

# PALLID AND SHOVELNOSE STURGEON LARVAE- MORPHOLOGICAL DEVELOPMENT AND IDENTIFICATION

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## Preface

This report is a revised description of pallid sturgeon *Scaphirhynchus albus* larvae based on a new preserved series of genetically pure specimens reared in 1997 and comparison with shovelnose sturgeon *S. platorynchus* reared in 1989 and 1992. At least one parent (four males used) of the 1992 pallid sturgeon series used for the original description and comparison (Snyder 1994) was subsequently determined or suspected to be a hybrid. The larvae in the probably impure series (at least 75% pallid sturgeon) are morphologically very similar to larvae in the pure series. Although specific criteria (character ranges) often differ, most characters found diagnostic or useful for identification in the original report remain valid. A few original characters were dropped (e.g., turns of the spiral valve—small number probably an anomaly), and a few others were added (e.g. pigmentation and lateral rostral plate characters for mesolarvae based on better coverage of this phase in the new series). Except for a couple minor details, drawings of impure pallid sturgeon the from the original description are sufficiently representative of the pure series to use herein without modification.

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## Abstract

Pallid sturgeon *Scaphirhynchus albus* and shovelnose sturgeon *S. platyrhynchus* are nearly identical as larvae, but, except for recently hatched specimens less than 10 mm TL, many can be at least tentatively identified to species using morphological criteria. Both species typically hatch at total lengths (TL) of 8 to 9 mm. By 10 to 11 mm TL, the eyes are well pigmented, the mouth has begun to form, and barbel buds are sufficiently formed to measure. The latter provide the only diagnostic criteria for protolarvae prior to pelvic bud formation at about 12 to 13 mm TL (e.g., inner-barbel length 3-7% of head length and 54-71% of outer-barbel length for pallid, 8-13% and 77-109%, respectively, for shovelnose.). For protolarvae with yolk and pelvic fin buds, barbel length is no longer diagnostic, although it is still useful for secondary taxonomic criteria for some specimens. Instead, these larvae are best distinguished by eye diameter (e.g., 12-15% of head length for pallid, 14-18% for shovelnose, with means of 13% and 16%, respectively). Yolk is absorbed by 18 to 19 mm TL. For protolarvae without yolk, eye diameter remains diagnostic (e.g., 11-13% of head length for pallid, 14-17% for shovelnose) and inner-barbel length relative to outer-barbel length again becomes diagnostic (51-71% for pallid, 66-129% for shovelnose) and remains so through the adult. Two diagnostic melanophore pigmentation characters also come into play during this phase and remain diagnostic in mesolarvae (shovelnose sturgeon are moderately to heavily pigmented over the heart and have a distinctive spot of pigment in the middle of each lower-lip lobe; pallid sturgeon have neither). The first median fin rays appear in the dorsal fin between 21 and 26 mm TL (25 mm TL in pallid sturgeon), marking transition to the mesolarval phase. Mesolarvae between 25 and 30 mm TL with obvious anal fin rays are shovelnose sturgeon; anal fin rays are not apparent in pallid sturgeon until 30 to 31 mm TL. Beginning with mesolarvae, the shape of the ventral aspect of the lateral rostral plate posterior to the outer barbel on each side of the head becomes diagnostic (somewhat deltoid in pallid, more semicircular in shovelnose). Acquisition of full complements of fin rays in all median fins marks transition to the metalarval phase. This occurs with completion of the caudal fin complement at about 56 to 60 mm TL in shovelnose sturgeon but at greater than 81 mm TL in pallid sturgeon. For metalarvae, caudal-fin-ray counts are diagnostic (62-69 for pallid, 51-65 for shovelnose). Pallid and shovelnose sturgeon still retain some preanal

finfold, and therefore remain metalarvae, through at least 200 mm TL (largest specimens examined). Mesolarvae and metalarvae were not analyzed for original morphometric data, but visually the eye is smaller, and previously reported proportions regarding length of the inner barbel have proven diagnostic for metalarvae through adults.

In addition to the diagnostic characters mentioned above, several secondary taxonomic characters are useful for identifying some larvae during specific intervals of development. These include dorsal and anal-fin-rays counts (37-43 and 23-28, respectively, for pallid; 30-39 and 18-25 for shovelnose). Preanal and total myomere counts typically range a couple segments higher for pallid sturgeon than shovelnose sturgeon (37-39 and 35-36 preanal myomeres, respectively, for protolarvae without pelvic fin buds and 34-37 and 33-36, respectively, for protolarvae with pelvic fin buds).

Fin-ray and scute counts for a series of F1 (50%) hybrids are sometimes intermediate but often match one or the other species, more often pallid sturgeon, and occasionally exceed counts for either species. Most characters for a series of impure larvae originally described as pallid sturgeon (at least 75% pallid) closely approximate those to the genetically pure specimens examined for this description. Considering the extreme similarity between the two species and generally overlapping ranges in most morphometric, meristic, and other characters, positive identification of hybrid larvae based on morphological criteria is not feasible.

Pallid and shovelnose sturgeon larvae should be readily distinguished from lake sturgeon. Lake are usually a few millimeters larger relative to state of development and, for specimens over 15 mm TL, have a distinctive lateral band of pigment.



## Introduction

Sturgeon (family Acipenseridae, class Osteichthyes) are an ancient, holarctic group of large (1-8 m total length) fishes characterized by cartilaginous skeletons, vertebrae without centra, persistent notochords, long flattened snouts, inferior mouths with upper jaws that don't articulate with the skull, spiral valves in the hind gut, heterocercal tails, and smooth skin covered in part by rows of bony plates or scutes (Bailey and Cross 1954, Vladykov and Greeley 1963; Scott and Crossman 1973). The living members of the family include 25 to 30 species in four genera (*Acipenser*, *Huso*, *Scaphirhynchus*, and *Pseudoscaphirhynchus*) (Robins et al. 1991a, 1991b).

In North America, sturgeon are represented by five species of *Acipenser* and two or three species of *Scaphirhynchus*. Four of the *Acipenser* species are anadromous, two associated with each coast. The remaining North American sturgeons are freshwater species which, with one exception, have distributional ranges that overlap in the Mississippi River Basin of central United States. The lake sturgeon, *Acipenser fulvescens*, is the most broadly distributed of North America's freshwater sturgeons. It inhabits the larger rivers and lakes of the Hudson Bay, St Lawrence River, Great Lakes, and Mississippi River Basins. In the latter, its range extends to below the confluence with the Ohio River but excludes the middle and upper reaches of the Missouri River (Scott and Crossman 1973; Lee et al. 1980). The genus *Scaphirhynchus*, collectively referred to as river sturgeon, includes the pallid sturgeon, *S. albus*, and the shovelnose sturgeon, *S. platorynchus*. Both are residents of the Mississippi River Basin. A third form of river sturgeon, very similar to shovelnose sturgeon but allopatric in distribution, was recently described from the Mobil Bay Basin as the Alabama sturgeon, *S. suttkusi*, by Williams and Clemmer (1991). Shovelnose sturgeon, the most abundant and broadly distributed of the river sturgeons, are found in larger rivers throughout much of the Mississippi River Basin. There are also old collections of shovelnose sturgeon from the Rio Grande near Albuquerque, New Mexico, and specimens from either Texas or Mexico documenting a still broader historical distribution (Bailey and Cross 1954; Lee et al. 1980). Pallid sturgeon, the largest of the river sturgeons (growing to 1.5 m versus 1 m or less for the other river sturgeons), is found primarily in main-stem portions of the Missouri and lower Mississippi River drainages. Throughout its range, it is sympatric with shovelnose sturgeon but much less common. In the

lower Missouri River and the Mississippi River near and for some distance below their confluence. pallid sturgeon is also sympatric with lake sturgeon. However, in this portion of its range, lake sturgeon are rare and probably not reproductively active (Carlson 1983).

North America's sturgeons have suffered substantial declines in abundance and distribution during the last century, and most species are now considered threatened or endangered by state, provincial, or federal agencies (Williams et al. 1989; Mayden et al. 1992). Unlike the shovelnose sturgeon which remains more abundant and widespread, the pallid sturgeon is among those species in danger of extinction. It is protected by all states of the Missouri River Basin (Gilbraith et al. 1988) and was added to the Federal (U.S. Fish and Wildlife Service) list of threatened and endangered species in 1990. A Pallid Sturgeon Recovery Team has been established to coordinate research and recovery plans.<sup>1</sup> Biologists suspect that reproductive or recruitment failure due to habitat alteration and range restriction are primarily responsible for the continuing decline of pallid sturgeon populations (Carlson et al. 1985, Gilbraith et al. 1988). Hybridization with shovelnose sturgeon has also been documented and poses an additional threat (Carlson et al. 1985, Keenlyne et al. 1994).

Research to document reproduction and determine abundance, distribution, and ecology of early life stages of fishes depends on accurate identification of collected larvae and early juveniles. Snyder (1980) and Wallus (1990) provided criteria for distinguishing river sturgeon larvae from the closely related and largely sympatric paddlefish (*Polyodon spathula*, Polyodontidae) as well as other families with larvae of similar form. Carlson (1981, 1983) and Wallus (1990) similarly provided criteria for distinguishing river sturgeon from lake sturgeon. Except for data based on specimens collected well outside the range of pallid sturgeon, the descriptions of larval river sturgeon by these authors, as well as a drawing by Cada (1977), could represent either pallid or shovelnose sturgeon (or even a hybrid). Criteria for distinguishing larvae of pallid and shovelnose sturgeon were unknown.

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Except for maximum size, juvenile and adult pallid sturgeon are morphologically similar to shovelnose sturgeon and are sometimes difficult to distinguish. Bailey and Cross (1954) conducted the first extensive comparison of the two species. They found that juvenile and adult pallid sturgeon have "37 to 43 dorsal rays and 24 to 28 anal rays, gill rakers on the lower half of the first arch mostly with 2 blunt tips," outer barbels "originating more posteriorly than inner pair," and no dermal scutes on the belly of adults; whereas, shovelnose sturgeon have "30 to 36 dorsal rays and 18 to 23 anal rays, gill rakers on the lower half of the first arch mostly with 3 or 4 blunt tips," outer barbels "originating on a level with or anterior to inner pair," and "small dermal scutes on belly in adults." Also, pallid sturgeon have a "larger head, wider mouth, shorter inner barbel, longer and sharper snout, more posterior placement of barbels . . . , smaller eye, smaller dermal plates, . . . and more pallid color" than shovelnose sturgeon. Among various proportional measurements they reported, inner-barbel length was found to fit more than 6.2 times in head length (to bony posterior margin of the operculum) for pallid sturgeon but less than 5.9 times for shovelnose sturgeon.

This report documents the morphological development of pallid and shovelnose sturgeon larvae, defines diagnostic and secondary morphological criteria for identification of field-collected specimens, makes some comparisons with hybrids, and reviews previously reported criteria for distinguishing lake and river sturgeon.

### **Specimens Examined**

Larvae and early juveniles examined in this and the preceding (Snyder 1994) investigation were reared from wild brood stock at state and federal fish hatcheries, killed and fixed in 10% formalin, and preserved in 3% phosphate-buffered formalin. The specimens are maintained as part of the Larval Fish Laboratory Collection at Colorado State University.

Shovelnose sturgeon were reared in 1989 and 1992 by the U.S. Fish and Wildlife Service Gavins Point National Fish Hatchery (NFH), Yankton, South Dakota. In 1989, brood stock was collected from the Yellowstone River, Montana, and spawned on 10 June at Miles City State Fish Hatchery; eggs were transported to Gavins Point NFH, incubated at about 16.5°C, and hatched on 17 to 20 June (R. Holm, personal communication; 17 June used as hatch date for ages

reported herein). A few of the preserved specimens had abnormally short barbels, missing barbels, or missing lips on the left side of the head. In 1992, shovelnose sturgeon were collected in May near the mouth of the Powder River, Montana, transported to Gavins Point NFH, injected with LHRH (luteinizing hormone releasing hormone), and spawned on 12 June (Werdon 1992). Eggs were incubated in well water at about 13°C and probably hatched between 20 and 25 June (23 June used as hatch date for ages reported herein); larvae were reared at mean monthly temperatures of 19-21°C (H. Bollig, personal communication).

Pallid sturgeon, originally assumed to be pure, and F1 pallid x shovelnose sturgeon hybrids (first generation cross, 50% pallid) were reared in 1992 by the Missouri Department of Conservation Blind Pony Hatchery, Sweet Springs. At about 50 mm total length (TL), F1 hybrids were transferred to Gavins Point NFH. Pallid sturgeon brood stock included two gravid females and two males taken from the lower Mississippi River (below the Missouri River confluence) by commercial fishermen and two males taken from the Missouri River near the mouth of the Platte River (Dryer and Werdon 1992; M. Dryer, personal communication). Milt from the four males was combined prior to fertilization of the eggs on 19 April, but the eggs from each female were reared separately (M. Dryer, personal communication). For the hybrid culture, shovelnose sturgeon milt was used to fertilize pallid sturgeon eggs from the same females on the same date. Eggs for both presumably pure and hybrid sturgeon were incubated at 16.7°C and began hatching on 26 April. Many embryos failed to hatch by 30 April, and those that did hatch late were abnormal (E. J. Hamilton, personal communication; 26 April used as hatch date for ages reported herein). Most preserved specimens appear normal. The pallid sturgeon brood stock for these cultures appeared morphologically pure, but the males from the lower Mississippi River were smaller than expected and are now believed to be hybrids or the progeny of hybrids with shovelnose sturgeon (M. Dryer, personal communication). If so, the larvae described as pallid sturgeon and taxonomically discriminated from shovelnose sturgeon in my previous report (Snyder 1994) are actually F2 or more distant hybrids with at least 75% pallid sturgeon genes). Genetic Analyses, Inc. (1994) failed to detect significant differences between pallid and shovelnose sturgeon DNA, and therefore were unable to assess purity of

suspected hybrids. For purposes of this investigation, the pallid sturgeon reared by Blind Pony Hatchery in 1992 are treated as impure representatives of the species.

Genetically pure pallid sturgeon were reared in 1997, also by Gavins Point NFH. Brood stock consisted of three males and two females collected from the Missouri River near its confluence with the Yellowstone River in North Dakota during September 1993 and September and October 1996. These fish were maintained at the hatchery, monitored for reproductive readiness, injected with LHRH, and spawned on 17 and 18 June 1997. Eggs were incubated in a mix of well and city water at 14°C and hatched on 22 June to 2 July (28 June used as hatch date for ages reported herein); larvae were reared at a relatively steady 19°C. (Herb Bollig, personal communication).

### Methods

Specimens were examined and analyzed to document and determine differences in developmental state relative size, externally visible morphology, fin, scute and myomere meristics, morphometrics, and melanophore pigmentation patterns under stereozoom microscopes (3.5 to 30X magnification) with various combinations of reflected, transmitted or polarized light. Rulers and eyepiece reticles calibrated against stage micrometers were used for some direct measurements. However, most measurements were obtained from computer-captured and stored images of specimens using an image analysis and measurement program (Optimas). Each captured image included an object of known length for calibration. Measurements on smaller specimens were usually repeatable within plus or minus 0.1 mm. Some measurements on specimens over 30 mm TL, especially those measured against a ruler, were repeatable within 1 or 2 mm. Notably dissimilar measurements among fish of similar size were rechecked for verification or correction.

Counts used in this investigation follow Snyder (1981, 1983, 1988) or Bailey and Cross (1954) with some modifications. Preanal, postanal, and total myomeres were counted (Figure 1). Preanal myomere counts include all myomeres even partially transacted by a vertical line from the posterior margin of the vent (Seifert 1969). The first few myomeres often appear epaxial, and become more difficult to observe as tissues at the back of the head thicken. The most

posterior myomeres are also hard to distinguish. Sometimes a few less-clear segments were observed beyond clearly defined myomeres in the tail. The latter were assumed to not be true myomeres and are not included in postanal and total myomere counts. Fin-ray counts include all discernible rays except those obviously incorporated in the spine-like structure along the anterior margin of the pectoral fin: in accord with Bailey and Cross (1954), the pectoral spine itself was counted as a single fin ray. Contrary to Bailey and Cross (1954), the last two rays of each fin were not counted as one. The skeletal fin-ray supports, referred to herein as pterygiophores for the dorsal and anal fins and as radials for the paired fins, were also counted, but the radials were often difficult to discern and some counts are questionable. Supports for the caudal fin rays were too indistinct for consistent counts. Counts of the dorsal, lateral, and ventral (ventrolateral) rows of scutes begin at or near the back of the head and respectively end just before the dorsal fin, with the last carinate scute on the lateral surface of the caudal fin, and just before the pelvic fin. Counts for paired fins and lateral and ventral scutes were made on one side only, usually the left. Counts were repeated at least once to minimize errors.

Measurements used in this investigation also follow Snyder (1981, 1983, 1988) and are diagramed in Figure 1. Barbel lengths and measurements to their anterior bases were recorded for both inner and outer barbels for comparison with diagnostic characters reported for adults and juveniles over 100 mm TL by Bailey and Cross (1954). Measurements were made for only one of each pair of barbels, the longer or more anterior if there was an obvious difference. However, unlike Bailey and Cross's measurements which were taken from point to point, all measurements except lengths of fins and barbels were measured along lines parallel or perpendicular to the horizontal axis of the body, as indicated in Figure 1. Barbels and fins, except the caudal fin, were measured point to point from their anterior base or origin to their most distal margin. The caudal fin was measured from its origin (OC) to its most distal margin (PC) parallel to the horizontal axis of the body and does not include the caudal filament which begins to develop at about 30 mm TL. Also, measurements to the anterior margin of the mouth are to the front of the mouth opening and not, as specified by Bailey and Cross (1954), to the anterior cartilaginous edge of the labial depression (into which the mouth is retracted); accordingly, all distances to the anterior margin of the mouth reported herein will be somewhat greater and less consistent (mouth

can be moved and extended) than corresponding measurements using Bailey and Cross's criteria.

Except as otherwise indicated, specimen lengths are reported as total lengths to avoid complications with use of standard length (SL) which is usually preferred in taxonomic and systematic investigations. Most proportional measurements are reported as a percentage of total length (%TL) rather than standard length (%SL) for the same reason. For early larvae of most fishes, standard length is equated with notochord length and defined as the measurement from the anterior margin of the snout to the posterior end of the notochord (Mansueti and Hardy 1967; Snyder 1981, 1983). For later larvae and older fish, standard length is typically defined according to Hubbs and Lagler (1947) as the measurement from the anterior margin of the snout to the end of the vertebral column. For fish with homocercal tails, this is the more-or-less vertical posterior margin of the hypural bones or plates that support the posteriorly extending principal caudal fin rays. However, for the later larvae, juveniles, and adults of sturgeon, which have heterocercal tails, this definition for standard length is difficult to apply. The vertebral column consists of a series of cartilaginous rings nearly encircling the notochord which continues to extend to near the end of the caudal fin (Ryder 1890). Whether the rings also continue to near the end of the tail has not been reported in descriptive literature reviewed for this study, but if the end of the notochord is considered the end of the vertebral column, standard length continues to very nearly approximate total length. Bailey and Cross (1954) defined standard length for late larval, juvenile, and adult river sturgeon as extending to the posterior margin of the last carinate (keeled or ridged) lateral scute. However, by this definition, standard length can extend well into the caudal fin and might not approximate a similar position on all sturgeons. Perhaps, if it can be consistently detected on adults, length to the origin of the caudal fin (the anterior base of the first caudal fin ray, SN to OC in Figure 1) might be a more appropriate criterion for standard length of late larval and older fishes with heterocercal tails. For river sturgeon over about 30 mm TL, the criterion for total length itself requires some clarification since it is often not clear whether the reported measurement includes the caudal filament. Among North American sturgeons, the caudal filament is unique to the river sturgeon (Bailey and Cross 1954). In this study, total length excludes the caudal filament and is defined to end where the notochord appears to end or become notably thinner. This point is not always clear but is closely approximated by a change

in the angle of the ventral margin of the fin membrane as it stops converging upon the notochord and begins to run parallel to the core of the filament.

Larval phases of development were designated as protolarva, mesolarva, or metalarva in accord with definitions by Snyder (1976, 1981, 1983). Protolarvae have no fin rays in the median (dorsal, anal, and caudal) fins. Mesolarvae have an incomplete count of principal rays in at least one median fin or lack pelvic fins or fin buds. Metalarvae have the adult complement of principal fin rays in all median fins but lack the full complement of fin rays in the paired fins, lack the full complement of fin spines or secondary rays in the median fins, or still bear some finfold. In sturgeon, all fin rays are treated as principal rays, and pelvic buds develop during the protolarval phase prior to full yolk absorption. Unlike other North American sturgeons which bypass the metalarval phase and transform directly from mesolarvae to juveniles with the long delayed acquisition of the adult complement of caudal fin rays (Jude 1982, Snyder 1988, Wallus 1990), river sturgeon acquire the full complement of fin rays in all fins long before the last of the preanal finfold is absorbed and therefore have a rather extensive metalarval phase. For data presentation and discussion, the protolarval phase was subdivided according to presence of yolk and pelvic fin buds. Specimens were categorized as protolarvae without yolk when yolk was no longer externally visible in the visceral cavity, although some might still have been present internally. Last remnants of externally visible yolk are divided ventrally and present only along either side of the stomach region of the visceral cavity.

Snyder and Muth (1988 and 1990) combined the developmental interval terminology used herein with another commonly used terminology (Ahlstrom et al. 1976; Kendall et al. 1984) based on flexion of the posterior portion of the notochord and development of caudal fin rays in fishes with homocercal tails. However, sturgeon have heterocercal tails and are among several groups of fish to which the latter terminology or its use as subdivisions of the mesolarval phase, as defined by Snyder and Muth, is not applicable.

