fago. 2000. *Wisconsin Fishes 2000: Status and Distribution*. University of Wisconsin Sea Grant Institute, Madison, WI.

- Madejczyk, J.C., N.D. Mundahl, and R.M. Lehtinen. 1998. Fish assemblages of natural and artificial habitats within the channel border of the upper Mississippi River. *American Midland Naturalist* 139:296-310.
- Maitland, P.S. 1995. The conservation of freshwater fish: past and present experience. *Biological Conservation* 72:259-270.
- Meffe, G.K. 1986. Conservation genetics and the management of endangered fishes. *Fisheries* 11:14-23.
- Meffe, G.K. 1987. Conserving fish genomes: philosophies and practices. *Environmental Biology of Fishes* 18:3-9.
- Mettee, M.F., P.E. O'Neil, and J.M. Pierson. 1996. *Fishes of Alabama and the Mobile Basin*. Oxmor House Inc., Birmingham, AL.
- Minckley, W.L. 1995. Translocation as a tool for conserving imperiled fishes: experiences in western United States. *Biological Conservation* 72:297-309.
- Minnesota Land Trust. 2002. Minnesota Land Trust: Preserving a sense of place. Annual Report 2002.
- Missouri Department of Conservation. 2000. Best management practices: crystal darter (*Crystallaria asprella*). Missouri Department of Conservation, Jefferson City, MO.
- Morrison, C.L., D.P. Lemarie, R.M. Wood, and T.L. King. 2003. Phylogenetic analyses suggest multiple lineages of *Crystallaria asprella* (Percidae: Etheostominae). *Conservation Genetics*, *in press*.
- Moyle, P.B. and G.M. Sato. 1991. On the design of preserves to protect native fishes. In *Battle Against Extinction: Native Fish management in the American West*. W.L. Minckley and J.E. Deacon (eds.). University of Arizona Press, Tucson, AZ.
- Noss, R.F. and A.Y. Cooperrider. 1994. *Saving Nature's Legacy: Protecting and Restoring Biodiversity*. Island Press, Washington, D.C.
- Page, L.M. 1983. *Handbook of Darters*. T.F.H. Publishers, Neptune City, NJ.

- Page, L.M. and B.M. Burr. 1991. *A Field Guide to Freshwater Fishes, North America North of Mexico*. Houghton Mifflin Company, Boston, MA.
- Pflieger, W.L. 1971. A distribution study of Missouri fishes. *University of Kansas Publications Museum of Natural History* 20:225-570.
- Pflieger, W.L. 1975. *The Fishes of Missouri*. Missouri Department of Conservation, Jefferson City, MO.
- Pierson, J.M., C.A. Schultz, and H.T. Boschung. 1986. Fishes of the Buttahatchee River system of Alabama and Mississippi. *Proceedings of the Southeastern Fisheries Council* 4:11-13.
- Poly, W.J. 2003. Design and evaluation of a translocation strategy for the fringed darter (*Etheostoma crossopterum*) in Illinois. *Biological Conservation* 113:13-22.
- Powell, J.R. 1999. Response of Fish Communities to Cropland Density and Natural Environmental Setting in the Eastern Highland Rim Ecoregion of the Lower Tennessee River Basin, Alabama and Tennessee. U.S. Geological Survey Water-Resources Investigations Report 02-4268. Nashville, Tennessee.
- Ramsey, J.S. 1976. Freshwater fishes. In *Endangered and Threatened Plants and Animals of Alabama*. *Bulletin of the Alabama Museum of Natural History* 2:53-65.
- Reash, R.J. and T.M. Berra. 1987. Comparison of fish communities in a clean-water stream and an adjacent polluted stream. *American Midland Naturalist* 118:301-322.
- Reynolds, J.T. 1971. Fishes of the Saline River, south central Arkansas. Unpubl. master's thesis, Northeast Louisiana Univ., Monroe.
- Robison, H.W. and T.M. Buchanan. 1988. *Fishes of Arkansas*. The University of Arkansas Press, Fayetteville, AR.
- Ross, S.T. 2001. *Inland Fishes of Mississippi*. University Press of Mississippi, Jackson, MS.
- Schmidt, K. 1995. The distribution and sampling gear vulnerability of the crystal darter (*Crystallaria asprella*) in Minnesota. Final Report to the Minnesota Nongame Research Program.
- Shepard, T.E., P.E. O'Neil, S.W. McGregor, M.F. Mettee and W.P. Henderson. 1999. Status Surveys of the Crystal Darter (*Crystallaria asprella*) and Freckled Darter (*Percina lenticula*) in Alabama: Summary of Results, 1996-99. Geological Survey of Alabama. Tuscaloosa, Alabama.
- Simon, T.P., E.J. Tyberghein, K.J. Scheidegger, and C.E. Johnston. 1992. Descriptions of protolarvae of the sand darters (Percidae: *Ammocrypta* and *Crystallaria*) with comments on systematic relationships. *Ichthyol. Explor. Freshwaters* 3:347-358.
- Simons, A.M. 1991. The phylogenetic relationships of the crystal darter, *Crystallaria asprella*

(Teleostei: Percidae). *Copeia* 1991(4): 927-936.

Smith, P.W. 1968. An assessment of changes in the fish fauna of two Illinois rivers and its bearing on their future. *Transactions of the Illinois State Academy of Science* 61:31-45.

Smith, P.W. 1979. *The Fishes of Illinois*. University of Illinois Press, Urbana, IL.

Smith-Vaniz, W.F. 1968. *Freshwater Fishes of Alabama*. Paragon Press, Montgomery, AL.

Stackhouse, R.A. 1982. A subsequent study of the fishes of the Saline River, south central Arkansas. Unpubl. master's thesis, Northeast Louisiana Univ., Monroe, LA.

Stauffer, J.R., J.M. Boltz, and L.A. White. 1995. *The Fishes of West Virginia*. Philadelphia Academy of Natural Sciences, Philadelphia, PA.

Stewart, J.H. 1992. Status review of the crystal darter. Draft status review for the U.S. Fish and Wildlife Service. Jackson, MS. 6pp.

Taylor, C.M., M. Pyron, and M.R. Winston. 1993. Zoogeographic implications for the first record of *Crystallaria asprella* (Percidae) from the Kiamichi River Drainage, and for the occurrence of *Notropis boops* (Cyprinidae) and *Luxilus chysoccephalus* (Cyprinidae) in the Wichita Mountains, Oklahoma. *Southwestern Naturalist* 38:302-303.

Trautman, M.B. 1981. *The Fishes of Ohio*. 2nd Edition. Ohio State University Press, Columbus, OH.

U.S. EPA. 2000a. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Endrin. EPA-822-R-00-004. Office of Science and Technology, Washington, DC

U.S. EPA. 2000b. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Dieldrin. EPA-822-R-00-003. Office of Science and Technology, Washington, DC

U.S. EPA. 2000c. Technical basis for the derivation of equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Nonionic organics. EPA-822-R-00-001. Office of Science and Technology, Washington, DC

U.S. EPA. 2000d. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Metal mixtures (cadmium, copper, lead, nickel, silver, and zinc). EPA-822-R-00-005. Office of Science and Technology, Washington, DC

U.S. EPA. 2002-draft. Methods for the derivation of site-specific equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Nonionic organics. Office of Science and Technology, Washington, DC

Walsh, S.H., W.B. Tate, and M.A. Burgess. 2003. Current distribution of the crystal darter

(*Crystallaria asprella*), river redhorse (*Moxostoma carinatum*), and cypress minnow (*Hybognathus hayi*) in Florida. Final Report to the Florida Fish and Wildlife Conservation Commission.

Warren, M.L., B.M. Burr, S.J. Walsh, H.L. Bart, Jr., R.C. Cashner, D.A. Etnier, B.J. Freeman, B.R. Kuhajda, R.L. Mayden, H.W. Robison, S.T. Ross, and W.C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. *Fisheries* 25:7-31.

Waters, T.F., ed., 1995. Sediment in streams: sources, biological effects, and control: American Fisheries Society Monograph 7.

Williams, J.D. 1975. Systematics of the percid fishes of the subgenus *Ammocrypta*, genus *Ammocrypta*, with descriptions of two new species. *Bulletin of the Alabama Museum of Natural History* 1:1-56.

Williams, J.E., D.W. Sada, C.D. Williams, J.R. Bennett, J.E. Johnson, P.C. Marsh, D.E. McAllister, E.P. Pister, R.D. Radant, J.N. Rinne, M.D. Stone, L. Ulmer, and D.L. Withers. 1988. American Fisheries Society guidelines for introductions of threatened and endangered fishes. *Fisheries* 13:5-11.

Winn, H.E. 1958a. Observation on the reproductive habits of darters (Pisces-Percidae). *American Midland Naturalist* 59:190-212.

Winn, H.E. 1958b. Comparative reproductive behavior and ecology of fourteen species of darters (Pisces-Percidae). *Ecological Monographs* 28:155-191.

Wisconsin Department of Natural Resources. 2001. The state of the lower Chippewa River basin. PUBL #WT 554-00.

Wisconsin Department of Natural Resources. 2002. The state of the lower Wisconsin River basin. PUBL #WT-559-2002.

Wood, R.M. and M.E. Raley. 2000. Cytochrome *b* sequence variation in the crystal darter *Crystallaria asprella* (Actinopterygii: Percidae). *Copeia* 2000:20-26.

Woolman, A.J. 1892. Report of an investigation of the rivers of Kentucky, with lists of the fishes obtained. *Bull. U.S. Fish Comm.* 10:249-288.

Yerger, R.W. and H.A. Beecher. 1975. First records of two percid fishes in Florida freshwaters. *Florida Scientist* 38:142-143.

INTERNET LITERATURE CITED

NatureServe Explorer: An online encyclopedia of life [web application]. 2002. Version 1.6. Arlington, Virginia, USA: NatureServe. Available: <http://natureserve.org/explorer>. (Accessed: June 3, 2003).