Dorsal, lateral and ventral drawings of selected larval stages were initially traced from enlarged prints of computer-captured images to provide for accurate body proportions and positioning of major features; they were completed while examining the imaged and other similar-size specimens under a stereozoom microscope. Although based on the imaged



specimen. the drawings are idealized composites of two or more specimens with closed fins opened, frayed fins smoothed, and curved bodies straightened. To avoid confusion of pigmentation with other aspects of the drawings, only surface or near-surface melanophores were represented in black ink; the rest of each drawing was produced with various shades of graphite. Except for slightly larger eyes in a couple drawings, illustrations of impure pallid sturgeon from an earlier description based on that developmental series (Snyder 1994) are sufficiently similar to pure specimens to represent them herein without modification.

### Results and Discussion

Specific data for 223 hatchery-reared specimens measuring 8 to 205 mm TL are summarized in Tables 1 to 8 and the Appendix. The Appendix tables summarize data for a series of impure pallid sturgeon larvae used for an earlier description of the species and comparison with shovelnose sturgeon (Snyder 1994). The data and observations are remarkably similar for both pure species, the impure pallid sturgeon, and the first generation (50%) pallid x shovelnose hybrid, with relatively few taxonomically useful differences.

Figures 2 through 8 illustrate typical developmental state, morphology, and melanophore pigmentation of reared pallid and shovelnose sturgeon at comparable stages from recently hatched, 9-mm TL protolarvae to 41-mm mesolarvae. The drawings for pallid sturgeon (upper set in each figure) are based on an impure series reared in 1992, but are sufficiently similar to the pure series reared in 1997 to represent the latter without modification. Figure 9 illustrates a 12-mm hybrid pallid x shovelnose sturgeon protolarva for comparison with representatives of pure forms illustrated in Figure 3. Because of extreme similarity to and between the pure species, additional stages of hybrid pallid x shovelnose sturgeon larvae were not drawn, nor were the larvae analyzed for morphometrics, myomere counts, or developmental state relative to size, but fin-ray and scute counts were determined and included in Table 3.

In the following discussion and Table 9, morphometric and meristic characters for distinguishing the larvae of pallid and shovelnose sturgeon are considered diagnostic (primary taxonomic criteria) if the means or modal values between species are well separated and their ranges are mutually exclusive, or nearly so. Lesser but sometimes useful differences are

considered secondary criteria for identification. Identifications should be based on multiple characters whenever possible; identities based only on a couple of secondary criteria should be considered tentative.

#### *Size Relative to Developmental State*

*Original observations*—Size of pallid sturgeon at onset of most developmental events considered in this investigation is similar to that of shovelnose sturgeon during the protolarval phase but diverges for many developmental events during the mesolarval phase (Table 1, Figures 2-8). Both fish hatch at approximately 8 to 9 mm TL (sometimes as small as 7 mm TL). For protolarvae of both species, pelvic fin buds are first evident at about 12 to 13 mm TL and all externally visible yolk appears to be absorbed by 18 to 19 mm TL. Also for both species, transition from the protolarval to mesolarval phase occurs (by definition) with acquisition of first fin rays in the median fins, in this case the dorsal or caudal fin, between 21 and 26 mm TL (about 25 mm TL for pallid sturgeon). However, transition to the metalarval phase, which occurs with acquisition of the full (adult) complement of fin rays in all fins, in this case the last being the caudal fin, takes place between 55 and 61 mm TL in shovelnose sturgeon but not until much later in pallid sturgeon at some length greater than 81 mm but less than 139 mm TL (probably less than 90 mm TL based on impure pallid sturgeon which acquire the adult complement of caudal fin rays between 75 and 87 mm TL; Appendix Table A1). This difference in onset of the metalarval phase is diagnostic with mesolarvae greater than 60 mm TL being only pallid sturgeon and metalarvae measuring 61 to at least 81 mm TL (maximum diagnostic size not yet determined) being only shovelnose sturgeon. Lack of a full complement of fin rays can usually be assessed by absence of clearly formed rays in the very posterior portion of the fin membrane (if uncertain, compare with much larger specimens for which all fin rays in the fin of concern should be present or do not use such criteria).

After acquisition of all caudal fin rays (and possibly all pectoral fin rays in pallid sturgeon), the only remaining criterion for transition to the juvenile period according to Snyder (1976, 1981, 1983) is loss of preanal finfold. Unexpectedly, preanal finfold is still present on the largest

specimens examined for both species, about 200 mm TL, and size at transition to the juvenile period by this criterion remains unknown.

Differences in size at the onset of many developmental events during the mesolarval phase are useful secondary criteria for identification (Table 1, Figures 2-8). Larvae with at least one anal-fin ray or one ventral scute or the full, adult complement of anal-fin pterygiophores, fin rays in any fin, or ventral scutes prior to development of these characters in pallid sturgeon are probably shovelnose sturgeon. In contrast, the full complement of lateral scutes is acquired at a smaller size in pallid sturgeon than shovelnose sturgeon, but the difference is not great.

*Comparisons with previous descriptions*—Comparisons with previously published data for river sturgeon and lake sturgeon are complicated by some apparent misinterpretations of key structures and events. Carlson (1983), in his comparison of river and lake sturgeon, appears to have mistaken "actinotrichia," defined as the striations or radial support structures of the finfold by Ryder (1890), for developing fin rays in the dorsal fin of a 19-mm specimen and the "completed" caudal fin of 15-mm "mesolarvae." He also noted that by 31 mm, lake sturgeon larvae were reported by Jude (1982) to have complete dorsal fins, but Jude made no such statement; the comment was probably based on misinterpretation of dorsal-fin pterygiophores (skeletal supports for fin rays) as fin rays in Jude's drawing of a 31-mm specimen. Jude (1982) apparently also mistook developing fin-ray supports (median-fin pterygiophores and paired-fin radials) for developing fin rays which he inappropriately called "actinotrichia" (in Table 1, Jude's observations for fin rays are applied to fin-ray supports). Harkness and Dymond (1961) described a "lateral finfold" from which the pectoral and pelvic fins develop in lake sturgeon, but this aspect of their description and the existence of a "lateral finfold" appear to be in error; perhaps they were referring to the membranous pectoral and pelvic fin buds prior to formation of radials and fin rays. Much of Carlson's (1983), Jude's (1982), and Harkness and Dymond's (1961) descriptions were incorporated in species accounts by Wallus (1990).

In sturgeon, the yolk in the abdominal cavity (yolk sac?) divides diagonally a few days after hatching. By 11 to 12 mm TL, the dorso-anterior portion of the yolk is associated with the stomach region and the ventro-posterior portion with the intestinal region anterior to the spiral valve (Figure 3). As reported by Wang et al. (1985), the yolk associated with the intestine is the

portion to be completely absorbed (Figures 4-5). The remaining yolk, which is associated with the stomach, then divides ventrally leaving portions visible only on the right and left sides (Figure 5). In the latter case, there might still be internal yolk above the stomach, or between stomach and liver connecting yolk on right and left sides. In many published descriptions of sturgeon larvae (e.g., Harkness and Dymond 1961, Carlson 1983, Snyder 1988, and possibly Jude 1982) absence of yolk in the ventro-posterior intestinal region is mistakenly treated as complete absorption of the yolk or yolk sac. Harkness and Dymond, suggested that once the yolk sac is absorbed, there is apparently still enough internal yolk reserves to sustain growth without feeding for another week. In the present study, all yolk is considered to be absorbed when it is no longer externally visible in the stomach region, although some internal yolk might still remain (Figure 6, Table 1).

Based on lake sturgeon data by Harkness and Dymond (1961), Jude (1982), Carlson (1983), and Wallus (1990), and as noted by Carlson (1983), lake sturgeon protolarvae are usually at least a few millimeters larger relative to developmental state than either species of river sturgeon (Table 1). Although lake sturgeon can reportedly hatch at sizes as small as the river sturgeons, larval descriptions suggest that they usually hatch a millimeter or two larger (10-11 mm TL). Lake sturgeon remain protolarvae until the first median fin rays develop at a total length greater than 31 mm. If lake sturgeon follow the same pattern as other members of the genus *Acipenser* (Snyder 1988), they lose all finfold and acquire the full complement of fin rays in dorsal, anal, pectoral, and pelvic fins before all caudal fin rays are formed. If so, lake sturgeon, like other *Acipenser* species, transform directly from mesolarvae to juveniles without a metalarval phase. According to Wallus (1990), lake sturgeon become juveniles at some total length between 75 and 123 mm.

### *Meristic Characters*

*Myomere counts*—Preanal, postanal, and total myomere counts are generally a myomere or two greater for pallid sturgeon larvae examined for this investigation than for shovelnose sturgeon (Table 2). Counts for recently hatched larvae of both species are higher than for later stages, but these may include structures falsely assumed to be first and last myomeres or real

myomeres not detected in later stages. Detection of the last few postanal (and therefore total) myomeres in sturgeon is especially difficult regardless of developmental phase and confidence in the accuracy, if not precision, of those counts is low. Accordingly, only preanal counts are considered useful as secondary criteria for identification. Preanal counts observed for recently hatched protolarvae resulted in adjacent but non-overlapping ranges; however combining data for all protolarvae reveals that preanal myomere counts of 37 or greater are uniquely characteristic of some pallid sturgeon, counts of 34 to 36 could apply to either species, and counts of uniquely 33 are characteristic of some shovelnose sturgeon.

Myomere counts reported by Carlson (1983) for wild-caught river sturgeon protolarvae (8-19 mm TL) are lower than those observed in this investigation for shovelnose sturgeon by an average of two preanal, two postanal and four total myomeres (Table 2). This discrepancy probably represents a difference in counting technique or criteria for designating the first and last couple myomeres.

*Fin meristics*—The full complement of dorsal-fin pterygiophores (supports) in river sturgeon is established at a total length just a millimeter or two less than that at which all yolk is absorbed (Table 1, Figures 6-7). For larvae 17 mm TL or larger, the number of dorsal-fin pterygiophores becomes useful as a secondary character for identification. Based on protolarvae without yolk (Table 2) and several pallid sturgeon mesolarvae through about 46 mm TL (Table 8), pallid sturgeon have 15 to 16 dorsal-fin pterygiophores with a mean of 15, whereas shovelnose sturgeon have 14 to 15 with a mean of 14.

Full (adult) complements of fin rays in all but the caudal fin of both species, and possibly the pectoral fin of pallid sturgeon, are established during the mesolarval phase and at a notably earlier age and smaller size for shovelnose sturgeon (Table 1, Figure 8). For both species, acquisition of the full complement of caudal fin rays marks transition to the metalarval phase, and as previously discussed, this apparently occurs much earlier and at a much smaller size in shovelnose sturgeon (56-60 mm TL) than pallid sturgeon (>81, <139 mm TL).

Based on a combination of original and previously reported data, full-complement counts for all fins average and range higher in pallid sturgeon than shovelnose sturgeon, but usually with range overlap including mean or modal values for one or both species (Table 3). Only fin-ray

counts for the caudal fin are sufficiently different (mutually exclusive) to be considered diagnostic. Differences in counts for the other fins, especially the dorsal fin, sometimes can be useful as secondary criteria for identification.

Stability of fin-ray counts can be complicated by the tendency for higher counts among fish of the same species incubated as embryos at lower temperatures. Comparison of fin-ray counts for 1989 shovelnose sturgeon larvae incubated at 17° C with those for 1997 pallid sturgeon reared at 14° C, results in mutually exclusive ranges for all but the anal fin (Table 3). However, 1992 shovelnose sturgeon were incubated at lower temperature (13°C) comparable to that of the 1997 pallid sturgeon, and their fin-ray counts are notably higher than for the 1989 shovelnose sturgeon but remain at least somewhat lower than counts for pallid sturgeon with only caudal and pectoral-fin-ray counts remaining mutually exclusive.

Original dorsal and anal-fin-ray counts for pallid sturgeon nearly match those previously reported by several authors (Table 3), whereas original pelvic-fin-counts and especially pectoral-fin-ray counts are notably higher than reported by Bailey and Cross (1954) and Carlson et al. (1985). For shovelnose sturgeon, mean dorsal-fin-ray counts reported by Bailey and Cross (1954; mostly Missouri River populations), Clay (1975; Ohio River population in Kentucky?), Carlson et al. (1985; Missouri and Mississippi River populations in or near Missouri), and Williams and Clemmer (1991; Mississippi River populations below confluence with the Missouri River) are intermediate to means reported herein for the 1989 and 1992 broods, whereas their means for anal-fin-ray counts match the mean for the 1989 brood and are notably lower than the mean for the 1992 brood. Mean pectoral-fin-ray counts for both 1989 and 1992 shovelnose sturgeon correspond closely with that previously reported by Bailey and Cross (1954) but are notably higher than those reported by Carlson et al. (1985) and Williams and Clemmer (1991). The mean pelvic-fin-ray count for 1992 shovelnose sturgeon matches the mean reported by Bailey and Cross (1954), whereas the lower mean for 1989 shovelnose sturgeon matches means reported by Carlson et al. (1985) and Williams and Clemmer (1991).

Full-complement dorsal and anal-fin-ray counts for late mesolarvae and metalarvae of hybrid pallid x shovelnose sturgeon, both the impure (at least  $\frac{3}{4}$  pallid sturgeon) and F1 (first generation,  $\frac{1}{2}$  pallid sturgeon) series reared in 1992 (incubation temperature for both  $\sim 17^{\circ}$  C), are

similar to and even exceed counts for pallid sturgeon and are modally higher than comparable counts reported by Carlson et. al. (1985) for hybrids (Table 3). Pelvic-fin-ray counts for both hybrid series are intermediate in range between pallid and shovelnose sturgeon, as are pectoral-fin-ray counts for the impure pallid series and caudal-fin-ray counts for the first generation hybrids. Pectoral-fin-ray counts for the F1 hybrid are comparable to counts for shovelnose sturgeon, whereas caudal-fin-ray counts for the impure series are comparable to counts for pallid sturgeon.

*Scutes*—Counts for scutes in the dorsal and ventral (ventrolateral) rows are similar for both pure species, and those for hybrids closely match pure-species counts previously reported by Bailey and Cross (1954), Clay (1975), and Williams and Clemmer (1991) (Table 3). Likewise for previously reported counts of lateral scutes. In contrast, modal lateral row scute counts for both 1989 and 1992 broods of shovelnose sturgeon are notably lower than observed for pallid sturgeon or reported by the above authors for either species. Previously reported ranges for counts tended to include higher extremes than original counts for either species. Lateral scute counts to the origin of the dorsal fin for both hybrid series and shovelnose sturgeon previously reported by Williams and Clemmer (1991) are somewhat greater than original counts for either species.

*Comparisons with descriptions of lake sturgeon larvae*—Carlson (1983) reported myomere counts for 11 to 21-mm-TL lake sturgeon to be diagnostically higher than counts for 8 to 19 mm TL river sturgeon (Table 2). However, his lake sturgeon counts are similar to and his river sturgeon counts lower than original river sturgeon counts (especially pallid sturgeon) reported herein. Jude (1982) reported even greater numbers of preanal and total myomeres but fewer postanal myomeres for 11 to 12-mm lake sturgeon. Wallus (1990) reiterated the lake sturgeon myomere counts of Jude (1982) and Carlson (1983) in his account for yolk-bearing protolarvae, but also indicated that original observations were within the ranges reported by Jude (1982). If Jude's counts, and Wallus's confirmation thereof, are accurate, then myomere counts are clearly diagnostic for distinguishing river sturgeon (38 or fewer preanal myomeres) from lake sturgeon (40 or more preanal myomeres). As discussed above for river sturgeon, Carlson's lower counts

for both species are probably the result of differences in criteria for determining first and last myomeres.

Based on previously published data by Vladykov and Beaulieu (1946), Clay (1975), Jollie (1980), and Jude (1982), fin-ray counts can be used to distinguish lake sturgeon from at least some pallid and shovelnose sturgeon (Table 3). Counts of caudal fin rays appear to be diagnostic with a notably higher number of rays for lake sturgeon than for either pallid or shovelnose sturgeon. However, the count for lake sturgeon is based on only one observation by Jude (1982) and until additional data is reported to verify this observation and document variation in the count, the character should be used with caution only as a secondary criterion (counts of about 80 or more rays unique to at least some lake sturgeon). For lake sturgeon, dorsal and anal-fin-ray counts are similar to those for pallid sturgeon and hybrids of pallid and shovelnose sturgeon and somewhat higher than for shovelnose sturgeon (with range overlap, especially for the dorsal fin). If pallid sturgeon and pallid x shovelnose hybrids can be eliminated as candidate species, then dorsal and anal-fin-ray counts may be useful as a secondary criterion for segregating some lake sturgeon from shovelnose sturgeon. The situation is reversed for pectoral and pelvic-fin-ray counts with lake sturgeon counts being similar to those for shovelnose and lower than those for pallid sturgeon.

Lake sturgeon scute counts reported by Vladykov and Beaulieu (1946) and Jollie (1980) generally range lower than those for either river sturgeon and are useful for helping to identify some lake sturgeon (Table 3). However, range overlap is extensive and the scute counts can only be considered as secondary taxonomic criteria.

### *Morphometric Characters*

*Yolk-bearing protolarvae prior to pelvic fin bud formation (larvae <13 mm TL)*—The only diagnostic character for protolarvae prior to pelvic fin bud formation is length of the inner barbels (BI) after barbel buds are sufficiently formed (larvae 10-12 mm TL). As in adults, inner-barbel length can be substantially shorter in pallid than in shovelnose sturgeon (Tables 6-7; Figure 3). Ranges for inner-barbel length relationships considered in this investigation are mutually exclusive relative to head length, outer-barbel length, and length from snout to anterior



margin of the mouth opening. Although the values are quite different, even the ranges for inner-barbel-length ratios similar to those found diagnostic for adults and juveniles over 100 mm TL by Bailey and Cross (1954) are mutually exclusive (Tables 6-7).

Differences in measured characteristics of the head are more obvious when considered relative to head length than total length (Tables 6-7). The greatest difference relative to head length, aside from inner-barbel length, is eye diameter, which is diagnostic for protolarvae after pelvic bud formation but best considered a very good secondary criterion for identification of these earlier stages. Excluding the smallest, just-hatched, pallid sturgeon larva analyzed (8 mm TL), the smaller mean value for pallid sturgeon eye diameter is included in the range for shovelnose sturgeon. Other secondary criteria relative to head length are distance from anterior base of inner barbel to anterior margin of mouth opening (sometimes greater for shovelnose sturgeon) and width of mouth opening (sometimes smaller for pallid sturgeon). The former measure is also useful as secondary criteria when considered relative to distances from snout to anterior base of outer barbel and snout to posterior margin of the operculum. Data for width of mouth opening, relative to both total length (Tables 4-5) and head length (Tables 6-7) suggest that width of the mouth opening is always smaller for pallid sturgeon at least 9 mm in total length; however, the differences are transitory and width of the mouth opening for protolarvae after pelvic fin bud formation is nearly the same for both species. Therefore, some pallid sturgeon prior to pelvic fin bud formation probably have mouth openings as great as those for shovelnose sturgeon and the real upper limit of the range for pallid sturgeon is likely to be about the same as for shovelnose sturgeon. Other relations between head morphometrics that are sometimes sufficiently different to qualify as a secondary taxonomic criteria are snout to anterior base of inner barbel as percentages of snout to anterior base of outer barbel and snout to mouth opening. Range overlap for most of these character relations is extensive and often only lower or upper ends of the ranges are exclusively characteristic of one or the other species. Few of the referenced structures are present or sufficiently distinct in recently hatched larvae. Accordingly, morphological identification of larvae less than 10 mm TL (Figure 2) must be considered very tentative, if not impossible .

*Yolk-bearing protolarvae with pelvic fin buds (larvae ~12-18 mm TL)*— No characters were found clearly diagnostic for larvae in this state of development. Among morphometric characters (Tables 4-7, Figures 4-5), eye diameter relative to head length and length from snout to anterior margin of the mouth opening is often smaller for pallid sturgeon and perhaps the closest to a diagnostic character (treated as such in Table 9). Mean eye diameters for each species are mutually exclusive of the respective ranges for the other species, but the differences are not great and the ranges overlap (Tables 6-7). Differences in inner-barbel length relative to various other head measures or structures are no longer diagnostic due to extensive overlap in character ranges including the mean for one or both species. However, the tendency for smaller inner barbels remains for pallid sturgeon and these relations can still be used as secondary criteria for identification, now include inner-barbel length relative to mouth width (including lips).

Other morphometric characters useful as secondary criteria prior to pelvic fin bud formation, except width of the mouth opening, remain useful as such. Distance from snout to origin of the anal fin (most anterior anal pterygophore) as a percentage of total length can also be considered a useful secondary criterion for identification (greater for some shovelnose sturgeon; Tables 6-7).

*Protolarvae without yolk (larvae ~18 to 25 mm TL)*—Once all externally visible yolk is absorbed, many protolarvae can be diagnosed by pallid sturgeon's smaller eye diameter relative to head length and distance from anterior margin of snout to anterior margin of mouth opening, smaller inner-barbel length relative to outer-barbel length, and lesser distance from snout to origin of dorsal fin (most anterior pterygiophore) relative to total length (Tables 4-7, Figure 6). Other inner-barbel length relations found useful as secondary criteria prior to yolk absorption remain useful as such, except relative to length from snout to anterior base of outer barbel. Distance from anterior base of the inner barbel to anterior margin of the mouth opening relative to head length and mouth width also remain useful as secondary criteria for identification. Likewise for distance from snout to anterior base of the inner barbel relative to distance from snout to mouth opening and snout to origin of the anal fin relative to total length. New morphometric characters sometimes useful as secondary criteria include a greater outer-barbel length relative to total and head lengths and a shorter distance between posterior margin of vent

and origin of dorsal fin relative to total length (dorsal fin origin over or just slightly behind vent) for some pallid sturgeon.

*Mesolarvae (~25 to between 55 and 139 mm TL), metalarvae, and older*—A limited set of morphometric data was determined for pallid sturgeon mesolarvae (Table 8) but not shovelnose sturgeon. These data complement Tables 4 and 6 (also Table 2 for selected meristics). The full set of morphometric measurements (as per protolarvae) was made for only a recently transformed, 26-mm mesolarva, but selected head measurements also were made for an additional 4 to 7 mesolarvae (30 to 46 mm TL, not including length of caudal filament).

The 26-mm pallid sturgeon mesolarva fits within all but one diagnostic and one secondary morphometric criteria discussed above for identification of pallid sturgeon protolarvae without yolk. However, snout length for this specimen increased notably over the largest protolarva examined and as a result most length measures relative to total length given in Table 8 exceed the ranges summarized for protolarvae without yolk in Table 4. These include length from snout to origin of dorsal and anal fins relative to total length, the diagnostic and secondary criteria for protolarvae which no longer fit.

Although the recently transformed mesolarva of pallid sturgeon discussed above conforms to most late protolarval morphometric criteria for identification of that species, without comparable morphometric data for shovelnose sturgeon, those taxonomic criteria, with one exception, cannot be applied confidently to even recently transformed mesolarvae. The one exception is the highly probable diagnostic relationship of inner-barbel length relative to outer-barbel length. Based on comparable values for this relationship within each species for protolarvae without yolk and for metalarvae and juveniles greater than 125 mm TL (>100 mm standard length), as reported by Bailey and Cross (1954), this relationship appears to remain stable and distinctive for all life stages after yolk absorption (Tables 6-7). The continuity of the relationship for pallid sturgeon is further documented by comparable measurements for eight mesolarvae less than 47 mm TL in this investigation (Table 8). Accordingly, for mesolarvae inner-barbel lengths that are 65 to 69% of outer-barbel lengths (i.e., fit 1.5 times in outer-barbel lengths) represent either species, smaller inner barbels relative to outer barbels (lesser percentages, greater number fitting in) characterize pallid sturgeon, and larger inner barbels characterize shovelnose sturgeon. Smaller eye diameters

probably also remain diagnostic for pallid sturgeon, but again, corresponding measures for shovelnose sturgeon mesolarvae were not determined and data for metalarvae and small juveniles have not been reported elsewhere.

*Comparisons with other descriptions of river sturgeon larvae*—Carlson (1983) and Wallus (1990) reported percentage total length data for several morphometric characters of wild-caught river sturgeon protolarvae. Most ranges are nearly identical to those reported herein for both species combined, but snout length (AS to AE), head length (prepectoral length, SN to OP1), predorsal-finfold length (SN to ODF), and head width ranges for 14- to 19-mm larvae have greater upper limits and snout to vent length (preanal length, AS to PV) for 14- to 19-mm larvae and head width for 7- to 12-mm larvae have lesser lower limits than observed in this investigation. These discrepancies may represent differences in either precision or measurement technique; none of the characters are considered useful for distinguishing species of river sturgeon.

*Comparisons with descriptions of lake sturgeon larvae*—Jude (1982), Carlson (1983), and Wallus (1990) similarly reported comparable morphometric data for cultured and wild-caught lake sturgeon. Like data for wild-caught river sturgeon, values for many characters reported have greater upper range limits than recorded herein for pallid and shovelnose sturgeon. For yolk-bearing protolarvae with pelvic fin buds, a comparison of combined data reported for lake sturgeon by these authors with combined data for river sturgeon from Carlson (1983), Wallus (1990), and that presented herein reveals substantial differences in ranges for preanal length (54-65% TL for lake sturgeon versus 46-59% TL for river sturgeon), head width (8-13% TL versus 11-14% TL, respectively), and longitudinal eye diameter (3-5% TL versus 2-3% TL, respectively). A similar comparison of morphometric data for larvae prior to pelvic fin bud formation reveals no notable differences between lake sturgeon and river sturgeon.

#### *Other Morphological Structures*

Differences in shape and proportional size of various structures or distances between landmark structures are effectively covered under morphometric analysis. However, one structural difference of diagnostic value for mesolarvae and metalarvae is better described

qualitatively—as defined (outlined) by the infraorbital canal, the shape of the ventral aspect of the lateral rostral plate posterior to each outer barbel (Figures 7-8). In pallid sturgeon, this portion of each lateral rostral plate is very angular and widest anteriorly near the barbel and results in a somewhat deltoid shape. In shovelnose sturgeon, this portion of each rostral plate is more semicircular along its inner margin and widest at a more posterior point nearly midway between the outer barbel and the corner of the mouth. In vicinity of the mouth, the inner margin of this structure tends to be distinctly concave in pallid sturgeon but more nearly straight in mesolarvae to slightly concave in metalarvae of shovelnose sturgeon.

### *Pigmentation*

Pigmentation is quite variable but similar for both species and hybrids (Figures 2-9). Within a few days after hatching, the caudal portion of the body, that posterior to the vent, becomes heavily and rather uniformly pigmented on all surfaces. Anterior to the vent, pigmentation is generally lighter and more variable on all but the ventral surface which is mostly unpigmented except for the snout and sparse patches or lines between the mouth and liver in later larvae.

Beginning with some 16-mm protolarvae with yolk and pelvic fin buds, at least light melanophore pigmentation develops in most of the pericardium or other tissues immediately ventral to the heart of most shovelnose sturgeon but not pallid sturgeon for which the tissues usually remain unpigmented (Figures 5-8). Some specimens of either species display a little pigment over only the anterior portion of the heart. For mesolarvae of either species greater than 45 mm TL, tissues over the ventral musculature along each side of the heart usually become at least moderately pigmented and should not be confused with pigmentation over the heart itself. For some early metalarvae of shovelnose sturgeon (>60 mm TL), presence of pigmentation over most of the heart remains diagnostic but is obliterated in others and later stages. For larvae of the impure pallid sturgeon series, pigmentation of the ventral surface of the heart often is lacking, as in pallid sturgeon, sometimes is confined to the anterior region, as for either pure species, or sometimes covers much of the heart, as in shovelnose sturgeon.

Beginning with protolarvae shortly after absorption of externally visible yolk, a diagnostic, eye-like spot or patch of light to moderately dense ventral pigment forms in the middle of each of

the two lower-lip lobes of shovelnose sturgeon but not pallid sturgeon for which the lip usually remain unpigmented (Figures 7-8). These mid-lower-lip-lobe spots remain distinctive in shovelnose sturgeon mesolarvae through about 45 mm TL, after which some patches become smaller and more elongate before dissipating in metalarvae. Rarely, either species can have a mid-spot or patch of pigment on just one lower-lip lobe. Occasionally, either species can have a little pigment along the outer margin of lower-lip lobes near the corners of the mouth. Posterior to the mouth, both species usually have sparse patches of ventral-surface or internal pigment associated with various structures in the branchial region. For larvae of the impure pallid sturgeon series, lower-lip-lobe pigmentation matches that of the pure pallid sturgeon series.

Mesolarvae of both species develop a "Y" pattern of pigment dorsally over the hindbrain (see shovelnose sturgeon in Figures 7-8). The tail of the "Y" points posteriorly and covers or outlines a portion of what appears to be a medial canal. The splayed arms of the "Y" extend from the point of juncture towards the eyes. For recently transformed specimens less than 30 mm TL, this pattern is light to moderately intense for either species but sometimes indistinct for pallid sturgeon. For larger mesolarvae, the pattern is moderately intense to dark for either species but sometimes light or indistinct for pallid sturgeon between 30 and 45 mm TL.

Carlson (1983) and Wallus (1990) report that by about 16 mm TL, a striking, bicolor pigment pattern develops on lake sturgeon and that the pattern is diagnostic for distinguishing lake sturgeon from river sturgeon. The pattern begins as dark lateral band of pigment that extends from around the snout and through the eyes to the origin of the dorsal fin, after which it broadens to first cover the dorsal surface and then all body surfaces in the caudal region (Jude 1982, Carlson 1983, Wang et al. 1985, and Wallus 1990). Above the band (dorso-lateral and dorsal surfaces anterior to the dorsal fin) the body is lightly pigmented and below it (ventro-lateral and ventral surfaces to behind the anal fin) the body is essentially unpigmented. The lower boundary between the dark lateral band is quite sharp. In contrast, the lateral pigmentation of river sturgeon extends over the ventrolateral to the ventral surface and the boundary is less well defined (Figures 6-7). Also, for protolarvae without yolk and early mesolarvae, the white ventral surface ends at the vent for river sturgeon but continues to well behind the anal fin in lake sturgeon. These differences in pigmentation of lake and river sturgeon persist in larvae at least as

large as 31 mm TL. The size at which the dorsal and lateral bicolor pattern of lake sturgeon breaks down has not been reported, but according to Wallus (1990), by 122 mm TL, it is replaced by large, dark blotches on the snout and body which persist over a lighter, more uniform background in juveniles up to about 600 mm TL. In late mesolarvae and metalarvae of river sturgeon, dorsal and lateral pigmentation is more uniform (no blotches).

#### *Correlation with Capture Date and Location*

In at least some cases, identity of sturgeon protolarvae can be corroborated with information on date and location of capture (Snyder 1988). In accord with recorded differences in distribution of pallid, shovelnose, and lake sturgeon, sturgeon larvae taken in the Ohio River Basin and Mississippi River Basin above the confluence with the Missouri River are most likely shovelnose sturgeon or lake sturgeon. Sturgeon larvae taken in the Missouri River Basin and Mississippi River Basin below the Missouri River Confluence are most likely shovelnose or pallid sturgeon (slim possibility of lake sturgeon larvae below the Missouri River confluence). Spawning seasons for all three sturgeon have been reported as April through mid June, and possibly July, depending on latitude (Wallus 1990), but specific seasons for the river sturgeon are not well documented (Gilbraith et al. 1988). The impure ( $\geq 3/4$ ) pallid and hybrid pallid x shovelnose sturgeon series examined for this study were artificially spawned in mid April at Missouri's Blind Pony Hatchery whereas both broods of shovelnose sturgeon and the pure series of pallid sturgeon were spawned in mid June at Gavins Point NFH, South Dakota. If there were a strong temporal difference in spawning season for sympatric populations, the identity of protolarvae, and possibly mesolarvae, could be correlated with spawning season. However, especially considering these hatchery efforts and high incidence of hybridization (Keenlyne et al. 1994), natural spawning seasons for both river sturgeon appear to coincide or broadly overlap.

#### **Conclusions**

As expected, the larvae of pallid and shovelnose sturgeon are extremely similar and protolarvae prior to yolk absorption are particularly difficult to identify. However, except for recently hatched specimens less than 10 mm TL, many protolarvae can be at least tentatively

identified to species. Once yolk is absorbed, most unhybridized specimens in good condition can be identified to species with reasonable certainty. Table 9 provides a summary of diagnostic (primary) and secondary morphological criteria for identification. Some characters found useful for identification (e.g., inner-barbel length relative to outer-barbel length and dorsal and anal-fin-ray counts) were previously reported as such by Bailey and Cross (1954) for metalarvae, juveniles, and adults.

The criteria detailed in this report for identifying pallid and shovelnose sturgeon are based on a limited number of observations made on specific broods of hatchery-reared specimens. It is probable that other specimens in these broods, specimens from other hatchery or laboratory reared broods, and wild-caught specimens will display extreme character states beyond those reported here. Accordingly, identities should be based on multiple characters when possible. Identities based entirely on secondary criteria must be treated conservatively. For some larvae, especially protolarvae prior to yolk absorption, criteria presented here will be inadequate for even tentative identification and they will remain "unidentified river sturgeon" (*Scaphirhynchus* sp.); recently hatched larvae less than 10 mm TL cannot be effectively distinguished. The identity of specimens with character states near regions of overlap should be considered tentative (i.e., question marks appended to the probable species designation). Analysis for unique DNA markers will probably be required to resolve or confirm the identity of specimens that are not confidently identified using morphological criteria.

Hybrid larvae may display intermediate character states or a mix of diagnostic and secondary character states for both species, but based on developmental series examined, many are likely to be identified, at least tentatively, as pallid sturgeon. Hybrid influence on the 1992 series of impure pallid sturgeon, which are at most second generation hybrids crossed back with pallid sturgeon, does not appear to be very strong with respect to morphology (compare Table 9 with Appendix Table A5 which similarly summarizes criteria reported by Snyder 1994 for distinguishing the impure series of pallid sturgeon from shovelnose sturgeon). Among characters that appear to be diagnostic for distinguishing impure but not pure pallid sturgeon larvae from shovelnose sturgeon are the number of externally obvious turns of the spiral valve in the hindgut and the distance between lower lip lobes. As expected, the larvae of first generation hybrid



pallid x shovelnose sturgeon are also very similar to the two parental forms (Figure 9). Fin ray and scute counts in late mesolarvae and early metalarvae, the only characters closely examined for these hybrids, were usually either intermediate between species or similar to those for pallid sturgeon (Table 3).

Based on the limited descriptive information available, lake sturgeon larvae can be readily distinguished from river sturgeon. Protolarvae over 15 mm TL are described by Carlson (1983) and Wallus (1990) to have a distinctive bicolor pigment pattern which begins as a broad lateral band of pigment that extends from around the snout to the origin of the dorsal fin, then broadens gradually to cover all posterior surfaces. Except for the hatching size of some specimens, lake sturgeon protolarvae and mesolarvae are generally at least a few millimeters larger than river sturgeon relative to developmental state. However, unlike river sturgeon, they transform directly from mesolarvae to juveniles with the acquisition of their full complement of caudal fin rays (all finfold is absorbed before this event) and do not develop the long, very thin caudal peduncle and caudal-fin filament. Reported fin-ray counts, except possibly for the caudal fin, are similar to those for either pallid or shovelnose sturgeon and are therefore of limited value in separating lake and river sturgeon. Scute counts overlap but tend to be somewhat lower than those for river sturgeon. Metalarval, juvenile, and adult river sturgeon are characterized by a very long, thin caudal peduncle and a long caudal-fin filament, whereas lake sturgeon have a relatively short, thick caudal peduncle and never develop a caudal filament.

Researchers seem to always want more data. So it is here. Recommendations for future work on the taxonomy of river sturgeon larvae are: (1) verification of taxonomic criteria reported herein using reared specimens from other broods and wild-caught specimens collected from localities outside the range for one or the other species; (2) head and barbel measurements for early mesolarvae of shovelnose sturgeon and later mesolarvae and metalarvae of both species, and perhaps hybrids, (3) determination of size of pallid sturgeon at acquisition of the full complement of caudal fin rays (transition to the metalarval phase), (4) determination of size at which each species absorbs the last of its preanal finfold (transition to the juvenile period); and (5) a similar, more detailed, description of lake sturgeon larvae for better comparison with river sturgeon.

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TABLE 1.—Size (mm TL, total length) and age (from hatching)<sup>a</sup> at apparent onset of selected developmental events for pallid, shovelnose, and lake sturgeon. Except as footnoted, data are original observations for pallid sturgeon reared in 1997 and shovelnose sturgeon reared in 1989 (<22 mm TL) and 1992 (>25 mm TL) by Gavins Point National Fish Hatchery. Data for lake sturgeon are based on published accounts and illustrations as footnoted. Fin rays and scutes are considered present when they are sufficiently distinct to be seen under low power magnification. Rare or questionable values are enclosed in parentheses.

Developmental Event	Pallid Sturgeon		Shovelnose Sturgeon		Lake Sturgeon	
	Size (mm TL)	Age (d) <sup>a</sup>	Size (mm TL)	Age (d) <sup>a</sup>	Size (mm TL)	Age (d) <sup>a</sup>
Hatching	(7)8-9	0	7 <sup>b</sup> - 9	0	(7)8-12 <sup>b,c,d</sup>	0
Eyes Well Pigmented	10	2	10, (12 <sup>b</sup> )	2	14 <sup>b,c</sup>	
Barbel Buds Formed	9	1	9	1	12-13 <sup>c</sup> , 14 <sup>b</sup> , 15 <sup>c</sup>	2-3 <sup>d</sup> , 3-4 <sup>c</sup>
Pectoral-Fin Buds Formed	8	0	9, (13 <sup>b</sup> )	0	11 <sup>c</sup> -12 <sup>c</sup>	2-3 <sup>d</sup>
Pelvic-Fin Buds Formed	12	5	12-13, (<15 <sup>b</sup> )	4	16 <sup>c</sup> , <18 <sup>b</sup> -18 <sup>c</sup>	4 <sup>c</sup>
All Yolk Absorbed <sup>f</sup>	18-19	12	(12 <sup>b</sup> <sup>h</sup> ), 18	11	(17 <sup>b</sup> <sup>h</sup> ), 19 <sup>c</sup> -21 <sup>c</sup> , 23 <sup>c</sup>	<9-10 <sup>c,d</sup> , 8-39 <sup>g</sup>
All Finfold Absorbed	>205	>186	>140 <sup>c</sup> , >198	>78	>75 <sup>c,e</sup>	
<u>First Element(s) Present</u>						
Fin-Ray Supports,						
Dorsal	11-12	4	11, (<14 <sup>b</sup> )	3	15-17 <sup>b,c</sup>	
Anal	11-12	4	11	3	18-19 <sup>c</sup>	
Pectoral	14	7	(14)15	(5)6	>19 <sup>c</sup> , ≤22 <sup>c</sup>	
Pelvic	15	8	15	6		
Fin Rays,						
Dorsal	25	20-22	(19 <sup>b</sup> ), >21, <26	>15, <21	>31 <sup>c</sup> , <75 <sup>c,h</sup>	
Anal	30-31	26	>21, <26	>15, <21	>31 <sup>c</sup> , <75 <sup>c,h</sup>	
Caudal	25	20-22	>21, <26	>15, <21	>31 <sup>c</sup> , <75 <sup>c,h</sup>	
Pectoral	25	20-22	>21, <26	>15, <21	>31 <sup>c</sup> , <42 <sup>c</sup>	7-8 <sup>d</sup>
Pelvic	30-31	26	>31, <34	>21, <24	>31 <sup>c</sup> , <75 <sup>c,h</sup>	13-14 <sup>d</sup>
Scute Series,						
Dorsal	23-24	19	>21, <26	>15, <21	>27 <sup>c</sup> , <31 <sup>c</sup>	
Lateral	30-31	26	>26, <31	>21, <24	>31 <sup>c</sup> , <75 <sup>c,h</sup>	
Ventral	>46, <53	>33-40	40-43	24	>31 <sup>c</sup> , <75 <sup>c,h</sup>	
<u>Full Complement Present</u>						
Fin-Ray Supports,						
Dorsal	15-17	9-11	14-16	5-7	<31 <sup>c</sup>	
Anal	16-18	9-12	12-14	3-5	<31 <sup>c</sup>	
Pectoral	15-16	9	(14)15	(5)6		
Pelvic	16	9-11	17	8-9		
Fin Rays,						
Dorsal	43	33-40	>34, <40	>21, <24	(<31 <sup>b</sup> ), >31 <sup>c</sup>	
Anal	46-54	33-40	>40, <43	24	>31 <sup>c</sup> , <123 <sup>c</sup>	
Caudal	>81, <139	54-<93	>55, <61	>31, <35	>31 <sup>c</sup> , <123 <sup>c</sup>	
Pectoral	>81, <139	>54, <93	>48, <55	>24, <31	>75 <sup>c</sup> , <123 <sup>c</sup>	
Pelvic	>46, <53	>33, <47	>40, <43	24	>31 <sup>c</sup> , <123 <sup>c</sup>	
Scute Series,						
Dorsal	23-24	19	>21, <26	>15, <21	>27 <sup>c</sup> , ≤31 <sup>c</sup>	
Lateral	41-42	33-40	>43, <48	24	>31 <sup>c</sup> , <123 <sup>c</sup>	
Ventral	68-80	54	>55, <61	>31, <35	>31 <sup>c</sup> , <123 <sup>c</sup>	

<sup>a</sup> The utility of ages reported herein is very limited since developmental state correlates much more closely with size than age. Age at a particular stage of development, or size, is dramatically affected by rearing temperature and even at the same temperature, the range of ages for a particular state of development, or size, becomes increasingly broad with time.

<sup>b</sup> Carlson (1983).

<sup>c</sup> Jude (1982)—observations of "actinotrichia" were probably of fin-ray supports and are treated as such in this table.

<sup>d</sup> Harkness and Dymond (1961).

<sup>e</sup> Wallus (1990).

<sup>f</sup> See text section on Size Relative to Developmental State for discussion of yolk absorption in sturgeon and discrepancies in reported sizes for that event.

<sup>g</sup> Wang et al. (1985), age data based on specimens reared at 10, 15 and 20°C

<sup>h</sup> Jude (1982) described a 75 mm TL larva as having 28 pectoral fin rays; such fish would be expected to have at least some fin rays in each fin and, based on other sturgeon, at least some scutes in the lateral and ventral (ventrolateral) series.



TABLE 2.—Summary of meristics for pallid sturgeon and shovelnose sturgeon protolarvae reared at Gavins Point National Fish Hatchery in 1997 and 1989, respectively, with previously published myomere counts for river sturgeon (probably shovelnose) and lake sturgeon. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to nearest integers. Bracketed data excludes smallest pallid sturgeon larva if different.