Alabama Rivers Discover Expedition (ALRDE):
<http://www.dcnr.state.al.us/riverdiscovery/index.asp>

Appendix 1. Figures 1 through 12

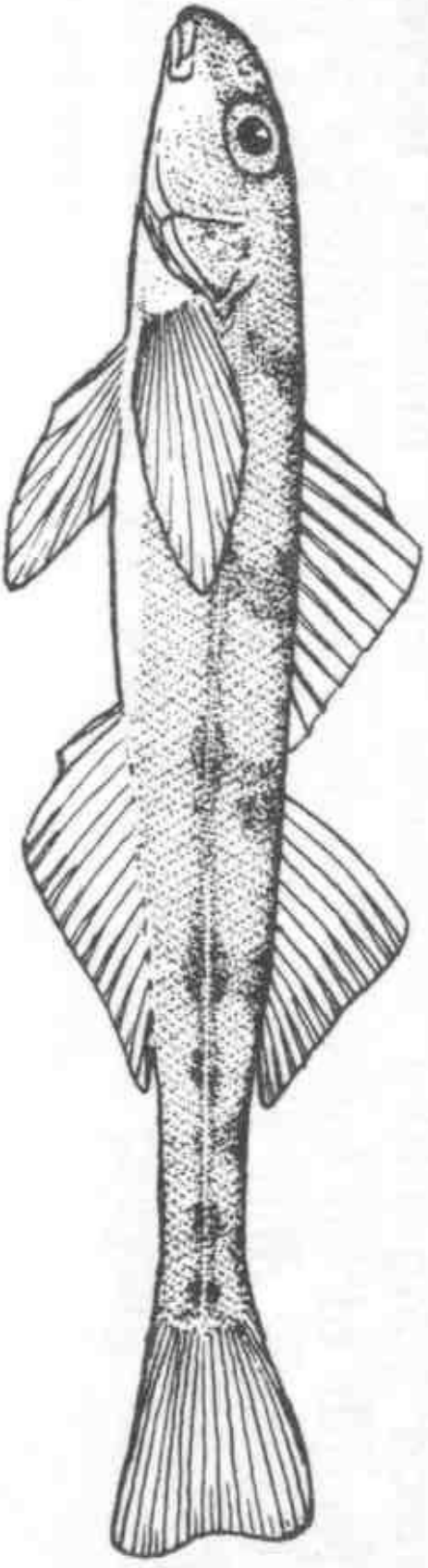


Figure 1. Crystal darter (*Crystallaria asprella* Jordan). Sketch by Samuel Eddy

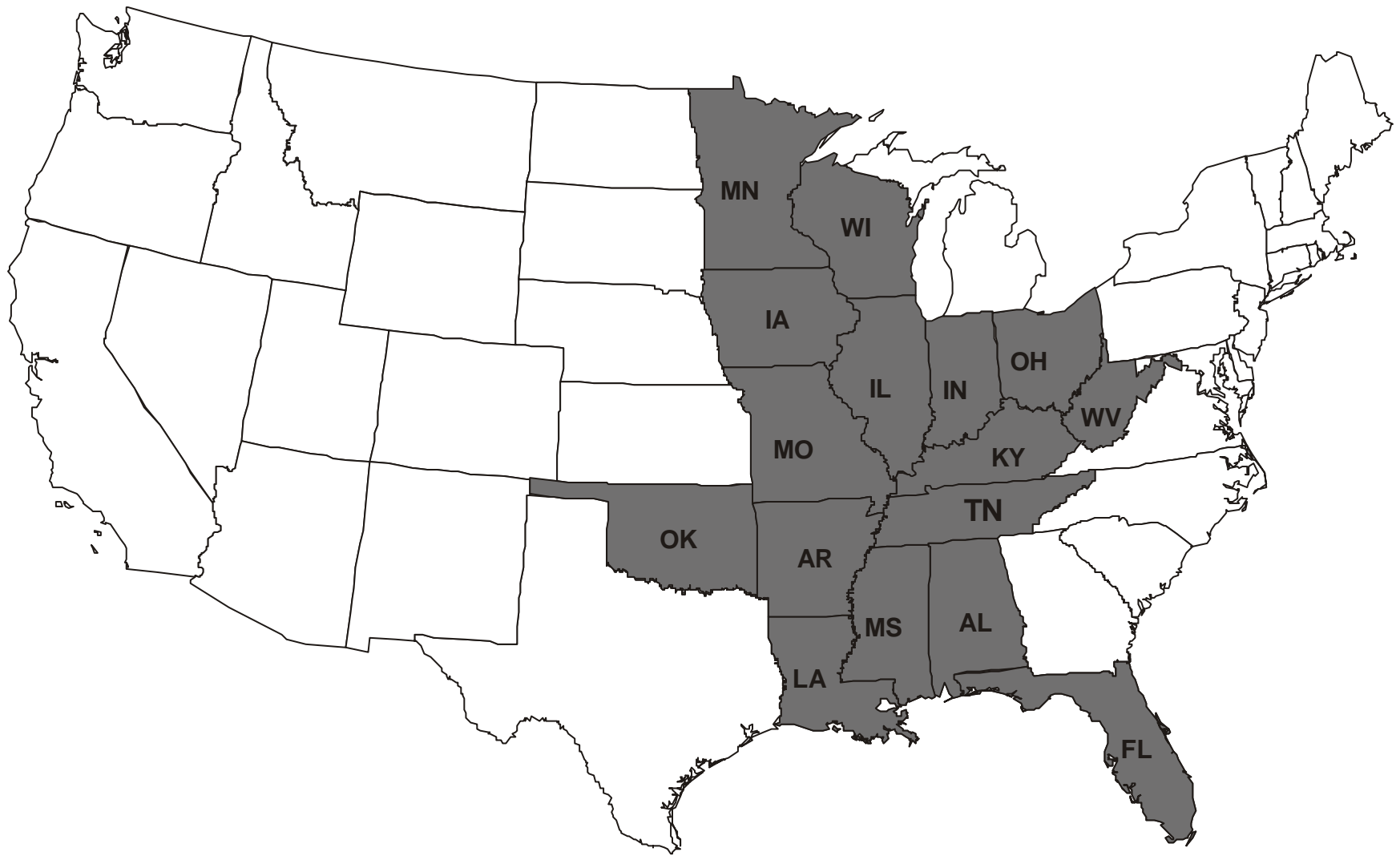


Figure 2. Crystal darter distribution in North America.