	Protolarvae with yolk, no pelvic buds			Protolarvae with yolk & pelvic buds			Protolarvae without yolk		
	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N
<b>Pallid Sturgeon</b>									
TL, mm	10 $\pm$ 1	[10]8 - 11	7[6]	15 $\pm$ 2	12 - 18	13	21 $\pm$ 2	19 - 25	6
Myomeres									
Prealanal	[37]38 $\pm$ 1	37 - 39[38]	7[6]	36 $\pm$ 1	34 - 37	13	36 $\pm$ 1	35 - 37	6
Postanal	23 $\pm$ 1	22 - 24[23]	7[6]	22 $\pm$ 1	20 - 23	13	22 $\pm$ 0	22 - 23	6
Total	[60]61 $\pm$ 1	60 - 63[61]	7[6]	57 $\pm$ 1	56 - 59	13	58 $\pm$ 0	58 - 59	6
Fin-Ray Supports									
D				14 $\pm$ 1	11 - 16	13	15 $\pm$ 1	15 - 16	6
A				8 $\pm$ 2	4 - 10	13	10 $\pm$ 0	10 - 11	6
P1 *				~8 $\pm$ 2	~6 - 10	9 <sup>b</sup>	~10 $\pm$ 1	~9 - 10	6
P2				8 $\pm$ 2	5 - 10	7 <sup>b</sup>	10 $\pm$ 0	9 - 10	6
Spiral-Valve Turns	7 $\pm$ 1	6 - 7	4	6 $\pm$ 0	6 - 7	13	6 $\pm$ 0	6 - 7	5
<b>Shovelnose Sturgeon</b>									
TL, mm:	10 $\pm$ 1	9 - 12	8	15 $\pm$ 2	13 - 17	12	19 $\pm$ 1	18 - 21	6
Myomeres									
Prealanal	36 $\pm$ 0	35 - 36	8	34 $\pm$ 1	33 - 36	12	35 $\pm$ 0	34 - 35	6
Postanal	21 $\pm$ 2	20 - 25	8	21 $\pm$ 1	20 - 21	12	21 $\pm$ 1	20 - 22	6
Total	57 $\pm$ 2	55 - 60	8	55 $\pm$ 1	53 - 57	12	56 $\pm$ 1	55 - 57	6
Fin-Ray Supports									
D	11 $\pm$ 2	9 - 12	3 <sup>b</sup>	13 $\pm$ 1	12 - 15	12	14 $\pm$ 0	14 - 15	6
A	6 $\pm$ 3	4 - 9	3 <sup>b</sup>	9 $\pm$ 1	7 - 10	12	10 $\pm$ 1	9 - 10	6
P1 *				~10 $\pm$ 0	~9 - 10	7 <sup>b</sup>	~10 $\pm$ 0	~9 - 10	6
P2				8 $\pm$ 1	7 - 9	6 <sup>b</sup>	9 $\pm$ 1	9 - 10	6
Spiral-Valve Turns	6 $\pm$ 1	5 - 7	8	7 $\pm$ 1	6 - 8	12	7 $\pm$ 0	7 - 7	3
<b>Published Myomere Counts for Comparison</b>									
	River (Shovelnose?) Sturgeon (Carlson 1983)			Lake Sturgeon (Carlson 1983)			Lake Sturgeon (Jude 1982 & Wallus 1990)		
	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N
TL, mm:		8 - 19	10		11 - 21	15		11 - 12	
Prealanal	33	32 - 34	10	35	34 - 37	15		40 - 43	
Postanal	18-19	16 - 20	10	22	20 - 25	15		17 - 22	
Total	52	50 - 53	10	57	55 - 59	15		57 - 64	

\* Because pectoral-fin radials are difficult to observe and distinguish, counts were approximated and may not be accurate.

<sup>b</sup> Fin supports (pterygiophores or radials) are not formed or apparent in smaller specimens of developmental group.

TABLE 3.—Summary of fin-ray and scute (bony-plate) counts for pallid, shovelnose, pallid x shovelnose hybrid ( $\frac{1}{2}$  and  $\geq \frac{3}{4}$  pallid), and lake sturgeon from original observations (Orig.)<sup>a</sup> and published (Lit.) accounts. Where appropriate and notable, mean or modal counts are underlined and rare or questionable extremes are enclosed in parentheses.

Character	Pallid Sturgeon		Pallid x Shovelnose Hybrids		Shovelnose Sturgeon		Lake Sturgeon	
	Counts	Sources <sup>b</sup>	Counts	Sources <sup>b</sup>	Counts	Sources <sup>b</sup>	Counts	Sources <sup>b</sup>
<b>Fin Rays</b>								
Dorsal Fin								
Orig.	37- <u>38</u> -41	23, 43-205	(34)37- <u>39</u> -40-42	$\frac{1}{2}$ :20, 58-134	31- <u>35</u> -39	'92: 22, 61-155		
			(35) <u>39</u> -41-44	$\frac{3}{4}$ :16, 67-130	30- <u>31</u> -33	'89: 5, 97-113		
Lit.	37- <u>38</u> -40-43	a-b, m-p	<u>38</u> ±2	$\frac{1}{2}$ ? : b	30- <u>32</u> -34-36	a-d, m-p	35- <u>38</u> -40(44)	d-e, g, i, l-m
Anal Fin								
Orig.	23- <u>25</u> -28	23, 39-205	23- <u>25</u> -26-27(29)	$\frac{1}{2}$ :20, 58-134	22- <u>24</u> -25	'92: 22, 61-155		
			24- <u>26</u> -28-30	$\frac{3}{4}$ :16, 67-130	20- <u>21</u> -23	'89: 5, 97-113		
Lit.	<u>24</u> -26-28	a-b, m-p	<u>24</u> ±1	$\frac{1}{2}$ ? : b	18- <u>20</u> -21-24	a-d, m-p	25- <u>28</u> -30	d-e, g, i, l-m
Caudal Fin								
Orig.	66- <u>68</u> -69; [53-64]	6, 139-205 8, 63-81] <sup>d</sup>	(58,60)62- <u>64</u> -68	$\frac{1}{2}$ :16, 72-134	(51,55)58- <u>61</u> -65	'92: 22, 61-155 '89: 5, 97-113		
Lit.			(64)66- <u>68</u> -69-73;	$\frac{3}{4}$ :12, 87-130	54- <u>58</u> -63		80	g, l
Pectoral Fin <sup>e</sup>								
Orig.	55- <u>56</u> -57(61)	6, 139-205	(42,43)45- <u>48</u> -51-53;	$\frac{1}{2}$ :20, 58-134	(42,43)45- <u>48</u> -52	'92: 22, 61-155		
	[(44)48-51]	9, 60-81] <sup>d</sup>	(45)47- <u>50</u> -54	$\frac{3}{4}$ :16, 67-130	(43)45- <u>46</u> -47	'89: 5, 97-113		
Lit.	46- <u>50</u> -51-56,46	a, b	<u>46</u> ±2	$\frac{1}{2}$ ? : b	44-47-48-51	a	40-45	e-f, g, l
					39-41-43-48	b-c		
Pelvic Fin								
Orig.	30- <u>33</u> -36(37)	21, 53-205	29- <u>31</u> -33-35	$\frac{1}{2}$ :20, 58-134	28- <u>29</u> -30-33	'92: 22, 61-155		
			<u>30</u> -31-35	$\frac{3}{4}$ :16, 67-130	26- <u>27</u> -28	'89: 5, 97-113		
Lit.	30- <u>33</u> -34	a-b	<u>28</u> ±1	$\frac{1}{2}$ ? : b	28- <u>29</u> -30-32	a	27-30	e, g, l
					<u>25</u> -27-31	b-c		
<b>Scutes<sup>e</sup></b>								
Dorsal Row								
Orig.	14- <u>15</u> -16-17	38, 26-205	(13)15- <u>16</u> -17-18	$\frac{1}{2}$ :20, 58-134	13- <u>15</u> -16	'92: 22, 61-155		
			13- <u>15</u> -16	$\frac{3}{4}$ :16, 67-130	<u>16</u> -17	'89: 5, 97-113		
Lit.	14- <u>15</u> -16-18	a			13- <u>16</u> -17-19	a, c, l	(9)10- <u>13</u> -17	d,e-f,g,i-m
Lateral Row								
Orig.	(40)41- <u>43</u> -46)	23, 43-205	41- <u>43</u> -44-47(49)	$\frac{1}{2}$ :16, 72-134	37- <u>38</u> -41-46	'92: 22, 61-155		
			(39)42- <u>45</u> -47(49);	$\frac{3}{4}$ :16, 67-130	39- <u>40</u> -41	'89: 5, 97-113		
Lit.	40- <u>43</u> -45-48	a, d			38- <u>42</u> -46-50	a, c-d, l	28- <u>35</u> -42	d,e-f,g-m
Lateral to OD <sup>f</sup>								
Orig.	(21)22- <u>23</u> -25	29, 34-205	(21)23- <u>24</u> -25-28	$\frac{1}{2}$ :20, 58-134	20- <u>22</u> -23-25(27)	'92: 22, 61-155		
			22- <u>25</u> -28	$\frac{3}{4}$ :16, 67-130	23- <u>24</u>	'89: 5, 97-113		
Lit.					(23)25- <u>27</u> -31	c		
Ventral Row								
Orig.	(8)9- <u>10</u> -(12)	16, 68-205	10- <u>12</u> -13	$\frac{1}{2}$ :16, 72-134	9- <u>11</u> -12	'92: 22, 61-155		
			9- <u>11</u> -13	$\frac{3}{4}$ :16, 67-130	11- <u>12</u>	'89: 5, 97-113		
Lit.	9- <u>11</u> -13	a			9- <u>11</u> -13-14	a, c, l	7-9-12	d,e-f,g,i-j,l-m

<sup>a</sup> Original counts are believed to represent adult complements but are based on late-stage mesolarvae and metalarvae reared by Gavins Point National Fish Hatchery in 1989 (shovelnose sturgeon) and 1992 (shovelnose and pallid x shovelnose sturgeons) and Missouri Department of Conservation Blind Pony Hatchery in 1992 (pallid sturgeon) (the hybrid sturgeon were initially reared through about 50 mm TL at Blind Pony Hatchery).

<sup>b</sup> Number of specimens and size range (mm TL, total length excluding caudal filament) for original counts; references for published counts as follows: a - Bailey and Cross (1954); b - Carlson et al. (1985); c - Williams and Clemmer (1991); d - Clay (1975); e - Vladyskov and Beaulieu (1946); f - Jollie (1980); g - Jude (1982); h - Dadswell et al. (1984); i - Scott and Crossman (1973); j - Smith (1985); k - Vladyskov and Greeley (1963); l - Wallus (1990); m - Moore (1968); n - Harlan and Speaker (1969); o - Pflieger (1975); p - Smith (1979). Underlined references in table indicate primary sources for the corresponding data.

<sup>c</sup> Original counts do not include rays incorporated in spine-like structure along anterior margin of fin, but unlike Snyder (1988), the spine itself is included in the count as specified by Bailey and Cross (1954).

<sup>d</sup> Incomplete counts for pallid sturgeon larvae similar in size to smaller shovelnose sturgeon and hybrids with apparently complete counts of pectoral or caudal fin rays.

<sup>e</sup> Original scute counts follow Bailey and Cross (1954). Unlike original counts in Snyder (1988), the count for the dorsal series excludes the predorsal plate (modified scute at anterior margin of dorsal fin). The ventral (ventro-lateral) series ends just anterior to pelvic fin; the lateral series includes small plates at the posterior end of the series only if they are carinate (have a ridge, keel, or spine).

<sup>f</sup> Lateral scutes to a vertical line from the origin of the dorsal fin (anterior base of the first apparent ray); scutes transected by the line are included in the count as specified by Williams and Clemmer (1991).

TABLE 4.--Summary of selected lengths, depths, and widths relative to total length for pallid sturgeon protolarvae reared at Gavins Point National Fish Hatchery in 1997. Bracketed data excludes smallest larva. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to integers.

	Protolarvae with yolk, no pelvic buds			Protolarvae with yolk and pelvic buds			Protolarvae without yolk		
	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N
TL, mm	10 $\pm$ 1	[10]8 - 11	7[6]	15 $\pm$ 2	12 - 18	13	21 $\pm$ 2	19 - 25	6
Lengths, % of TL									
AS to AE	[5]4 $\pm$ 1[0]	[4]3 - 5	7[6]	6 $\pm$ 1	5 - 8	13	8 $\pm$ 1	7 - 10	6
to PE	[8]7 $\pm$ 1	[7]5 - 8	7[6]	9 $\pm$ 1	8 - 10	13	11 $\pm$ 1	10 - 12	6
to ABI	7 $\pm$ 0	7 - 7	6	5 $\pm$ 1	4 - 7	13	4 $\pm$ 0	3 - 4	6
to ABO	7 $\pm$ 0	7 - 7	6	5 $\pm$ 1	4 - 7	13	4 $\pm$ 0	4 - 5	6
to AM	9 $\pm$ 0	8 - 10	6	9 $\pm$ 0	8 - 10	13	11 $\pm$ 1	10 - 12	6
to PO	15 $\pm$ 1	[14]13 - 17	7[6]	19 $\pm$ 2	17 - 22	13	23 $\pm$ 1	23 - 24	6
to OP1	[23]24 $\pm$ 2	22 - 27[24]	7[6]	20 $\pm$ 1	19 - 22	13	22 $\pm$ 0	21 - 22	6
to OP2				47 $\pm$ 3	44 - 52	13	45 $\pm$ 1	44 - 45	6
to IP2				53 $\pm$ 2	50 - 56	13	50 $\pm$ 0	49 - 51	6
to AY	11 $\pm$ 1	10 - 12	7[6]	17 $\pm$ 2	14 - 20	13			
to PY	[43]45 $\pm$ 4[2]	42 - 54	7[6]	39 $\pm$ 3	33 - 43	13			
to ODF	[21]22 $\pm$ 3[2]	18 - 27	7[6]	19 $\pm$ 1	18 - 20	13	19 $\pm$ 0	19 - 20	6
to OPAF	[41]43 $\pm$ 5[2]	39 - 53	7[6]	37 $\pm$ 2	34 - 40	13	36 $\pm$ 1	35 - 37	6
to PV	[62]63 $\pm$ 4[2]	60 - 73	7[6]	55 $\pm$ 2	51 - 59	13	51 $\pm$ 1	50 - 52	6
to OD				58 $\pm$ 3	53 - 62	13	52 $\pm$ 0	52 - 53	6
to ID				65 $\pm$ 2	63 - 68	10	61 $\pm$ 1	60 - 62	6
to OA				61 $\pm$ 2	59 - 63	10	57 $\pm$ 1	57 - 58	6
to IA				67 $\pm$ 2	64 - 70	10	63 $\pm$ 1	62 - 64	6
to AMPM	90 $\pm$ 2[1]	88 - 94[92]	7[6]	83 $\pm$ 3	79 - 88	13	79 $\pm$ 2	76 - 81	6
to PN	99 $\pm$ 0	98 - 99	7[6]	99 $\pm$ 0	99 - 99	13	99 $\pm$ 1	98 - 99	6
BI	1 $\pm$ 0	1 - 2	3	3 $\pm$ 1	2 - 5	13	6 $\pm$ 1	5 - 7	6
BO	2 $\pm$ 0	2 - 2	3	6 $\pm$ 2	3 - 9	13	10 $\pm$ 0	10 - 11	6
P1	6 $\pm$ 0	5 - 6	7[6]	9 $\pm$ 1	7 - 11	13	13 $\pm$ 1	12 - 14	6
P2				7 $\pm$ 1	4 - 8	13	8 $\pm$ 1	8 - 11	6
D				12 $\pm$ 1	11 - 14	7	14 $\pm$ 0	14 - 15	6
A				8 $\pm$ 0	7 - 9	7	9 $\pm$ 1	8 - 10	6
Depths, % of TL									
at BPE	[12]13 $\pm$ 1	12 - 15[13]	7[6]	11 $\pm$ 1	10 - 13	13	10 $\pm$ 1	8 - 11	6
at OP1 B	[21]25 $\pm$ 3[2]	22 - 30[27]	7[6]	15 $\pm$ 4	10 - 20	13	11 $\pm$ 0	10 - 11	6
at OP1 T	[25]26 $\pm$ 2	23 - 30[28]	7[6]	16 $\pm$ 4	10 - 21	12	12 $\pm$ 1	11 - 12	6
at OP2 B	10 $\pm$ 0	9 - 11[10]	7[6]	9 $\pm$ 1	8 - 10	13	8 $\pm$ 0	7 - 8	6
at OP2 T	17 $\pm$ 1	16 - 18	7[6]	15 $\pm$ 2	12 - 18	13	13 $\pm$ 1	11 - 14	6
at OP2 DF	3 $\pm$ 0	3 - 3	7[6]	3 $\pm$ 0	2 - 3	13	3 $\pm$ 1	2 - 3	6
at BPV B	8 $\pm$ 1	7 - 8	7[6]	7 $\pm$ 0	6 - 8	13	7 $\pm$ 0	6 - 7	6
at BPV T	14 $\pm$ 1[0]	14 - 15	7[6]	12 $\pm$ 1	10 - 14	13	11 $\pm$ 1	10 - 12	6
at OLLC B	5 $\pm$ 1[0]	4 - 6[5]	7[6]	4 $\pm$ 1	3 - 5	13	3 $\pm$ 0	3 - 3	6
at OLLC T	[14]15 $\pm$ 1	13 - 17[15]	7[6]	10 $\pm$ 1	8 - 13	13	8 $\pm$ 1	7 - 9	6
at AMPM B	3 $\pm$ 1[0]	2 - 4[3]	7[6]	3 $\pm$ 0	2 - 4	13	2 $\pm$ 0	2 - 2	6
at AMPM T	14 $\pm$ 0[1]	13 - 15	7[6]	11 $\pm$ 1	9 - 13	13	9 $\pm$ 1	8 - 10	6
Yolk, Maximum	[19]20 $\pm$ 3[2]	17 - 25[23]	7[6]	11 $\pm$ 3	6 - 16	13			
Widths, % of TL									
at BPE	10 $\pm$ 0	10 - 11	7[6]	12 $\pm$ 1	10 - 14	13	16 $\pm$ 1	16 - 17	6
at AM	12 $\pm$ 0	11 - 12	6	13 $\pm$ 1	11 - 14	13	16 $\pm$ 0	16 - 17	6
at OP1	[21]22 $\pm$ 4[1]	19 - 32[22]	7[6]	13 $\pm$ 2	8 - 16	13	15 $\pm$ 1	13 - 16	6
at OP2	5 $\pm$ 0	5 - 5	7[6]	5 $\pm$ 0	4 - 5	13	5 $\pm$ 0	4 - 5	6
at BPV	4 $\pm$ 0	4 - 5	7[6]	4 $\pm$ 0	4 - 5	13	4 $\pm$ 0	3 - 4	6
at OLLC	3 $\pm$ 0	3 - 4[3]	7[6]	3 $\pm$ 0	2 - 3	13	2 $\pm$ 0	2 - 2	6
at AMPM	2 $\pm$ 0	2 - 2	7[6]	2 $\pm$ 0	1 - 2	13	2 $\pm$ 0	1 - 2	6
M				9 $\pm$ 0	9 - 10	13	11 $\pm$ 0	11 - 12	6
MO	3 $\pm$ 1	2 - 4	6	8 $\pm$ 1	7 - 8	13	9 $\pm$ 0	9 - 10	6
ILL				2 $\pm$ 0	1 - 2	13	1 $\pm$ 0	1 - 2	6
IOR	7 $\pm$ 0	6 - 7	3	8 $\pm$ 1	6 - 10	13	10 $\pm$ 0	10 - 11	6
Yolk, Maximum	[21]23 $\pm$ 4[1]	19 - 32[22]	7[6]	12 $\pm$ 3	9 - 17	13			

TABLE 5.-- Summary of selected lengths, depths, and widths relative to total length for shovelnose sturgeon protolarvae reared at Gavins Point National Fish Hatchery in 1989. See Figure 1 for abbreviations and diagram of measurements. Data rounded to nearest integers.