Figure 4. Alabama River basin with general land ownership categories included.

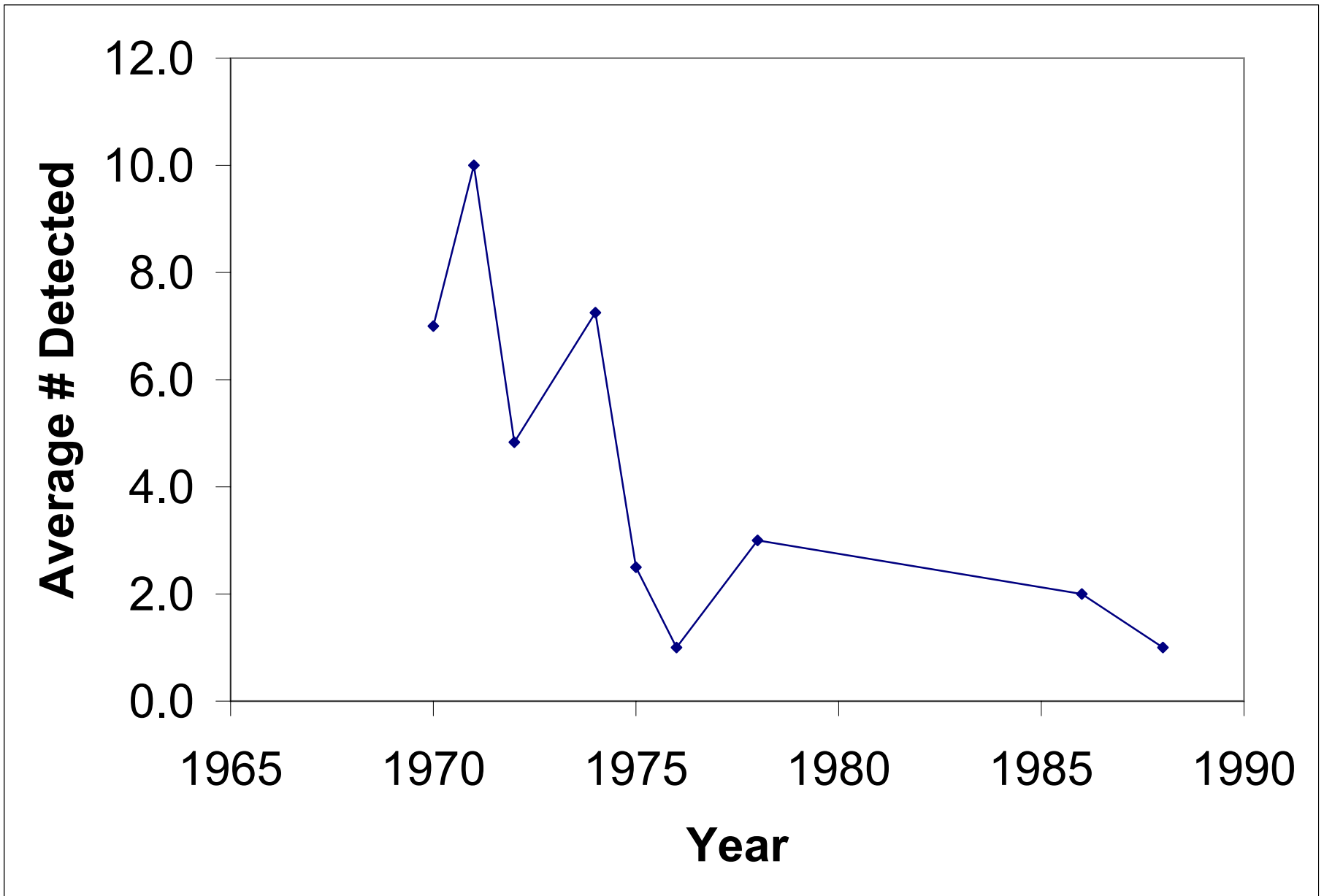


Figure 5. Average number of crystal darter specimens collected per year between 1970 and 1988 in the Bayou Pierre River, Mississippi.