	Protolarvae with yolk, no pelvic buds			Protolarvae with yolk and pelvic buds			Protolarvae without yolk		
	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N
TL, mm	10 $\pm$ 1	9 - 12	8	15 $\pm$ 2	13 - 17	12	19 $\pm$ 1	18 - 21	6
<b>Lengths, % of TL</b>									
AS to AE	4 $\pm$ 1	3 - 5	8	6 $\pm$ 1	5 - 7	12	7 $\pm$ 1	7 - 8	6
to PE	8 $\pm$ 1	7 - 9	8	9 $\pm$ 1	8 - 10	12	11 $\pm$ 1	9 - 12	6
to ABI	6 $\pm$ 1	5 - 8	6	4 $\pm$ 1	3 - 5	12	3 $\pm$ 0	3 - 4	6
to ABO	7 $\pm$ 1	6 - 8	6	5 $\pm$ 1	3 - 6	12	4 $\pm$ 0	3 - 4	6
to AM	9 $\pm$ 1	8 - 10	8	9 $\pm$ 0	8 - 10	12	11 $\pm$ 1	10 - 11	6
to PO	15 $\pm$ 2	11 - 17	8	19 $\pm$ 1	17 - 21	12	22 $\pm$ 1	20 - 24	6
to OP1	22 $\pm$ 1	20 - 24	8	20 $\pm$ 1	18 - 21	12	21 $\pm$ 1	19 - 22	6
to OP2				49 $\pm$ 2	45 - 53	12	46 $\pm$ 1	45 - 47	6
to IP2				54 $\pm$ 2	51 - 58	12	51 $\pm$ 1	50 - 53	6
to AY	12 $\pm$ 1	10 - 14	8	19 $\pm$ 4	14 - 25	12			
to PY	43 $\pm$ 1	42 - 45	8	36 $\pm$ 3	33 - 42	12			
to ODF	20 $\pm$ 1	19 - 22	8	18 $\pm$ 1	16 - 20	12	18 $\pm$ 1	16 - 19	6
to OPAF	40 $\pm$ 2	37 - 42	8	35 $\pm$ 3	31 - 40	12	33 $\pm$ 1	30 - 34	6
to PV	63 $\pm$ 2	61 - 65	8	55 $\pm$ 2	53 - 59	12	53 $\pm$ 1	52 - 53	6
to OD				59 $\pm$ 3	55 - 64	12	55 $\pm$ 1	54 - 57	6
to ID				66 $\pm$ 2	64 - 70	9	63 $\pm$ 1	63 - 64	6
to OA				64 $\pm$ 3	60 - 68	12	60 $\pm$ 1	58 - 62	6
to IA				68 $\pm$ 2	65 - 71	9	65 $\pm$ 1	64 - 66	6
to AMPM	88 $\pm$ 2	86 - 91	8	84 $\pm$ 3	81 - 88	12	80 $\pm$ 1	79 - 80	6
to PC	99 $\pm$ 0	99 - 99	8	99 $\pm$ 0	98 - 99	12	98 $\pm$ 1	98 - 99	6
B1	2 $\pm$ 0	2 - 3	6	4 $\pm$ 1	3 - 6	12	7 $\pm$ 1	6 - 9	6
BO	2 $\pm$ 0	2 - 3	6	6 $\pm$ 1	4 - 8	12	7 $\pm$ 2	5 - 10	6
P1	6 $\pm$ 1	6 - 8	8	9 $\pm$ 1	7 - 11	12	14 $\pm$ 1	13 - 15	6
P2				6 $\pm$ 1	5 - 8	12	9 $\pm$ 1	8 - 10	6
D				12 $\pm$ 1	10 - 14	10	13 $\pm$ 0	12 - 13	6
A				7 $\pm$ 1	6 - 9	7	9 $\pm$ 0	8 - 10	6
<b>Depths, % of TL</b>									
at BPE	13 $\pm$ 1	12 - 16	8	11 $\pm$ 1	9 - 13	12	10 $\pm$ 2	8 - 12	6
at OP1 B	26 $\pm$ 3	23 - 30	8	15 $\pm$ 4	10 - 20	12	11 $\pm$ 1	10 - 13	6
at OP1 T	27 $\pm$ 3	23 - 31	8	16 $\pm$ 4	11 - 21	12	12 $\pm$ 1	11 - 14	6
at OP2 B	11 $\pm$ 1	10 - 12	8	9 $\pm$ 1	8 - 10	12	8 $\pm$ 1	7 - 9	6
at OP2 T	19 $\pm$ 1	17 - 20	8	16 $\pm$ 2	14 - 18	12	13 $\pm$ 1	11 - 14	6
at OP2 DF	3 $\pm$ 0	2 - 3	8	3 $\pm$ 0	3 - 4	12	3 $\pm$ 1	2 - 3	6
at BPV B	9 $\pm$ 1	8 - 10	8	8 $\pm$ 0	7 - 8	12	6 $\pm$ 1	5 - 7	6
at BPV T	15 $\pm$ 1	14 - 17	8	13 $\pm$ 1	11 - 14	12	11 $\pm$ 1	9 - 12	6
at OLLC B	5 $\pm$ 1	5 - 7	8	4 $\pm$ 1	3 - 6	12	3 $\pm$ 0	3 - 3	6
at OLLC T	15 $\pm$ 2	13 - 18	8	9 $\pm$ 1	8 - 12	12	8 $\pm$ 1	7 - 9	6
at AMPM B	4 $\pm$ 0	3 - 4	8	3 $\pm$ 0	2 - 4	12	3 $\pm$ 0	2 - 3	6
at AMPM T	14 $\pm$ 2	13 - 17	8	11 $\pm$ 1	9 - 12	12	9 $\pm$ 1	8 - 11	6
Yolk, Maximum	21 $\pm$ 3	15 - 24	8	10 $\pm$ 5	4 - 15	12			
<b>Widths, % of TL</b>									
at BPE	11 $\pm$ 1	9 - 14	8	13 $\pm$ 1	12 - 14	12	16 $\pm$ 0	15 - 16	6
at AM	12 $\pm$ 1	10 - 13	8	13 $\pm$ 1	12 - 14	12	16 $\pm$ 1	15 - 17	6
at OP1	22 $\pm$ 4	18 - 26	8	11 $\pm$ 3	8 - 16	12	13 $\pm$ 1	11 - 14	6
at OP2	6 $\pm$ 0	5 - 6	8	5 $\pm$ 1	4 - 6	12	5 $\pm$ 0	4 - 5	6
at BPV	5 $\pm$ 1	4 - 6	8	4 $\pm$ 1	4 - 5	12	4 $\pm$ 0	4 - 4	6
at OLLC	3 $\pm$ 1	2 - 4	8	3 $\pm$ 1	2 - 3	12	2 $\pm$ 0	1 - 2	6
at AMPM	2 $\pm$ 0	1 - 3	8	2 $\pm$ 0	1 - 2	12	1 $\pm$ 0	1 - 2	6
M				10 $\pm$ 0	9 - 10	12	11 $\pm$ 1	10 - 12	6
MO	6 $\pm$ 1	5 - 7	8	8 $\pm$ 1	7 - 9	12	8 $\pm$ 0	8 - 9	6
ILL				1 $\pm$ 0	1 - 2	12	1 $\pm$ 1	0 - 2	6
IOR	7 $\pm$ 1	5 - 8	8	8 $\pm$ 1	7 - 9	12	10 $\pm$ 0	10 - 11	6
Yolk, Maximum	23 $\pm$ 3	19 - 27	8	13 $\pm$ 3	9 - 17	12			

TABLE 6.--Summary of selected morphometric relationships for pallid sturgeon protolarvae reared at Gavins Point National Fish Hatchery in 1997, including ratios Bailey and Cross (1954) found diagnostic for larger fish. Bracketed data excludes smallest larva. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to integers, except Bailey and Cross ratios.

	Protolarvae with yolk, no pelvic buds			Protolarvae with yolk and pelvic buds			Protolarvae without yolk		
	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N
TL, mm	10 $\pm$ 1	[10]8 - 11	7[6]	15 $\pm$ 2	12 - 18	13	21 $\pm$ 2	19 - 25	6
% of Head Length (snout to origin of pectoral fin, OP1)									
SN to AE	[20]18 $\pm$ 4[2]	[17]11 - 21	7[6]	31 $\pm$ 4	25 - 38	13	39 $\pm$ 3	34 - 43	6
SN to ABI	30 $\pm$ 1	29 - 32	6	25 $\pm$ 4	19 - 32	13	17 $\pm$ 2	15 - 19	6
SN to ABO	29 $\pm$ 1	28 - 31	6	26 $\pm$ 4	20 - 33	13	20 $\pm$ 2	18 - 23	6
SN to AM	38 $\pm$ 2	35 - 41	6	46 $\pm$ 3	41 - 50	13	49 $\pm$ 3	46 - 54	6
ABI to AM	8 $\pm$ 1	6 - 10	6	21 $\pm$ 4	14 - 30	13	32 $\pm$ 3	28 - 35	6
Head Width at AM	50 $\pm$ 2	47 - 53	6	64 $\pm$ 6	54 - 75	13	75 $\pm$ 3	71 - 78	6
M Width				47 $\pm$ 3	42 - 51	13	52 $\pm$ 1	50 - 53	6
MO Width	14 $\pm$ 5	7 - 20	6	37 $\pm$ 3	32 - 42	13	42 $\pm$ 1	40 - 43	6
ILL Width				8 $\pm$ 1	6 - 9	13	7 $\pm$ 2	3 - 9	6
IOR Width	29 $\pm$ 1	28 - 30	3	38 $\pm$ 7	30 - 52	13	47 $\pm$ 2	44 - 49	6
BI Length	6 $\pm$ 1	5 - 7	3	17 $\pm$ 5	12 - 25	13	28 $\pm$ 2	25 - 31	6
BO Length	10 $\pm$ 1	9 - 11	3	30 $\pm$ 11	16 - 46	13	46 $\pm$ 2	44 - 50	6
Eye Diameter	[13]12 $\pm$ 2	[11]7 - 15	7[6]	13 $\pm$ 1	12 - 15	13	12 $\pm$ 1	11 - 13	6
% of SN to AM Length (snout to anterior margin of mouth opening)									
SN to ABI	78 $\pm$ 3	74 - 82	6	55 $\pm$ 8	39 - 68	13	35 $\pm$ 3	30 - 39	6
BI Length	16 $\pm$ 4	12 - 18	3	37 $\pm$ 10	25 - 54	13	57 $\pm$ 4	50 - 60	6
Eye Diameter	34 $\pm$ 4	30 - 42	6	29 $\pm$ 2	25 - 33	13	25 $\pm$ 2	23 - 28	6
% of SN to ABO Length (snout to anterior base of barbel, outer)									
SN to ABI	101 $\pm$ 3	97 - 105	6	97 $\pm$ 4	86 - 104	13	84 $\pm$ 6	77 - 91	6
% of BO Length (barbel, outer)									
BI Length	63 $\pm$ 9	54 - 71	3	60 $\pm$ 9	46 - 76	13	61 $\pm$ 7	51 - 71	6
% of M Width (mouth, between outer limits of lips)									
ILL Width				16 $\pm$ 2	13 - 19	13	13 $\pm$ 4	6 - 18	6
ABI to AM				44 $\pm$ 7	34 - 59	13	62 $\pm$ 6	53 - 68	6
BI Length				36 $\pm$ 8	26 - 50	13	53 $\pm$ 4	49 - 60	6
Measurement Ratios "Similar" to Those of Bailey and Cross (1954) Given Below									
ABI to AM in SN to ABO	3.7 $\pm$ 0.6	3.0 - 4.6	6	1.3 $\pm$ 0.4	0.7 - 2.2	13	0.6 $\pm$ 0.1	0.6 - 0.7	6
ABI to AM in M Width				2.3 $\pm$ 0.3	1.7 - 2.9	13	1.6 $\pm$ 0.2	1.5 - 1.9	6
ABI to AM in SN to PO	7.9 $\pm$ 1.0	6.8 - 9.2	6	4.7 $\pm$ 0.5	3.6 - 5.7	13	3.3 $\pm$ 0.3	3.0 - 3.7	6
BI Length in SN to ABO	5.0 $\pm$ 1.3	4.2 - 6.4	3	1.7 $\pm$ 0.7	0.8 - 2.7	13	0.7 $\pm$ 0.1	0.6 - 0.8	6
BI Length in BO Length	1.6 $\pm$ 0.2	1.4 - 1.9	3	1.7 $\pm$ 0.3	1.3 - 2.2	13	1.7 $\pm$ 0.2	1.4 - 2.0	6
BI Length in SN to PO	11.3 $\pm$ 2.4	9.7 - 14.1	3	5.7 $\pm$ 1.0	4.3 - 7.0	13	3.8 $\pm$ 0.3	3.5 - 4.3	6

Measurement Ratios Found Diagnostic by Bailey and Cross (1954, Fig. 9, Table 4)\*

	Sm. Juveniles, 100 to 200 mm SL		Juveniles & Adults, >200 mm SL		
Inner barbel to mouth in snout to outer barbel (b in a)	2.4	1	2.9	2.3 - 3.3	12
Inner barbel to mouth in mouth width (including lips, b in e)	1.7	1	1.8	1.6 - 2.0	12
Inner barbel to mouth in head length (b in f)	5.6	1	6.3	5.5 - 7.0	12
Inner-barbel length in snout to outer barbel (c in a)	2.8	1	3.5	2.6 - 3.7	12
Inner-barbel length in outer-barbel length (c in d)	1.6	1	2.0	1.7 - 2.4	12
Inner-barbel length in head length (bony edge of operculum, c in f)	6.5	1	7.2	6.4 - 8.0	12

\* Bailey and Cross (1954) defined SL, standard length, to end at the posterior margin of the last carinate lateral scute or plate; also, their measurements were point to point, not along lines parallel or perpendicular to the body axis, and they defined anterior margin of the mouth as the anterior cartilaginous edge of the labial depression (into which the protrusible mouth is retracted), not the anterior margin of the mouth opening.

TABLE 7.--Summary of selected morphometric relationships for shovelnose sturgeon protolarvae reared at Gavins Point National Fish Hatchery in 1989, including ratios Bailey and Cross (1954) found diagnostic for larger fish. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to integers except Bailey and Cross ratios.

	Protolarvae with yolk, no pelvic buds			Protolarvae with yolk and pelvic buds			Protolarvae without yolk		
	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N	Mean $\pm$ SD	Range	N
TL, mm	10 $\pm$ 1	9 - 12	8	15 $\pm$ 2	13 - 17	12	19 $\pm$ 1	18 - 21	6
% of Head Length (snout to origin of pectoral fin, OP1)									
SN to AE	19 $\pm$ 3	14 - 22	6	29 $\pm$ 4	23 - 34	12	36 $\pm$ 4	31 - 40	6
SN to ABI	28 $\pm$ 3	24 - 34	6	21 $\pm$ 3	16 - 26	12	16 $\pm$ 2	14 - 17	6
SN to ABO	30 $\pm$ 3	27 - 34	6	23 $\pm$ 3	18 - 28	12	18 $\pm$ 1	16 - 19	6
SN to AM	40 $\pm$ 4	35 - 45	6	46 $\pm$ 2	42 - 51	12	52 $\pm$ 3	47 - 56	6
ABI to AM	12 $\pm$ 5	7 - 18	6	26 $\pm$ 5	20 - 34	12	36 $\pm$ 4	31 - 42	6
Head Width at AM	53 $\pm$ 6	43 - 59	8	64 $\pm$ 3	59 - 68	12	76 $\pm$ 5	69 - 82	6
M Width				49 $\pm$ 2	45 - 53	12	52 $\pm$ 5	46 - 59	6
MO Width	29 $\pm$ 4	22 - 35	8	38 $\pm$ 3	34 - 43	12	41 $\pm$ 3	36 - 45	6
ILL Width				7 $\pm$ 2	3 - 11	12	8 $\pm$ 2	6 - 11	5
JOR Width	29 $\pm$ 4	23 - 36	8	41 $\pm$ 5	33 - 49	12	50 $\pm$ 4	46 - 55	6
BI Length	10 $\pm$ 2	8 - 13	6	22 $\pm$ 4	17 - 30	12	32 $\pm$ 5	28 - 40	6
BO Length	11 $\pm$ 3	8 - 15	6	29 $\pm$ 8	18 - 41	12	36 $\pm$ 8	24 - 46	6
Eye Diameter	17 $\pm$ 3	13 - 20	6	16 $\pm$ 1	14 - 18	12	15 $\pm$ 1	14 - 17	6
% of SN to AM Length (snout to anterior margin of mouth opening)									
SN to ABI	71 $\pm$ 10	58 - 81	6	45 $\pm$ 8	33 - 55	12	30 $\pm$ 4	25 - 34	6
BI Length	24 $\pm$ 4	19 - 31	6	48 $\pm$ 7	37 - 59	12	62 $\pm$ 12	51 - 86	6
Eye Diameter	42 $\pm$ 2	38 - 45	6	36 $\pm$ 3	30 - 40	12	29 $\pm$ 3	26 - 36	6
% of SN to ABO Length (snout to anterior base of barbel, outer)									
SN to ABI	93 $\pm$ 4	88 - 99	6	89 $\pm$ 3	81 - 93	12	87 $\pm$ 7	77 - 97	6
% of BO Length (barbel, outer)									
BI Length	88 $\pm$ 11	77 - 109	6	78 $\pm$ 11	55 - 95	12	92 $\pm$ 23	66 - 129	6
% of M Width (mouth, between outer limits of lips)									
ILL Width				14 $\pm$ 4	8 - 21	12	15 $\pm$ 3	11 - 20	5
ABI to AM				52 $\pm$ 8	42 - 68	12	69 $\pm$ 8	58 - 78	6
BI Length				45 $\pm$ 7	37 - 59	12	62 $\pm$ 14	50 - 88	6
Measurement Ratios "Similar" to Those of Bailey and Cross (1954) Given Below									
ABI to AM in SN to ABO	2.9 $\pm$ 1.2	1.6 - 4.5	6	0.9 $\pm$ 0.3	0.6 - 1.3	12	0.5 $\pm$ 0.1	0.4 - 0.6	6
ABI to AM in M Width				2.0 $\pm$ 0.3	1.5 - 2.4	12	1.5 $\pm$ 0.2	1.3 - 1.7	6
ABI to AM in SN to PO	6.8 $\pm$ 2.1	4.5 - 9.6	6	3.8 $\pm$ 0.5	3.0 - 4.3	12	3.0 $\pm$ 0.3	2.6 - 3.4	6
BI Length in SN to ABO	3.2 $\pm$ 0.7	2.1 - 3.9	6	1.1 $\pm$ 0.3	0.7 - 1.6	12	0.6 $\pm$ 0.1	0.4 - 0.7	6
BI Length in BO Length	1.2 $\pm$ 0.1	0.9 - 1.3	6	1.3 $\pm$ 0.2	1.1 - 1.8	12	1.1 $\pm$ 0.3	0.8 - 1.5	6
BI Length in SN to PO	7.6 $\pm$ 1.1	6.1 - 9.3	6	4.4 $\pm$ 0.5	3.4 - 5.1	12	3.4 $\pm$ 0.4	2.7 - 3.8	6
Measurement Ratios Found Diagnostic by Bailey and Cross (1954, Fig. 9, Table 4)*									
	Sm. Juveniles, 100 to 200 mm SL			Juveniles & Adults, >200 mm SL					
Inner barbel to mouth in snout to outer barbel (b in a)	1.5	1.3 - 1.7	6	1.6	1.3 - 2.2	47			
Inner barbel to mouth in mouth width (including lips, b in e)	1.3	1.2 - 1.4	6	1.3	1.1 - 1.4	47			
Inner barbel to mouth in head length (b in f)	4.3	4.1 - 4.6	6	4.4	4.0 - 5.0	47			
Inner-barbel length in snout to outer barbel (c in a)	1.7	1.4 - 1.9	6	1.6	1.3 - 2.5	47			
Inner-barbel length in outer-barbel length (c in d)	1.4	1.3 - 1.5	6	1.3	1.2 - 1.5	47			
Inner-barbel length in head length (bony edge of operculum, c in f)	4.8	4.5 - 5.2	6	4.5	3.7 - 5.8	47			

\* Bailey and Cross (1954) defined SL, standard length, to end at the posterior margin of the last carinate lateral scute or plate; also, their measurements were point to point, not along lines parallel or perpendicular to the body axis, and they defined anterior margin of the mouth as the anterior cartilaginous edge of the labial depression (into which the protrusible mouth is retracted), not the anterior margin of the mouth opening.

TABLE 8.--Summary of selected lengths, depths, and widths relative to total length, other morphometric relationships, and fin pterygiophore, and spiral valve meristics for mesolarvae of pallid sturgeon less than 47 mm TL. Larvae reared at Gavins National Fish Hatchery in 1997. See Figure 1 for abbreviations and diagram of measurements and counts. Data corresponds protolarvae in Tables 2, 4, and 6.

Mesolarvae up to 46 mm TL*							
	Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N
TL, mm	35 $\pm$ 7	26 - 46	8	TL, mm	35 $\pm$ 7	26 - 46	8
<b>Lengths, % of TL</b>				<b>% of Head Length (snout to origin of pectoral fin, OP1)</b>			
AS to AE	12 $\pm$ 1	11 - 13	5	SN to AE	47 $\pm$ 4	45 - 53	5
to PE	14 $\pm$ 1	13 - 15	5	SN to ABI	24 $\pm$ 3	21 - 29	8
to ABI	6 $\pm$ 1	5 - 7	8	SN to ABO	28 $\pm$ 3	23 - 31	8
to ABO	7 $\pm$ 1	6 - 8	8	SN to AM	61 $\pm$ 5	54 - 68	8
to AM	15 $\pm$ 2	13 - 17	8	ABI to AM	37 $\pm$ 4	32 - 42	8
to PO	27 $\pm$ 1	26 - 28	6	Head Width at AM	71 $\pm$ 4	66 - 77	8
to OP1	25 $\pm$ 1	24 - 27	8	M Width	46 $\pm$ 2	43 - 49	8
to OP2	47		1	MO Width	37 $\pm$ 2	35 - 40	8
to IP2	52		1	ILL Width	4 $\pm$ 1	2 - 6	8
to ODF	20		1	IOR Width	44		1
to OPAF	39		1	BI Length	21 $\pm$ 3	18 - 27	8
to PV	53		1	BO Length	37 $\pm$ 5	31 - 46	8
to OD	56		1	Eye Diameter	10 $\pm$ 1	8 - 11	5
to ID	64		1				
to OA	60		1	<b>% of SN to AM Length (snout to anterior margin of mouth opening)</b>			
to IA	64		1	SN to ABI	40 $\pm$ 3	38 - 47	8
to AMPM	80		1	BI Length	35 $\pm$ 7	28 - 49	8
to OLLC	77 $\pm$ 2	75 - 79	5	Eye Diameter	16 $\pm$ 3	13 - 19	5
BI	5 $\pm$ 1	5 - 7	8				
BO	9 $\pm$ 1	7 - 11	8	<b>% of SN to ABO Length (snout to anterior base of barbel, outer)</b>			
P1	13 $\pm$ 0	12 - 14	8	SN to ABI	88 $\pm$ 4	81 - 93	8
P2	10		1				
D	14		1	<b>% of BO Length (barbel, outer)</b>			
A	11		1	BI Length	57 $\pm$ 5	51 - 67	8
<b>Depths, % of TL</b>				<b>% of M Width (mouth, between outer limits of lips)</b>			
at BPE	10		1	ILL Width	8 $\pm$ 2	5 - 12	8
at OP1 B	11		1	ABI to AM	80 $\pm$ 10	67 - 94	8
at OP1 T	13		1	BI Length	45 $\pm$ 4	41 - 54	8
at OP2 B	8		1				
at OP2 T	12		1	<b>Measurement Ratios "Similar" to Those of Bailey and Cross (1954)</b>			
at OP2 DF	3		1	<b>Given at the Bottom of Table 3..</b>			
at BPV B	7		1	ABI to AM in SN to ABO	0.8 $\pm$ 0.1	0.7 - 1.0	8
at BPV T	10		1	ABI to AM in M Width	1.3 $\pm$ 0.1	1.1 - 1.5	8
at OLLC B	3		1	ABI to AM in SN to PO	2.9 $\pm$ 0.2	2.6 - 3.2	6
at OLLC T	7		1	BI Length in SN to ABO	1.3 $\pm$ 0.2	0.9 - 1.5	8
at AMPM B	3		1	BI Length in BO Length	1.8 $\pm$ 0.1	1.5 - 2.0	8
at AMPM T	8		1	BI Length in SN to PO	5.1 $\pm$ 0.6	3.9 - 5.7	6
<b>Widths, % of TL</b>				<b>Selected Meristics</b>			
at BPE	18 $\pm$ 1	17 - 19	6	Myomeres			
at AM	18 $\pm$ 1	17 - 19	8	Preanal	36		1
at OP1	15		1	Postanal	22		1
at OP2	5		1	Total	58		1
at BPV	4		1	Fin-Ray Supports			
at OLLC	2		1	D	15 $\pm$ 0	15 - 16	8
at AMPM	2		1	A	10 $\pm$ 0	10 - 10	8
M	12 $\pm$ 1	10 - 12	8	P1	9 $\pm$ 1	8 - 9	2
MO	9 $\pm$ 1	8 - 10	8	P2	10 $\pm$ 1	9 - 10	8
ILL	1 $\pm$ 0	1 - 1	8	Spiral-Valve Turns	7 $\pm$ 1	6 - 7	2
IOR	11		1				

\* When N=1, data based only on 26 mm TL larva.

TABLE 9.—Summary of diagnostic (in *italics*) and selected secondary morphological criteria for distinguishing the larvae of pallid sturgeon and shovelnose sturgeon. See Figure 1 for abbreviations and diagram of measurements. Specimens near a transition from one group to another (e.g., 17 or 18-mm protolarvae with yolk and 18 or 19-mm larvae without yolk) can be checked against criteria for both groups. See conclusions in text for a discussion of limitations in the use of these criteria.

Characters	Criteria		
	Pallid Sturgeon	Either Species	Shovelnose Sturgeon
<b>Protolarvae with Yolk Prior to Pelvic-Fin Bud Formation (~10-12 mm TL) *</b>			
<i>Inner-barbel Length (BI)</i>			
As % outer-barbel length (BO)	≤ 71%		≥ 77%
As % head length (SN to OP1)	≤ 7%		≥ 8%
As % length from snout to mouth opening (SN to AM)	≤ 18%		≥ 19%
Times in outer-barbel length (BO)	≥ 1.4		≤ 1.3
Times in length from snout to outer barbel (SN to ABO)	≥ 4.2		≤ 3.9
Times in length from snout to end of opercle (SN to PO)	≥ 9.7		≤ 9.3
Myomeres			
Preanal count	≥ 37	≤ 36 <sup>b,c</sup>	
Eye Diameter (AE to PE)			
As % head length (SN to OP1)	≤ 12%	13-15 <sup>d</sup>	≥ 16%
Width of Mouth Opening (MO)			
As % total length (TL, SN to PC)	≤ 4%	≥ 5% <sup>c</sup>	
As % head length (SN to OP1)	≤ 21%	≥ 22% <sup>c</sup>	
Snout to Anterior Base of Inner Barbel (SN to ABI)			
As % snout to anterior base of outer barbel (SN to ABO)	≥ 100%	97-99%	≤ 96%
As % length from snout to mouth opening (SN to AM)		≥ 74% <sup>d</sup>	≤ 73%
Ant. Base of Inner Barbel to Mouth Opening (ABI to AM)			
As % head length (SN to OP1)		≤ 10% <sup>d</sup>	≥ 11%
Times in length from snout to outer barbel (SN to ABO)		≥ 3.0 <sup>d</sup>	≤ 2.9
Times in length from snout to end of opercle (SN to PO)		≥ 6.8 <sup>e</sup>	≤ 6.7
<b>Protolarvae with Yolk and Pelvic-Fin Buds (~12-18 mm TL)</b>			
<i>Eye Diameter (AE to PE)</i>			
As % head length (SN to OP1)	≤ 13%	14-15	≥ 16%
As % length from snout to mouth opening (SN to AM)	≤ 29%	30-33	≥ 34%
Tissues over heart from ventral view (larvae ≥ 16 mm TL)			
Pigmentation		None or little anteriorly	Over most of heart
Dorsal-fin pterygiophores (larvae ≥ 17 mm TL)			
Count	16	15 <sup>d</sup>	14
Myomeres			
Preanal count	37	34-36 <sup>e</sup>	33
Full Complement of Anal-fin pterygiophores <sup>f</sup>			
Total length when present		≥ 16 mm	≤ 15 mm
<i>Inner-barbel Length (BI)</i>			
As % head length (SN to OP1)	≤ 16%	17-25% <sup>e</sup>	≥ 26%
As % mouth width (M, with lips)	≤ 36%	37-50% <sup>e</sup>	≥ 51%
As % length from snout to mouth opening (SN to AM)	≤ 36%	37-54% <sup>e</sup>	≥ 55%
As % outer-barbel length (BO)	≤ 54%	55-76% <sup>d</sup>	≥ 77%
Times in outer-barbel length (BO)	≥ 1.9	1.3-1.8 <sup>e</sup>	≤ 1.2
Times in length from snout to outer barbel (SN to ABO)	≥ 1.7	0.8-1.6 <sup>e</sup>	0.7
Times in length from snout to end of opercle (SN to PO)	≥ 5.2	4.3-5.1 <sup>e</sup>	≤ 4.2
Snout to Anterior Base of Inner Barbel (SN to ABI)			
As % snout to anterior base of outer barbel (SN to ABO)	≥ 94%	86-93% <sup>e</sup>	≤ 85%
As % length from snout to mouth opening (SN to AM)	≥ 56%	39-55% <sup>e</sup>	≤ 38%
Ant. Base of Inner Barbel to Mouth Opening (ABI to AM)			
As % head length (SN to OP1)	≤ 19%	20-30% <sup>e</sup>	≥ 31%
As % mouth width (M, with lips)	≤ 41%	42-59% <sup>e</sup>	≥ 60%
Times in length from snout to outer barbel (SN to ABO)	≥ 1.4	≤ 1.3 <sup>e</sup>	
Times in length from snout to end of opercle (SN to PO)	≥ 4.4	3.6-4.3 <sup>e</sup>	≤ 3.5
Snout to Origin of the Anal Fin (SN to OA)			
As % total length (TL, SN to PC)		≤ 63% <sup>d</sup>	≥ 64%

(continued)



TABLE 9 —Continued

Characters	Criteria		
	Pallid Sturgeon	Either Species	Shovelnose Sturgeon
<b>Protolarvae without Yolk (~18 to 25 mm TL)</b>			
<i>Tissues over heart from ventral view</i>			
<i>Pigmentation</i>	None	Little anteriorly	Over most of heart
<i>Eye Diameter</i>			
As % head length (SN to OP1)	≤ 13%		≥ 14%
As % length from snout to mouth opening (SN to AM)	≤ 25%	26-28%	≥ 29%
<i>Inner-barbel Length (BI)</i>			
As % outer-barbel length (BO)	≤ 65%	66-71%	≥ 72%
Times in outer-barbel length (BO)	≥ 1.6	1.4-1.5	≤ 1.3
<i>Snout to Origin of the Dorsal Fin (SN to OD)</i>			
As % total length (TL, SN to PC)	≤ 53%		≥ 54%
<i>Middle of Lower-Lip Lobes (ventral view)</i>			
<i>Pigmentation</i> <sup>f</sup>		None; rarely spot on one lobe only	Spot on each lobe
<i>Myomeres</i>			
Preanal count	37	34-36 <sup>e</sup>	33
<i>Dorsal-fin pterygiophores</i>			
Count	16	15 <sup>d</sup>	14
<i>Inner-barbel Length (BI)</i>			
As % head length (SN to OP1)	≤ 27%	28-31% <sup>d</sup>	≥ 32%
As % length from snout to mouth opening (SN to AM)		≤ 60% <sup>d</sup>	≥ 61%
As % mouth width (M, with lips)		≤ 60% <sup>d</sup>	≥ 61%
Times in length from snout to end of opercle (SN to PO)	≥ 3.9	3.5-3.8% <sup>d</sup>	≤ 3.4
<i>Outer-barbel Length (BO)</i>			
As % total length (TL, SN to PC)	11%	10% <sup>d</sup>	≤ 9%
As % head length (SN to OP1)	≥ 47%	44-46% <sup>d</sup>	≤ 43%
<i>Snout to Anterior Base of Inner Barbel (SN to ABI)</i>			
As % length from snout to mouth opening (SN to AM)	≥ 35 %	30-34% <sup>e</sup>	≤ 29%
<i>Snout to Origin of the Anal Fin (SN to OA)</i>			
As % total length (TL, SN to PC)		≤ 58% <sup>d</sup>	≥ 59%
<i>Ant. Base of Inner Barbel to Mouth Opening (ABI to AM)</i>			
As % head length (SN to OP1)	≤ 30%	31-35% <sup>d</sup>	≥ 36%
As % mouth width (M, with lips)	≤ 57%	58-68% <sup>d</sup>	≥ 69%
<i>Length from Origin of Dorsal Fin to Vent (OD to PC)</i>			
As % total length (TL, SN to PC)	≤ 1% (dorsal origin over or slightly behind vent)	≥ 2% <sup>e</sup> (dorsal origin a bit further behind vent)	
<b>Mesolarvae (~25 to &gt; between 55 and 139 mm TL)</b>			
<i>Total Length (based on presence of less than full complement of caudal fin rays)<sup>f</sup></i>	≥ 61 mm	≤ 60 mm	
<i>Tissues over heart from ventral view</i>			
<i>pigmentation</i> <sup>b</sup>	None	Little anteriorly	Over most of heart
<i>Middle of Lower-Lip Lobes (ventral view)</i>			
<i>pigmentation</i> <sup>e</sup>	None	Spot on 1 lobe (rare)	Spot on both lobes
<i>Ventral Aspect of Lateral Rostral Plate</i>			
<i>shape posterior to outer barbel</i> <sup>i</sup>	Somewhat deltoid, very angular and widest near barbel		More semicircular, widest near middle
<i>Inner-barbel Length (BI)<sup>j</sup></i>			
As % outer-barbel length (BO)	≤ 64%	65-69%	≥ 70%
Times in outer-barbel length (BO)	≥ 1.6	1.5	≤ 1.4
<i>"Y" Pigment Pattern on Head (tail pointing posteriorly and arms to eyes). Intensity (&lt;30 mm TL) (≥ 30 mm TL)</i>	Indistinct Indistinct to light	Light to moderate Moderate to dark	
<i>Dorsal-fin pterygiophores</i>			
Count	16	15 <sup>d</sup>	14

(continued)

TABLE 9—Continued

Characters	Criteria		
	Pallid Sturgeon	Either Species	Shovelnose Sturgeon
Dorsal Fin Rays (only larvae >43 mm TL)			
Count	≥40	37-39 <sup>d</sup>	≤36
Anal Fin Rays (only larvae >54 mm TL)			
Count	≥26	23-25 <sup>e</sup>	≤22
Some Anal Fin Rays			
Total length when present		≥30 mm	≤29 mm
Full Complement of Dorsal Fin Rays <sup>f</sup>			
Total length when present		≥43 mm	≤42 mm
Full Complement of Anal Fin Rays <sup>f</sup>			
Total length when present		≥46 mm	≤45 mm
Full Complement of Pelvic Fin Rays <sup>f</sup>			
Total length when present		≥46 mm	≤45 mm
Some Ventral (Ventrolateral) Scutes			
Total length when present		≥47 mm	≤46 mm
Full Complement of Lateral Scutes			
Total length when present	≤43 mm	≥44 mm	
Full Complement of Ventral Scutes			
Total length when present	≥68 mm		≤60 mm
<b>Metalarvae and Older Fish (&gt;between 55 and 139 mm TL)</b>			
Total Length (based presence of full complement of caudal fin rays) <sup>j</sup>		≥82 mm	≤81 mm
Ventral Aspect of Lateral Rostral Plate			
Shape posterior to outer barbel <sup>k</sup> (at least for fish up to 200 mm TL)	Somewhat deltoid, very angular and widest near barbel		More semicircular, widest near middle
Inner-barbel Length (BI) <sup>k</sup>			
As % outer-barbel length (BO)	≤64%	65-69%	≥70%
Times in outer-barbel length (BO)	≥1.6	1.5	≤1.4
Tissues over heart from ventral view			
pigmentation		None to little anteriorly	Over most of heart
Middle of Lower-Lip Lobes (ventral view)			
pigmentation		None	Trace of former spots
Caudal Fin Rays			
Count	≥66		≤65
Dorsal Fin Rays			
Count	≥40	37-39 <sup>d</sup>	≤36
Anal Fin Rays			
Count	≥26	23-25 <sup>e</sup>	≤22
Pectoral Fin Rays			
Count	≥53	46-52 <sup>e</sup>	≤45
Pelvic Fin Rays			
Count	≥34	30-33 <sup>e</sup>	≤29
Full Complement of Pectoral Fin Rays <sup>f</sup>			
Total length when present		≥81 mm	≤80 mm

<sup>a</sup> Specimens less than 10 mm TL not distinguishable by morphological criteria except by preanal myomere count for some pallid sturgeon.

<sup>b</sup> Myomere count data for protolarvae without pelvic fin buds suggest that counts of <37 are unique to shovelnose sturgeon, but when counts for all protolarvae are combined, counts of 34-36 can be characteristic of either species.

<sup>c</sup> Includes the mean or some mean or modal values for shovelnose sturgeon.

<sup>d</sup> Includes the mean or some mean or modal values for pallid sturgeon.

<sup>e</sup> Includes the mean or some mean or modal values for both species.

<sup>f</sup> If uncertain whether the full complement of fin ray supports or fin rays are present, these criteria should not be used.

<sup>g</sup> Rare specimens of either species have a little pigment along the outer margin of the lower-lip lobes near the corners of the mouth; posterior to the mouth, most specimens have sparse patches of ventral or internal pigment associated with structures of the branchial region.

<sup>h</sup> For specimens >45 mm TL, ventral pigmentation usually forms on the musculature along either side of the heart for both species, but for pallid sturgeon, tissues over the heart itself are usually unpigmented or bear just a small patch of pigment anteriorly.

<sup>i</sup> Inner margin of shape defined by infraorbital canal.

<sup>j</sup> Based on measures of inner and outer-barbel length for eight 26-46 mm TL pallid sturgeon mesolarvae (Table 8) and extension of comparable measurements for shovelnose sturgeon protolarvae without yolk (justified on basis of similar ratios for reported by Bailey and Cross (1954) for older fish (Table 7).

<sup>k</sup> Data from or calculated from Bailey and Cross (1954) and assumption based on mesolarval data that some pallid sturgeon metalarvae might have an outer-barbel length to inner-barbel length ratio as low as 1.5.

## **Appendix**

### **Corresponding Data for A Series of Impure Pallid Sturgeon Larvae**

The tables in this appendix summarize data (A1-A4) and taxonomic criteria (A5) for a series of impure pallid sturgeon larvae reared at Missouri's Blind Pony Hatchery in 1992 and are provided for comparison with data in this report for pure pallid sturgeon. The fish were originally believed to be pure, but subsequently were determined to be the progeny of a hybrid (larvae at most second generation hybrids; at least 75% pallid sturgeon). While still assumed to be pure, these larvae served as the basis for an earlier description of pallid sturgeon and comparison with shovelnose sturgeon (Snyder 1994). The present description and comparison, based on pure pallid sturgeon larvae, serves as revision of that earlier report. The tables in this appendix are adapted from that earlier report and include corrections based on a re-examination of pectoral and pelvic fin radial counts and, in the taxonomic criteria table, a typographic reversal of criteria regarding the Y-shaped pigment pattern on the dorsal surface of the head.

TABLE A1.—Size (mm TL, total length) and age (from hatching)<sup>a</sup> at apparent onset of selected developmental events for impure (≥ 75%) pallid sturgeon reared by Missouri's Blind Pony Hatchery in 1992. Provided for comparison with pure pallid, shovelnose, and lake sturgeon in Table 1. Fin rays and scutes are considered present when they are sufficiently distinct to be seen under low power magnification. Rare or questionable values are enclosed in parentheses.

Developmental Event	Impure Pallid Sturgeon	
	Size (mm TL)	Age (d) <sup>a</sup>
Hatching	(7)8-9	0
Eyes Well Pigmented	10	2
Barbel Buds Formed	10	2
Pectoral-Fin Buds Formed	9	0-1
Pelvic-Fin Buds Formed	12	5
All Yolk Absorbed <sup>b</sup>	19	11
All Finfold Absorbed	>130	>71
<u>First Element(s) Present</u>		
Fin-Ray Supports,		
Dorsal	12	4
Anal	12	4
Pectoral	13	6
Pelvic	16	8
Fin Rays,		
Dorsal	>22, <26	>14, <17
Anal	>30, <34	>19, <22
Caudal	>26, <30	18
Pectoral	>22, <26	>14, <17
Pelvic	>30, <34	>19, <22
Scute Series,		
Dorsal	>22, <26	>14, <17
Lateral	>26, <30	18
Ventral	45-46	33
<u>Full Complement Present</u>		
Fin-Ray Supports,		
Dorsal	17	9
Anal	17	9
Pectoral	17	9
Pelvic	19	10-11
Fin Rays,		
Dorsal	>34, <40	>22, <26
Anal	>41, <45	>26, <33
Caudal	>75, <87	>43, <71
Pectoral	>56, <67	>36, <43
Pelvic	45-46	33
Scute Series,		
Dorsal	>22, <26	>14, <17
Lateral	>41, <45	>26, <33
Ventral	>46, <56	34

<sup>a</sup> The utility of ages reported herein is very limited since developmental state correlates much more closely with size than age. Age at a particular stage of development, or size, is dramatically affected by rearing temperature and even at the same temperature, the range of ages for a particular state of development, or size, becomes increasingly broad with time.

<sup>b</sup> See text section on Size Relative to Developmental State for discussion of yolk absorption in sturgeon and discrepancies in reported sizes for that event.

TABLE A2.--Summary of meristics for impure (>74%) pallid sturgeon protolarvae reared at Blind Pony Hatchery in 1992. See Figure 1 for abbreviations and diagram of measurements and Table 2 for comparison with pallid sturgeon. Data are rounded to nearest integers.

	Protolarvae with yolk, no pelvic buds				Protolarvae with yolk and pelvic buds				Protolarvae without yolk			
	Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N	
<b>Pallid Sturgeon</b>												
TL, mm	10 $\pm$ 1	9 - 12	9		15 $\pm$ 2	12 - 19	13		20 $\pm$ 1	19 - 22	5	
Myomeres												
Preanal	37 $\pm$ 1	36 - 39	9		36 $\pm$ 1	35 - 37	13		36 $\pm$ 1	36 - 37	3	
Postanal	21 $\pm$ 2	19 - 24	9		21 $\pm$ 1	20 - 22	13		20 $\pm$ 1	19 - 21	3	
Total	59 $\pm$ 2	56 - 63	9		57 $\pm$ 1	56 - 58	13		56 $\pm$ 1	55 - 57	3	
Fin-Ray Supports												
D	11 $\pm$ 1	10 - 11	2*		14 $\pm$ 2	11 - 17	13		16 $\pm$ 1	15 - 18	5	
A	4 $\pm$ 1	3 - 5	2*		9 $\pm$ 1	6 - 10	13		10 $\pm$ 1	9 - 11	5	
P1*					~7 $\pm$ 2	4 - 10	11		~10 $\pm$ 0	~9 - 10	5	
P2					8 $\pm$ 1	6 - 10	5*		9 $\pm$ 1	8 - 10	5	
Spiral-Valve Turn	5 $\pm$ 0	5 - 6	8		5 $\pm$ 1	5 - 6	13		6 $\pm$ 0	6 - 6	5	

\* Because pectoral-fin radials are difficult to observe and distinguish, counts were approximated and may not be accurate.

\*\* Fin supports (pterygiophores or radials) not formed or apparent in smaller specimens of group examined.

TABLE A3.--Summary of selected lengths, depths, and widths relative to total length for impure (>74%) pallid sturgeon protolarvae reared at Blind Pony Hatchery in 1992. See Figure 1 for abbreviations and diagram of measurements and Table 4 for comparison with pure pallid sturgeon. Data are rounded to nearest integers.