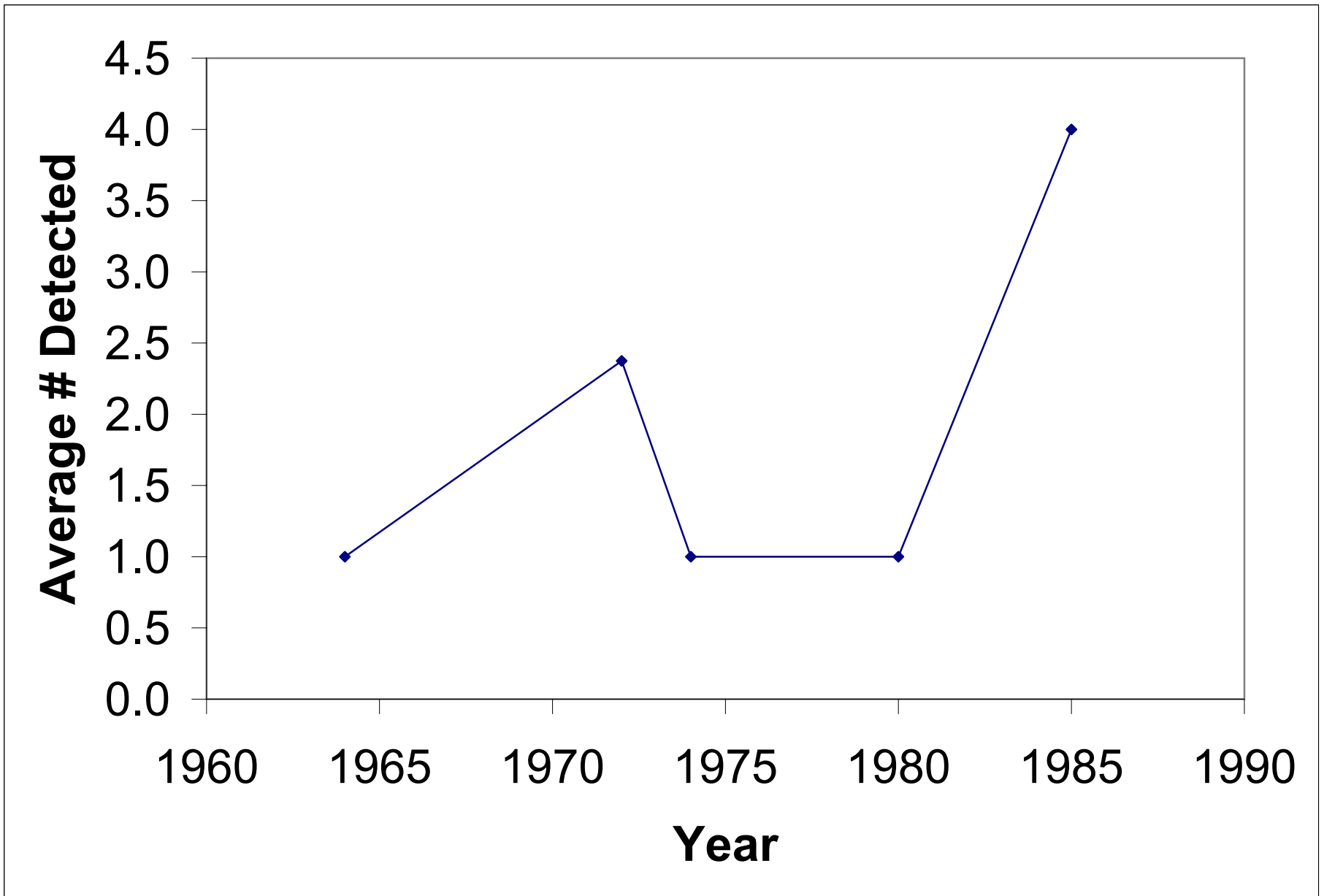


Figure 6. Average number of crystal darter specimens collected per year between 1964 and 1985 in the Buttahatchie River, Mississippi.