	Protolarvae with yolk, no pelvic buds				Protolarvae with yolk and pelvic buds				Protolarvae without yolk			
	Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N	
TL, mm	10 $\pm$ 1	9 - 12	9		15 $\pm$ 2	12 - 19	13		20 $\pm$ 1	19 - 22	5	
Lengths, % of TL												
AS to AE	4 $\pm$ 1	3 - 5	9		5 $\pm$ 1	4 - 7	13		7 $\pm$ 1	6 - 9	5	
to PE	7 $\pm$ 1	5 - 9	9		8 $\pm$ 1	8 - 10	13		10 $\pm$ 1	9 - 12	5	
to AB1	6 $\pm$ 0	6 - 7	6		5 $\pm$ 1	3 - 6	13		3 $\pm$ 0	3 - 4	5	
to ABO	7 $\pm$ 0	6 - 7	6		5 $\pm$ 1	4 - 6	13		4 $\pm$ 0	3 - 4	5	
to AM	8 $\pm$ 1	7 - 9	9		9 $\pm$ 0	9 - 10	13		11 $\pm$ 1	10 - 12	5	
to PO	15 $\pm$ 2	11 - 17	9		18 $\pm$ 2	16 - 21	13		22 $\pm$ 1	20 - 24	5	
to OP1	23 $\pm$ 1	22 - 25	8		20 $\pm$ 1	19 - 21	13		21 $\pm$ 1	19 - 22	5	
to OP2					49 $\pm$ 2	46 - 52	13		46 $\pm$ 0	46 - 46	5	
to IP2					55 $\pm$ 2	52 - 57	13		52 $\pm$ 1	51 - 52	5	
to AY	11 $\pm$ 1	9 - 13	9		19 $\pm$ 4	14 - 26	13					
to PY	43 $\pm$ 2	40 - 46	9		37 $\pm$ 3	34 - 42	13					
to ODF	20 $\pm$ 1	18 - 22	8		19 $\pm$ 1	18 - 20	13		19 $\pm$ 1	18 - 19	5	
to OPAF	42 $\pm$ 2	39 - 44	9		37 $\pm$ 2	34 - 39	13		35 $\pm$ 1	34 - 36	5	
to PV	64 $\pm$ 3	60 - 68	9		56 $\pm$ 2	52 - 59	13		53 $\pm$ 1	52 - 54	5	
to OD					59 $\pm$ 3	55 - 63	13		54 $\pm$ 0	54 - 54	5	
to ID					68 $\pm$ 2	64 - 70	13		64 $\pm$ 0	63 - 64	5	
to OA					64 $\pm$ 3	59 - 68	13		59 $\pm$ 0	58 - 59	5	
to IA					68 $\pm$ 2	65 - 71	11		64 $\pm$ 1	63 - 65	5	
to AMPM	89 $\pm$ 2	85 - 91	9		85 $\pm$ 3	79 - 88	13		80 $\pm$ 1	79 - 83	5	
to PN	99 $\pm$ 0	98 - 99	9		99 $\pm$ 0	98 - 99	13		99 $\pm$ 0	98 - 99	5	
B1	1 $\pm$ 0	1 - 2	6		4 $\pm$ 1	2 - 6	13		6 $\pm$ 0	5 - 7	5	
BO	2 $\pm$ 0	2 - 2	6		5 $\pm$ 2	3 - 9	13		10 $\pm$ 0	9 - 10	5	
P1	6 $\pm$ 0	6 - 7	8		8 $\pm$ 2	7 - 11	13		12 $\pm$ 1	11 - 13	5	
P2					6 $\pm$ 1	4 - 7	13		8 $\pm$ 1	8 - 9	5	
D					13 $\pm$ 1	11 - 13	11		14 $\pm$ 1	13 - 15	5	
A					8 $\pm$ 0	7 - 9	8		9 $\pm$ 0	9 - 10	5	
Depths, % of TL												
at BPE	13 $\pm$ 1	12 - 14	9		12 $\pm$ 0	12 - 13	13		12 $\pm$ 1	11 - 13	5	
at OP1 B	26 $\pm$ 2	23 - 29	9		16 $\pm$ 3	11 - 21	13		12 $\pm$ 0	11 - 12	5	
at OP1 T	26 $\pm$ 2	24 - 30	8		17 $\pm$ 3	12 - 21	13		13 $\pm$ 0	12 - 13	5	
at OP2 B	10 $\pm$ 1	9 - 11	9		9 $\pm$ 1	8 - 10	13		8 $\pm$ 1	8 - 9	5	
at OP2 T	17 $\pm$ 1	15 - 18	8		16 $\pm$ 1	13 - 18	13		14 $\pm$ 0	13 - 14	5	
at OP2 DF	3 $\pm$ 0	2 - 3	8		3 $\pm$ 0	2 - 3	13		3 $\pm$ 0	3 - 3	5	
at BPV B	8 $\pm$ 1	7 - 9	9		8 $\pm$ 0	7 - 8	13		7 $\pm$ 0	7 - 7	5	
at BPV T	14 $\pm$ 1	13 - 16	8		13 $\pm$ 1	11 - 14	13		12 $\pm$ 1	11 - 12	5	
at OLLC B	5 $\pm$ 0	4 - 6	9		4 $\pm$ 1	3 - 6	13		3 $\pm$ 0	3 - 3	5	
at OLLC T	15 $\pm$ 1	13 - 16	8		10 $\pm$ 2	8 - 13	13		9 $\pm$ 1	8 - 9	5	
at AMPM B	3 $\pm$ 1	2 - 5	9		3 $\pm$ 0	3 - 4	13		3 $\pm$ 0	2 - 3	5	
at AMPM T	14 $\pm$ 0	14 - 15	8		11 $\pm$ 1	9 - 13	13		10 $\pm$ 0	9 - 10	5	
Yolk, Maximum	21 $\pm$ 3	17 - 26	9		11 $\pm$ 4	4 - 18	13					
Widths, % of TL												
at BPE	10 $\pm$ 1	8 - 12	9		13 $\pm$ 2	11 - 15	13		16 $\pm$ 1	15 - 18	5	
at AM	11 $\pm$ 1	10 - 12	9		13 $\pm$ 1	12 - 15	13		16 $\pm$ 1	15 - 17	5	
at OP1	23 $\pm$ 4	18 - 31	9		13 $\pm$ 2	10 - 16	13		11 $\pm$ 1	10 - 11	5	
at OP2	5 $\pm$ 0	5 - 6	9		5 $\pm$ 0	5 - 6	13		5 $\pm$ 0	5 - 5	5	
at BPV	5 $\pm$ 0	4 - 5	9		5 $\pm$ 0	4 - 5	13		4 $\pm$ 0	4 - 4	5	
at OLLC	3 $\pm$ 0	3 - 3	9		3 $\pm$ 0	2 - 3	13		2 $\pm$ 0	2 - 2	5	
at AMPM	2 $\pm$ 0	1 - 2	9		2 $\pm$ 0	2 - 2	13		2 $\pm$ 0	1 - 2	5	
M					10 $\pm$ 1	8 - 11	13		11 $\pm$ 0	11 - 12	5	
MO	5 $\pm$ 1	3 - 7	9		7 $\pm$ 1	6 - 9	13		9 $\pm$ 0	9 - 10	5	
ILL					1 $\pm$ 0	1 - 2	13		1 $\pm$ 0	1 - 1	5	
IOR	6 $\pm$ 1	4 - 7	9		8 $\pm$ 1	6 - 10	13		10 $\pm$ 1	9 - 11	5	
Yolk, Maximum	24 $\pm$ 4	19 - 31	9		13 $\pm$ 3	8 - 18	13					

TABLE A4.--Summary of selected morphometric relationships for impure (>74%) pallid sturgeon protolarvae reared Blind Pony Hatchery in 1992, including ratios Bailey and Cross (1954) found diagnostic for larger fish. See Figure 1 for abbreviations and diagram of measurements and Table 6 for comparison with pure pallid sturgeon. Data are rounded to nearest integers except Bailey and Cross ratios.

	Protolarvae with yolk, no pelvic buds				Protolarvae with yolk and pelvic buds				Protolarvae without yolk			
	Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N		Mean $\pm$ SD	Range	N	
TL, mm	10 $\pm$ 1	9 - 12	9		15 $\pm$ 2	12 - 19	13		20 $\pm$ 1	19 - 22	5	
<b>% of Head Length (snout to origin of pectoral fin, OP1)</b>												
SN to AE	18 $\pm$ 4	13 - 23	8		27 $\pm$ 4	21 - 35	13		36 $\pm$ 5	29 - 42	5	
SN to ABI	27 $\pm$ 1	26 - 30	6		23 $\pm$ 5	16 - 31	13		15 $\pm$ 2	13 - 17	5	
SN to ABO	29 $\pm$ 2	27 - 32	6		25 $\pm$ 4	20 - 32	13		19 $\pm$ 2	16 - 20	5	
SN to AM	37 $\pm$ 2	32 - 39	8		47 $\pm$ 2	43 - 51	13		52 $\pm$ 4	48 - 57	5	
ABI to AM	16 $\pm$ 11	8 - 36	8		24 $\pm$ 5	15 - 33	13		36 $\pm$ 2	34 - 40	5	
Head Width at AM	49 $\pm$ 3	43 - 53	8		65 $\pm$ 4	57 - 72	13		78 $\pm$ 2	74 - 80	5	
M Width					48 $\pm$ 4	40 - 54	13		55 $\pm$ 2	51 - 57	5	
MO Width	21 $\pm$ 6	13 - 30	8		37 $\pm$ 4	29 - 43	13		43 $\pm$ 3	39 - 46	5	
ILL Width					6 $\pm$ 2	3 - 9	13		4 $\pm$ 1	2 - 6	5	
IOR Width	25 $\pm$ 4	19 - 31	8		41 $\pm$ 6	31 - 49	13		50 $\pm$ 3	45 - 52	5	
BI Length	6 $\pm$ 1	5 - 7	6		19 $\pm$ 5	11 - 28	13		29 $\pm$ 2	28 - 32	5	
BO Length	9 $\pm$ 1	8 - 11	6		27 $\pm$ 9	17 - 44	13		47 $\pm$ 2	45 - 50	5	
Eye Diameter	14 $\pm$ 1	13 - 16	8		15 $\pm$ 1	13 - 17	13		13 $\pm$ 0	13 - 14	5	
<b>% of SN to AM Length (snout to anterior margin of mouth opening)</b>												
SN to ABI	73 $\pm$ 4	67 - 78	6		49 $\pm$ 11	33 - 66	13		30 $\pm$ 2	26 - 32	5	
BI Length	16 $\pm$ 2	15 - 19	6		41 $\pm$ 11	25 - 57	13		56 $\pm$ 3	51 - 59	5	
Eye Diameter	38 $\pm$ 5	30 - 44	9		32 $\pm$ 3	26 - 37	13		26 $\pm$ 2	23 - 27	5	
<b>% of SN to ABO Length (snout to anterior base of barbel, outer)</b>												
SN to ABI	96 $\pm$ 3	92 - 100	6		93 $\pm$ 6	79 - 103	13		83 $\pm$ 6	74 - 88	5	
<b>% of BO Length (barbel, outer)</b>												
BI Length	68 $\pm$ 3	61 - 70	6		71 $\pm$ 9	60 - 91	13		62 $\pm$ 5	57 - 68	5	
<b>% of M Width (mouth, between outer limits of lips)</b>												
ILL Width					14 $\pm$ 4	8 - 21	13		7 $\pm$ 2	5 - 11	5	
ABI to AM					49 $\pm$ 9	33 - 66	13		67 $\pm$ 4	62 - 70	5	
BI Length					40 $\pm$ 9	25 - 53	13		53 $\pm$ 3	50 - 56	5	
<b>Measurement Ratios "Similar" to Those of Bailey and Cross (1954) Given Below</b>												
ABI to AM in SN to ABO	2.9 $\pm$ 0.5	2.2 - 3.7	6		1.1 $\pm$ 0.5	0.6 - 2.0	13		0.5 $\pm$ 0.0	0.5 - 0.6	5	
ABI to AM in M Width					2.1 $\pm$ 0.4	1.5 - 3.0	13		1.5 $\pm$ 0.1	1.4 - 1.6	5	
ABI to AM in SN to PO	5.1 $\pm$ 2.8	1.5 - 8.9	9		4.0 $\pm$ 0.6	3.1 - 5.1	13		3.0 $\pm$ 0.2	2.8 - 3.2	5	
BI Length in SN to ABO	4.8 $\pm$ 0.4	4.2 - 5.2	6		1.5 $\pm$ 0.7	0.7 - 2.8	13		0.6 $\pm$ 0.0	0.6 - 0.7	5	
BI Length in BO Length	1.5 $\pm$ 0.1	1.4 - 1.6	6		1.4 $\pm$ 0.2	1.1 - 1.7	13		1.6 $\pm$ 0.1	1.5 - 1.8	5	
BI Length in SN to PO	11.6 $\pm$ 0.8	10.3 - 12.6	6		5.1 $\pm$ 1.0	3.7 - 7.0	13		3.7 $\pm$ 0.2	3.4 - 3.8	5	
<b>Measurement Ratios Found Diagnostic by Bailey and Cross (1954, Fig. 9, Table 4)*</b>												
	Sm. Juveniles, 100 to 200 mm SL				Juveniles & Adults, >200 mm SL							
Inner barbel to mouth in snout to outer barbel (b in a)	2.4				2.9				2.3 - 3.3			
Inner barbel to mouth in mouth width (including lips, b in e)	1.7				1.8				1.6 - 2.0			
Inner barbel to mouth in head length (b in f)	5.6				6.3				5.5 - 7.0			
Inner-barbel length in snout to outer barbel (c in a)	2.8				3.3				2.6 - 3.7			
Inner-barbel length in outer-barbel length (c in d)	1.6				2.0				1.7 - 2.4			
Inner-barbel length in head length (bony edge of operculum, c in f)	6.5				7.2				6.4 - 8.0			

\* Bailey and Cross (1954) defined SL, standard length, to end at the posterior margin of the last carinate lateral scute or plate; also, their measurements were point to point, not along lines parallel or perpendicular to the body axis, and they defined anterior margin of the mouth as anterior cartilaginous edge of the labial depression (into which the protrusible mouth is retracted), not the anterior margin of the mouth openi

TABLE A5.—Summary of diagnostic (in *italics*) and selected secondary morphological criteria for distinguishing the larvae of impure ( $\geq 75\%$ ) pallid sturgeon and shovelnose sturgeon (modified from Snyder 1994). Provided for comparison with criteria in Table 9 for distinguishing pure pallid and shovelnose sturgeon. See Figure 1 for abbreviations and diagram of measurements. Specimens near a transition from one group to another (e.g., 17 or 18-mm protolarvae with yolk and 19 or 20-mm larvae without yolk) can be checked against criteria for both groups. See conclusions section in text for a discussion of limitations in the use of criteria here and in Table 9.

Characters	Criteria		
	Impure Pallid Sturgeon	Either	Shovelnose Sturgeon
<b>Protolarvae with Yolk Prior to Pelvic-Fin Bud Formation (~10-12 mm TL)<sup>a</sup></b>			
<i>Inner-Barbel Length (BI)</i>			
as % head length (SN to OP1)	$\leq 7\%$		$\geq 8\%$
as % outer-barbel length (BO)	$\leq 70\%$		$\geq 77\%$
as % length from snout to mouth opening (SN to AM)	$\leq 18\%$	19%	$\geq 20\%$
times in length from snout to outer barbel (SN to ABO)	$\geq 4.2$		$\leq 3.9$
times in outer-barbel length (BO)	$\geq 1.4$		$\leq 1.3$
times in head length (SN to PO)	$\geq 10.3$		$\leq 9.3$
<i>Outer-Barbel Length (BO)</i>			
as % head length (SN to OP1)		$\leq 11\%^b$	$\geq 12\%$
<i>Eye Diameter (AE to PE)</i>			
as % head length (SN to OP1)		$\leq 16\%^c$	$\geq 17\%$
<i>Width of Mouth Opening (MO)</i>			
as % head length (SN to OP1)	$\leq 21\%$	$\geq 22\%^d$	
<i>Mouth Opening to Anterior Base of Inner Barbel (AM to ABI)</i>			
as % head length (SN to OP1)	$\geq 19\%$	$\leq 18\%^b$	
<b>Protolarvae with Yolk and Pelvic-Fin Buds (~13-18 mm TL)</b>			
<i>Spiral Valve Turns</i>			
Count	5	6	7
<i>Dorsal-Fin Pterygiophores (only larvae <math>\geq 17</math> mm TL)</i>			
Count	$\geq 16$	15	$\geq 14$
<i>Inner-Barbel Length (BI)</i>			
as % head length (SN to OP1)	$\leq 16\%$	$\geq 17\%^b$	
as % mouth width (M, with lips)	$\leq 36\%$	$\geq 37\%^b$	
as % length from snout to mouth opening (SN to AM)	$\leq 36\%$	$\geq 37\%^b$	
times in length from snout to outer barbel (SN to ABO)	$\geq 1.7$	$\leq 1.6^b$	
times in head length (SN to PO)	$\geq 5.2$	$\leq 5.1^b$	
<i>Full Complement of Dorsal-Fin Pterygiophores<sup>h</sup></i>			
Total length when first present	17 mm		14 mm
<i>Full Complement of Anal-Fin Pterygiophores<sup>h</sup></i>			
Total length when first present	17 mm		12 mm
<b>Protolarvae without Yolk (~19 to 23, 24, or 25 mm TL)</b>			
<i>Inner-Barbel Length (BI)</i>			
as % outer-barbel length (BO)	$\leq 65\%$	66-68%	$\geq 69\%$
times in outer-barbel length (BO)	$\geq 1.6$	1.5	$\leq 1.4$
<i>Inter-lip-lobe Distance (ILL, between lower lip lobes)</i>			
as % head length (SN to OP1)	$\leq 5\%$	6%	$\geq 7\%$
as % mouth width (M, with lips)	$\leq 10\%$	11%	$\geq 12\%$
<i>Dorsal-Fin Pterygiophores</i>			
Count	$\geq 16$	15	$\leq 14$
<i>Inner-Barbel Length (BI)</i>			
as % head length (SN to OP1)		$\leq 32\%^b$	$\geq 33\%$
as % length from snout to mouth opening (SN to AM)		$\leq 59\%$	$\geq 60\%$
times in head length (SN to PO)		$\geq 3.4^b$	$\leq 3.3$
<i>Outer-Barbel Length (BO)</i>			
as % head length (SN to OP1)	$\geq 47\%$	45-46%	$\leq 44\%$
as % total length (TL, SN to PC)		$\geq 9\%$	$\leq 8\%^c$
<i>Eye Diameter</i>			
as % head length (SN to OP1)	$\leq 13\%$	14%	$\geq 15\%$
as % length from snout to mouth opening (SN to AM)	$\leq 25\%$	26-27% <sup>e</sup>	$\geq 28\%$
<i>Pelvic-Fin Length</i>			
as % total length (TL, SN to PC)	$\leq 12\%$	13% <sup>e</sup>	$\geq 14\%$

(continued)



TABLE A5—Continued.

Characters	Criteria		
	Pallid Sturgeon	Either Species	Shovelnose Sturgeon
Length from Origin to Insertion of Dorsal Fin (OD to ID, base length)			
as % total length (TL, SN to PC)	≥ 10%	9%	≥ 8%
Length from Vent to Origin of Dorsal Fin (PV to OD)			
as % total length (TL, SN to PC)	≥ 1% (dorsal fin over	2%	≥ 3% (dorsal fin a bit
or slightly behind vent)		further behind vent)	
Spiral-Valve Turns			
Count	5	6 <sup>c</sup>	7
Mesolarvae (23, 24, or 25 to between 55 and 87 mm TL)			
<i>Inner-Barbel Length (BI)<sup>a</sup></i>			
as % outer-barbel length (BO)	≥ 65%	66-68%	≥ 69%
times in outer-barbel length (BO)	≥ 1.6	1.5	≥ 1.4
<i>Dorsal-Fin Pterygiophores</i>			
Count	≥ 16	15	≥ 14
<i>First Anal-Fin Rays<sup>b</sup></i>			
Total length when first present	≥ 31, ≤ 33 mm		≥ 22, ≤ 25 mm
<i>Dorsal-Fin Rays (only larvae &gt;between 34 and 40 mm TL)</i>			
Count	≥ 40	35-39 <sup>f</sup>	≤ 34
<i>Anal-Fin Rays (only larvae &gt;between 40 and 45 mm TL)</i>			
Count	≥ 26	24-25 <sup>f</sup>	≤ 23
<i>First Caudal-Fin Rays<sup>b</sup></i>			
Total length when first present	≥ 27, ≤ 29 mm		≥ 22, ≤ 25 mm
<i>Full Complement of Pectoral-Fin Rays<sup>b</sup></i>			
Total length when first present	≥ 57, ≤ 66 mm		≥ 49, ≤ 54 mm
<i>Full Complement of Pelvic-Fin Rays<sup>b</sup></i>			
Total length when first present	45-46 mm		≥ 41, ≤ 42 mm
<i>First Ventral (Ventrolateral) Scutes<sup>b</sup></i>			
Total length when first present	45-46 mm		40-43 mm
<i>Full Complement of Ventral Scutes<sup>b</sup></i>			
Total length when first present	≥ 47, ≤ 55 mm		≥ 56, ≤ 60 mm
"Y" Pigment Pattern on Head (at least on larvae through 40 mm TL)			
Prominence (tail pointing posteriorly and arms to eyes)	Absent to Light		Moderate to Dark
Metalarvae and Older Fish (>between 55 and 87 mm TL)			
<i>Inner-Barbel Length (BI)<sup>a</sup></i>			
as % outer-barbel length (BO)	≤ 63%		≥ 67%
times in outer-barbel length (BO)	≥ 1.6		≤ 1.5
<i>Caudal-Fin Rays</i>			
Count	≥ 66	64-65	≤ 63
<i>Full Complement of Caudal-Fin Rays<sup>b</sup> (beginning of metalarval phase)</i>			
Total length when first present	≥ 76, ≤ 86 mm		≥ 56, ≤ 60 mm
<i>Dorsal-Fin Rays</i>			
Count	≥ 40	35-39 <sup>f</sup>	≤ 34
<i>Anal-Fin Rays</i>			
Count	≥ 26	24-25 <sup>f</sup>	≤ 23

<sup>a</sup> Specimens less than 10 mm TL are not distinguishable by morphological criteria.

<sup>b</sup> Includes the mean values for both species.

<sup>c</sup> Includes the mean value for pallid sturgeon.

<sup>d</sup> Includes the mean value for shovelnose sturgeon.

<sup>e</sup> Extension of measurements for protolarvae without yolk justified on basis of similar results for older fish by Bailey and Cross (1954).

<sup>f</sup> Includes at least some mean or modal values for both species.

<sup>g</sup> Data from or calculated from Bailey and Cross (1954).

<sup>h</sup> If there is uncertainty regarding whether the full complement of fin-ray supports or fin rays are present, these criteria should not be used for identification.