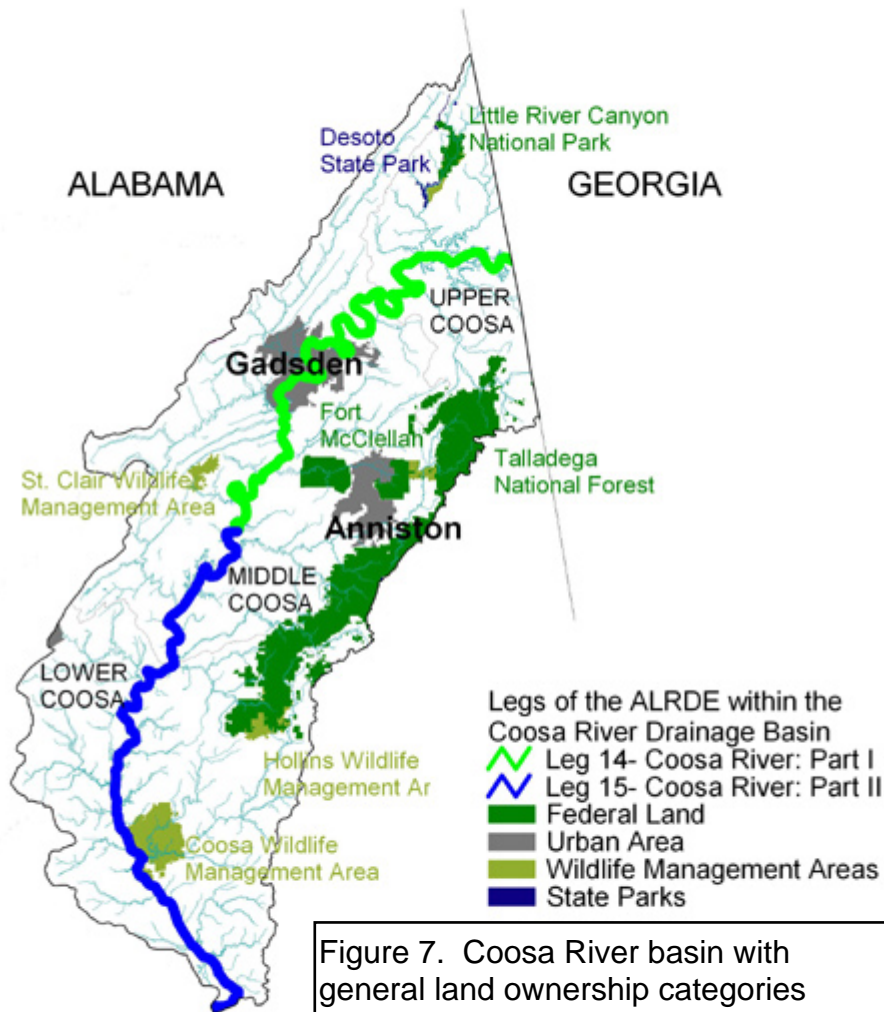


Figure 7. Coosa River basin with general land ownership categories included.

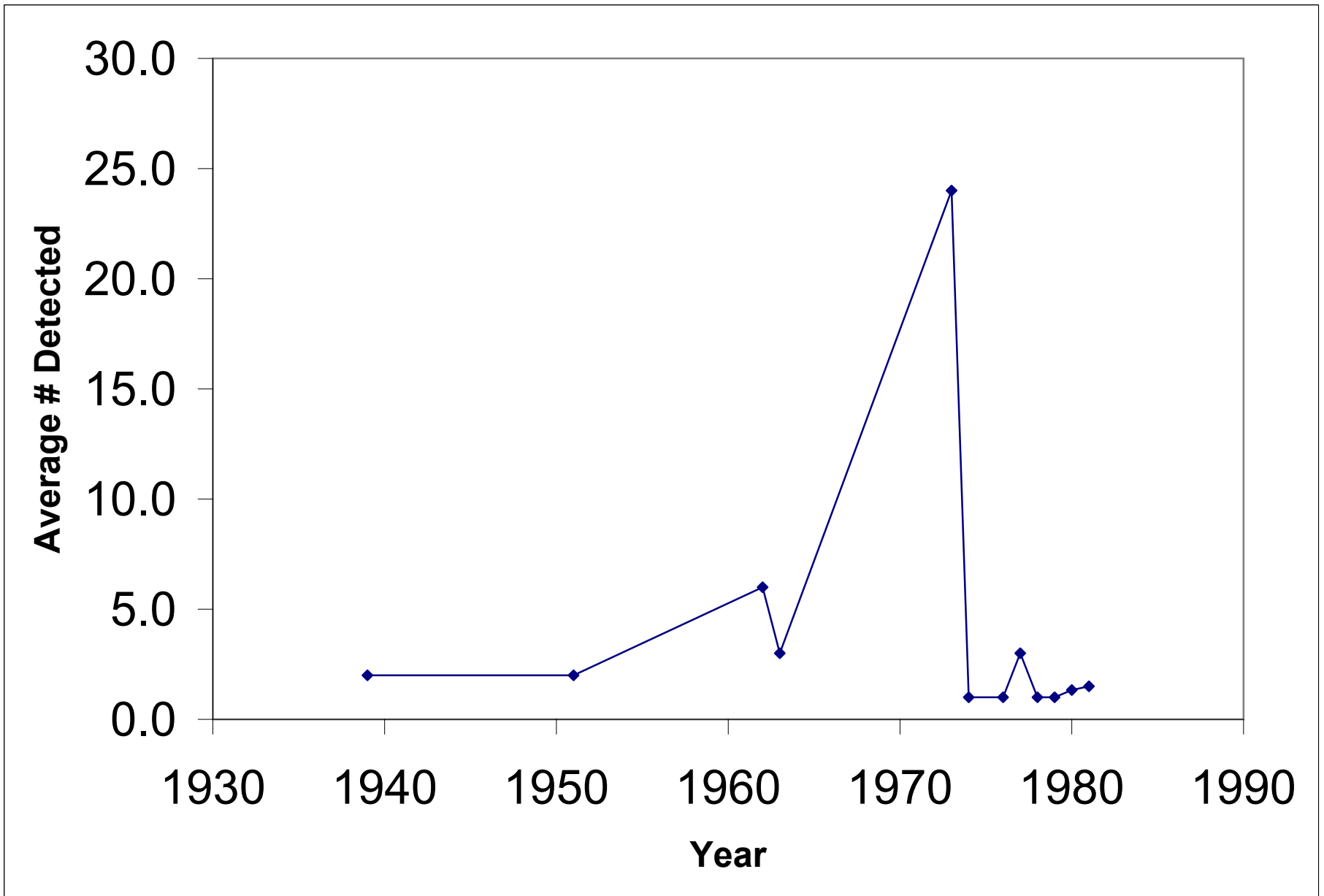


Figure 8. Average number of crystal darter specimens collected between 1939 and 1981 in the Pearl River, Mississippi.

Legs of the ALRDE within the Tallapoosa River Drainage Basin

- Leg 11- Tallapoosa River
- Federal Land
- Urban Area
- State Parks

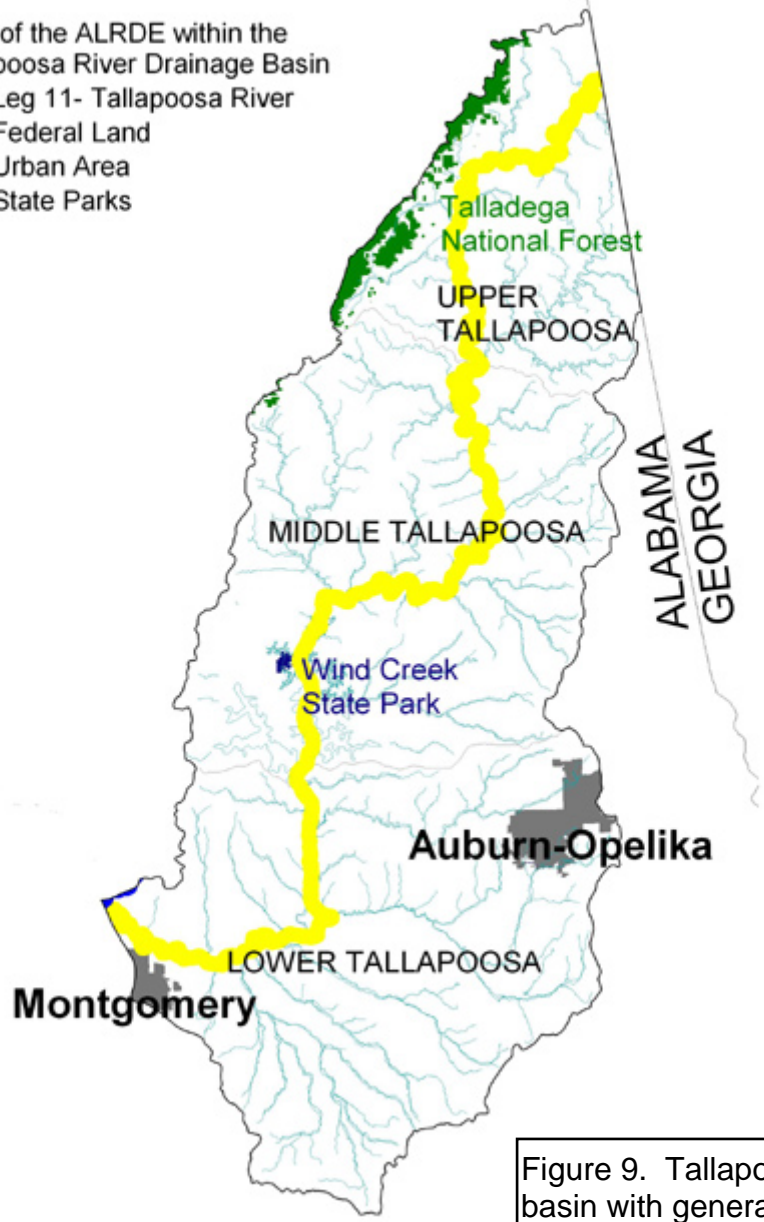


Figure 9. Tallapoosa River basin with general land ownership categories included.

MISSISSIPPI

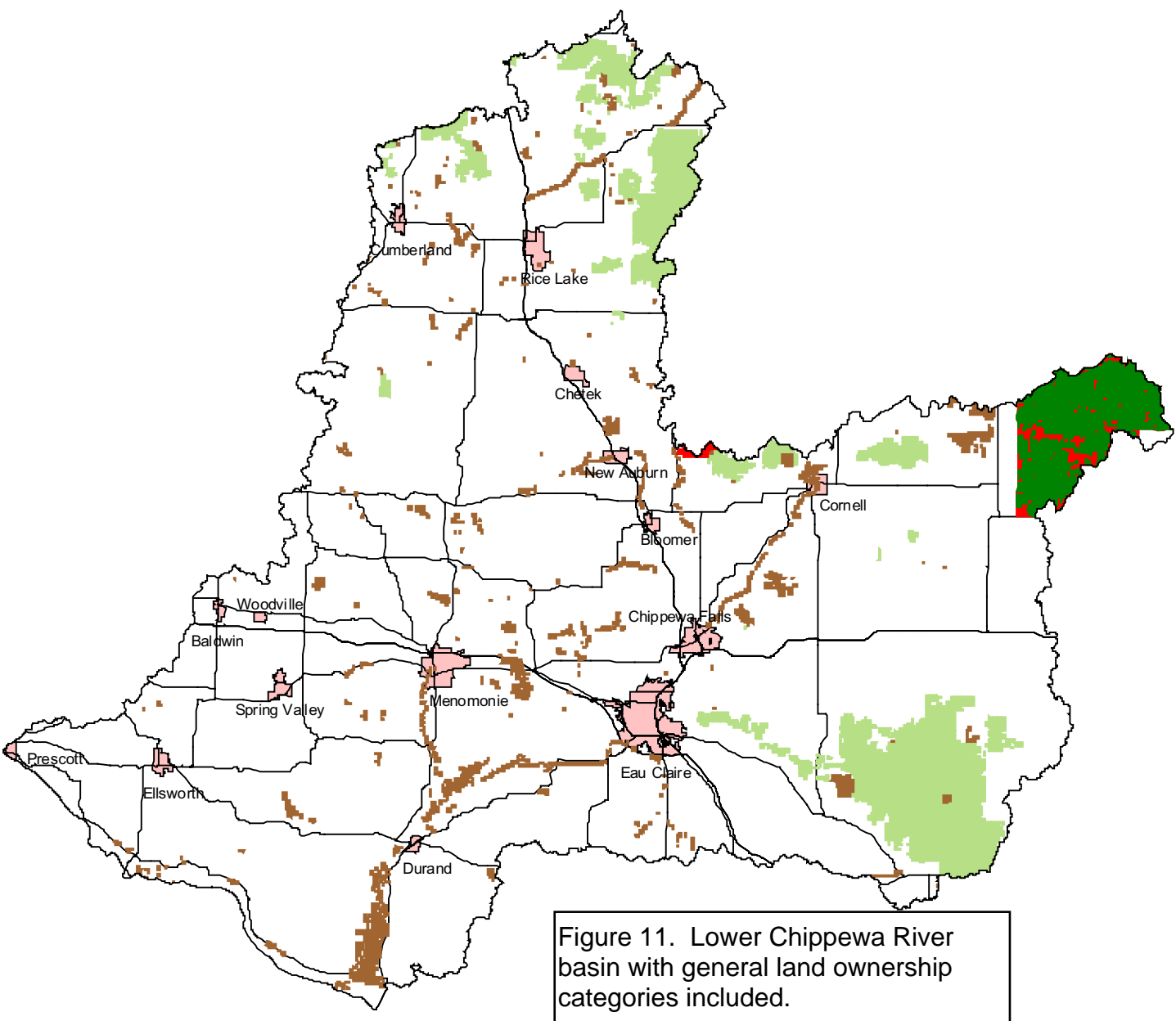
ALABAMA



Legs of the ALRDE within the Lower Tombigbee River Drainage Basin
- Leg 16- Tombigbee River:Part II
- Wildlife Management Areas
- State Parks

Figure 10. Lower Tombigbee River basin with general land ownership categories included.

Land Ownership in the Lower Chippewa River Basin



- Federal Lands
- State Owned (Public) Lands
- National Forest
- County Forest
- State Highways
- Cities & Towns
- Basin Boundary



0 8 16 Miles

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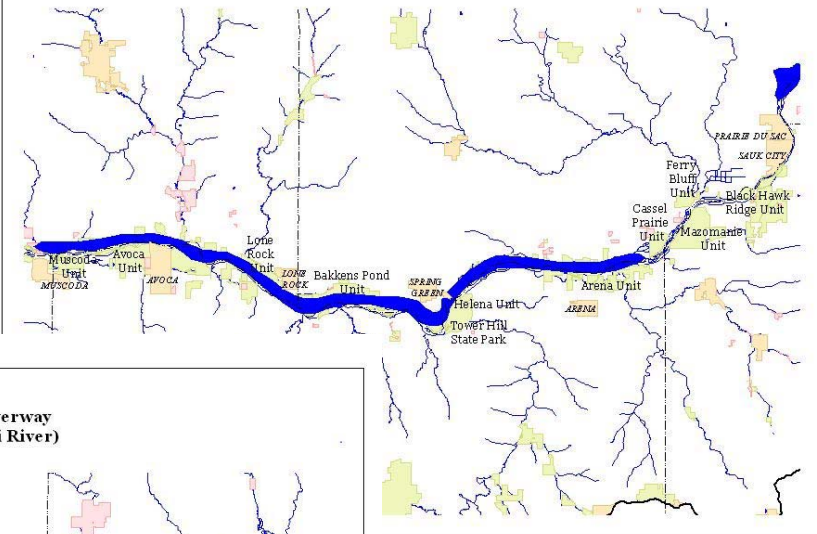


Figure 11. Lower Chippewa River basin with general land ownership categories included.

Cartographer:
West Central Region
Department of Natural Resources



**Lower Wisconsin State Riverway
(Prairie du Sac to Muscod)**



**Lower Wisconsin State Riverway
(Muscod to the Mississippi River)**

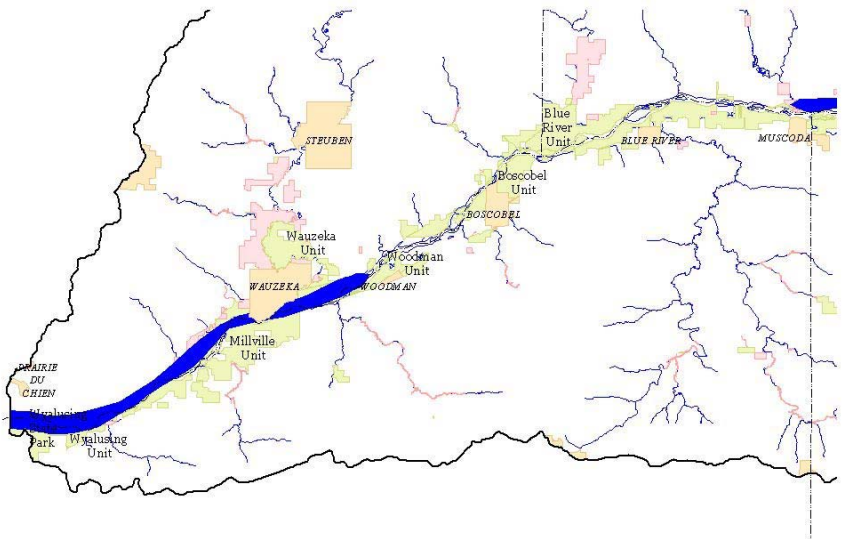


Figure 12. Lower Wisconsin Riverway Project map.