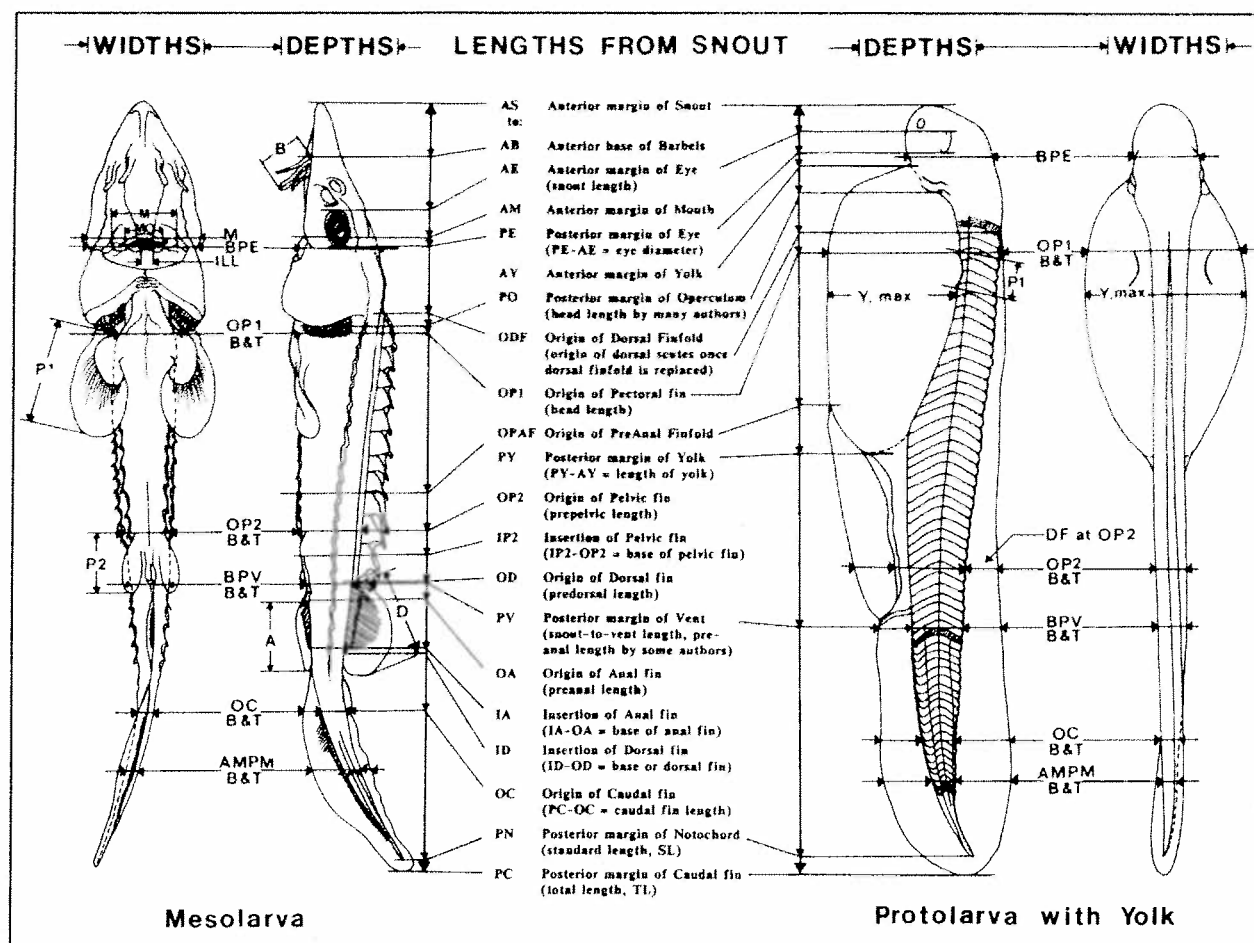


FIGURE 1.—Measurements used in morphometric analysis of sturgeon larvae. First preanal and first and last postanal myomeres stippled in lateral view of protolarva. Abbreviations not defined above are: **B**—barbel (length, BI for inner barbel, BO for outer barbel); **A**, **D**, **P1**, and **P2**—anal, dorsal, pectoral and pelvic fins (lengths, from origin to most distal margin); **DF**—dorsal finfold; **M**—mouth (with lips for mouth width, anterior margin of mouth opening, AM, for head width at mouth); **MO**—mouth opening (width between inner corners of lips); **ILL**—inter-lip-lobe distance (lower lip); **BPE**—just behind posterior margin of eye; **BPV**—just behind posterior margin of vent; **AMPM**—anterior margin of most posterior myomere; and **B&T** associated with depth and width measures—**B** for body exclusive of finfolds, fins, and scutes, and **T** for total, inclusive of those structures. **IOR**, interorbital distance (not illustrated), is the fleshy width between orbits of eyes. Positions for **OP2** and **OC** widths and depths prior to formation of referenced structures were approximated at 2/3 PY to PV and 1/2 PV to PC, respectively. Position of **AMPM** on some mesolarvae was approximated.

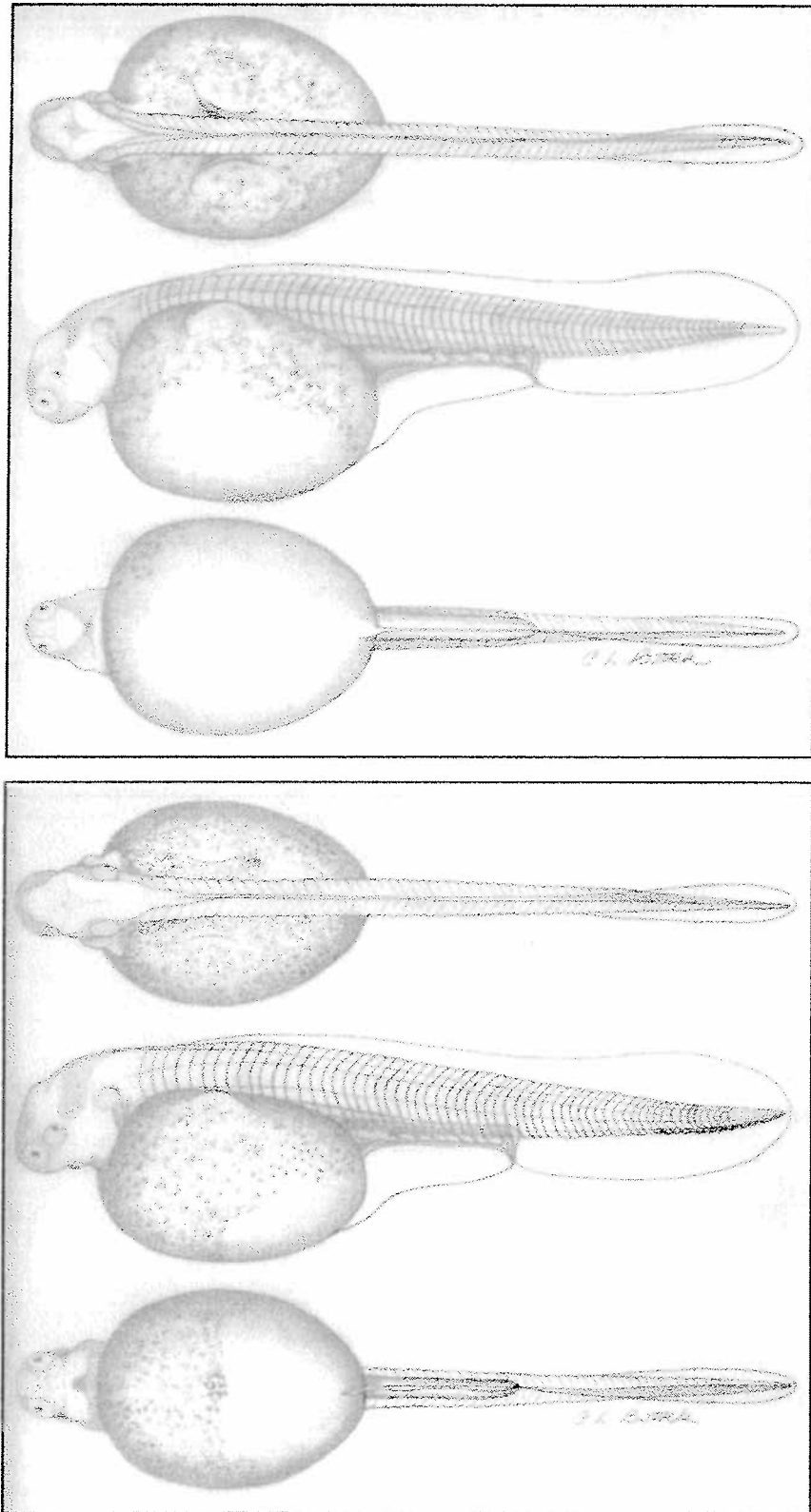


FIGURE 2.—Sturgeon protolarvae with yolk, 0 to 1 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 8.7 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 27 April 1992. **Below:** shovelnose sturgeon, 9.1 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched and preserved 17 June 1989.

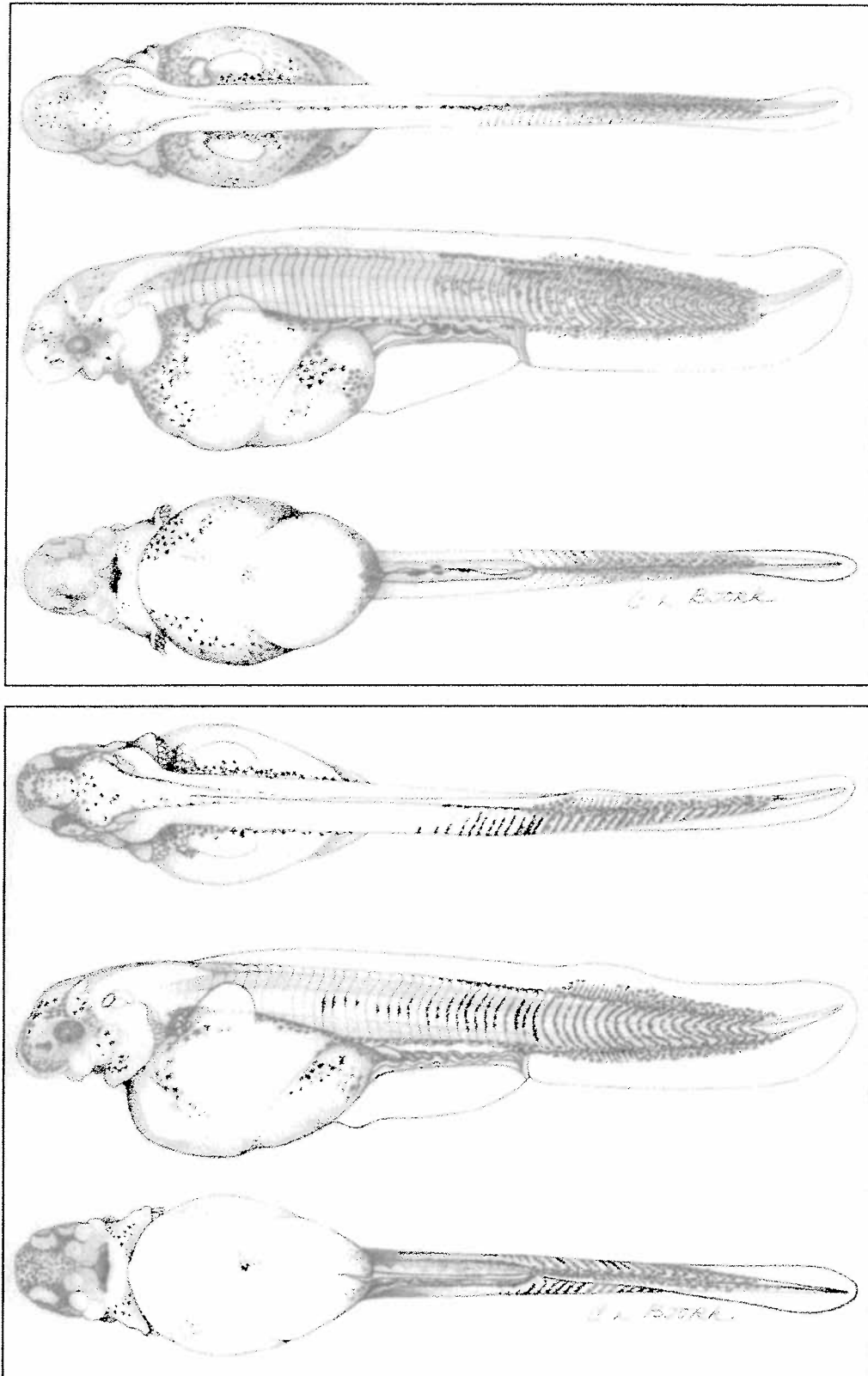


FIGURE 3.—Sturgeon protolarvae with yolk, 3 to 4 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 11.7 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 30 April 1992. **Below:** shovelnose sturgeon, 11.6 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched June 17, and preserved 20 June 1989.

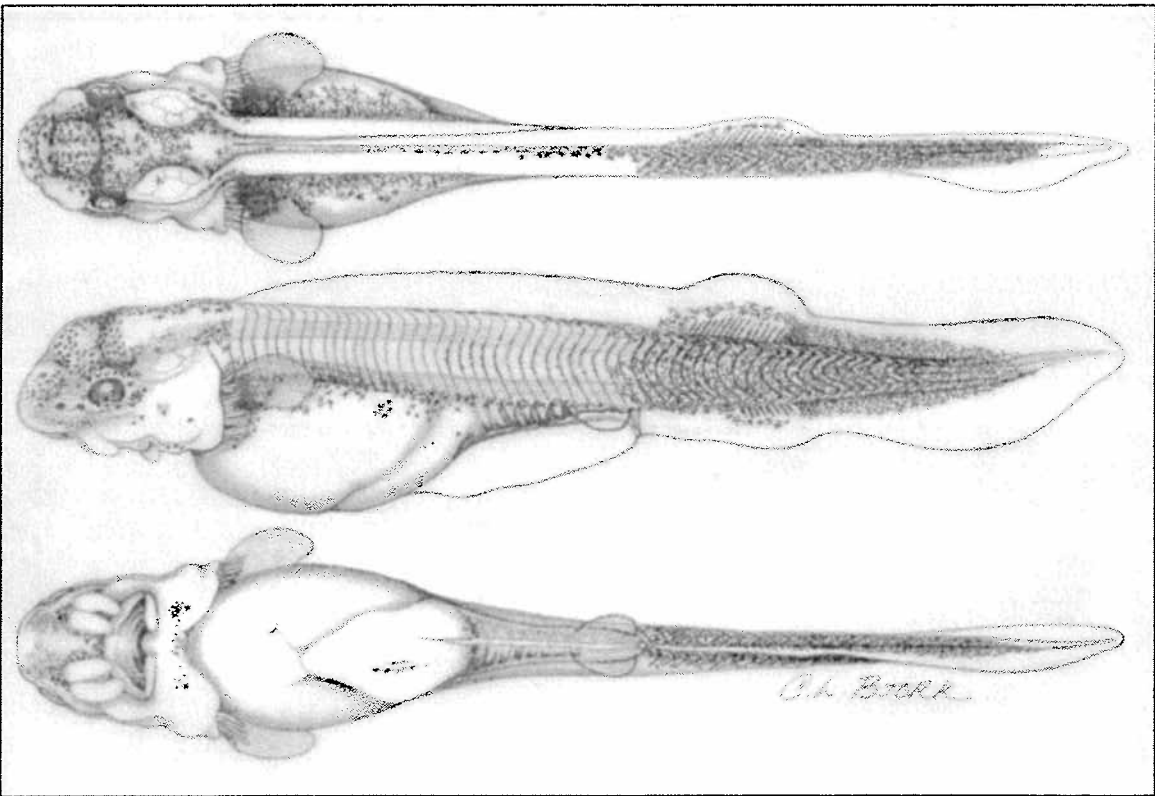
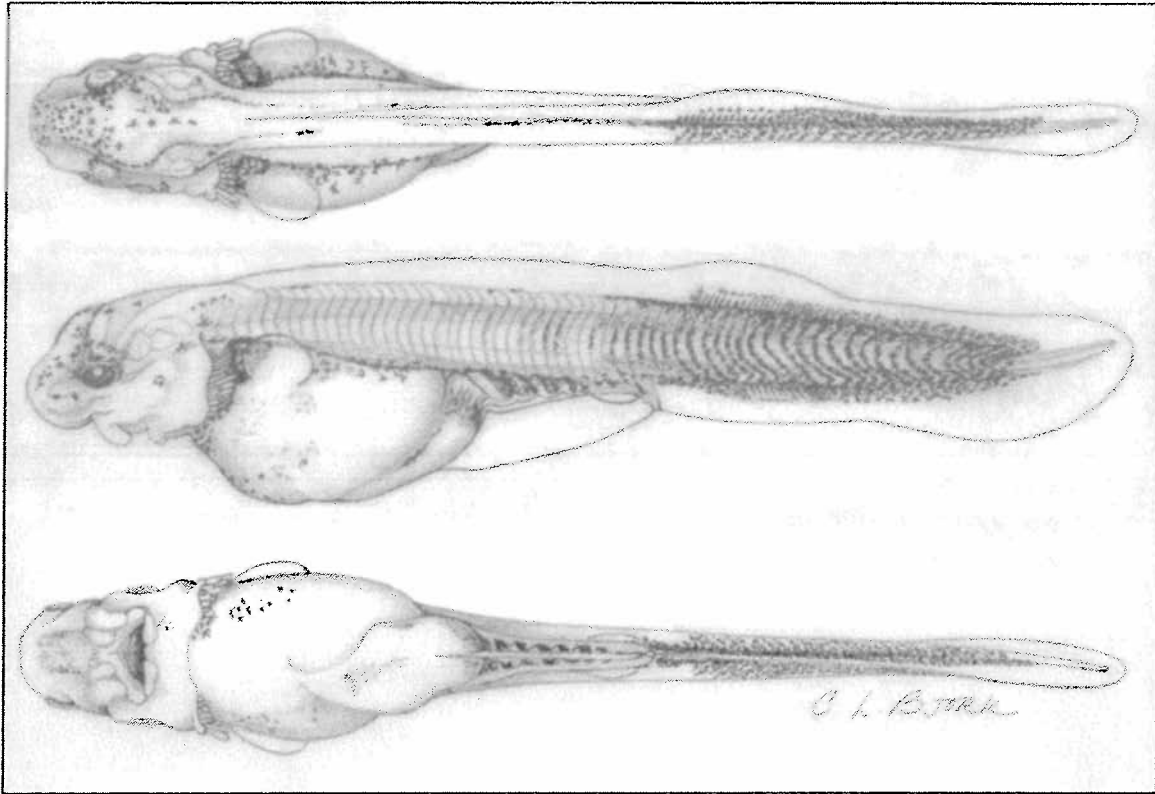


FIGURE 4.—Sturgeon protolarvae with yolk and pelvic buds, 5 to 6 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 13.9 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 2 May 1992. **Below:** shovelnose sturgeon, 13.6 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched 17 June, and preserved 22 June, 1989.

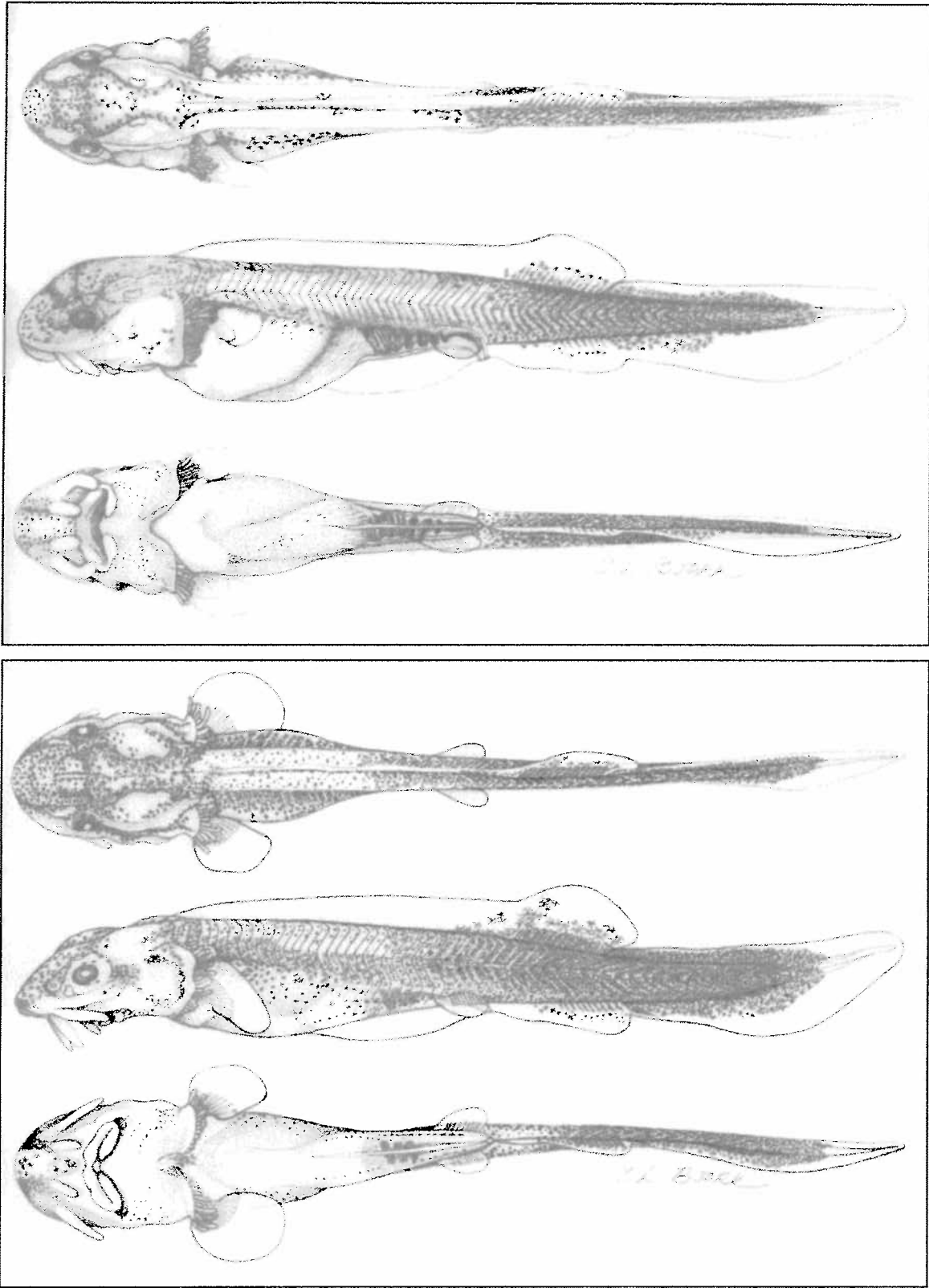


FIGURE 5.—Sturgeon protolarvae with yolk and pelvic fin buds, 7 to 8 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 16.2 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 4 May 1992. **Below:** shovelnose sturgeon, 15.9 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched 17 June, and preserved 24 June, 1989.

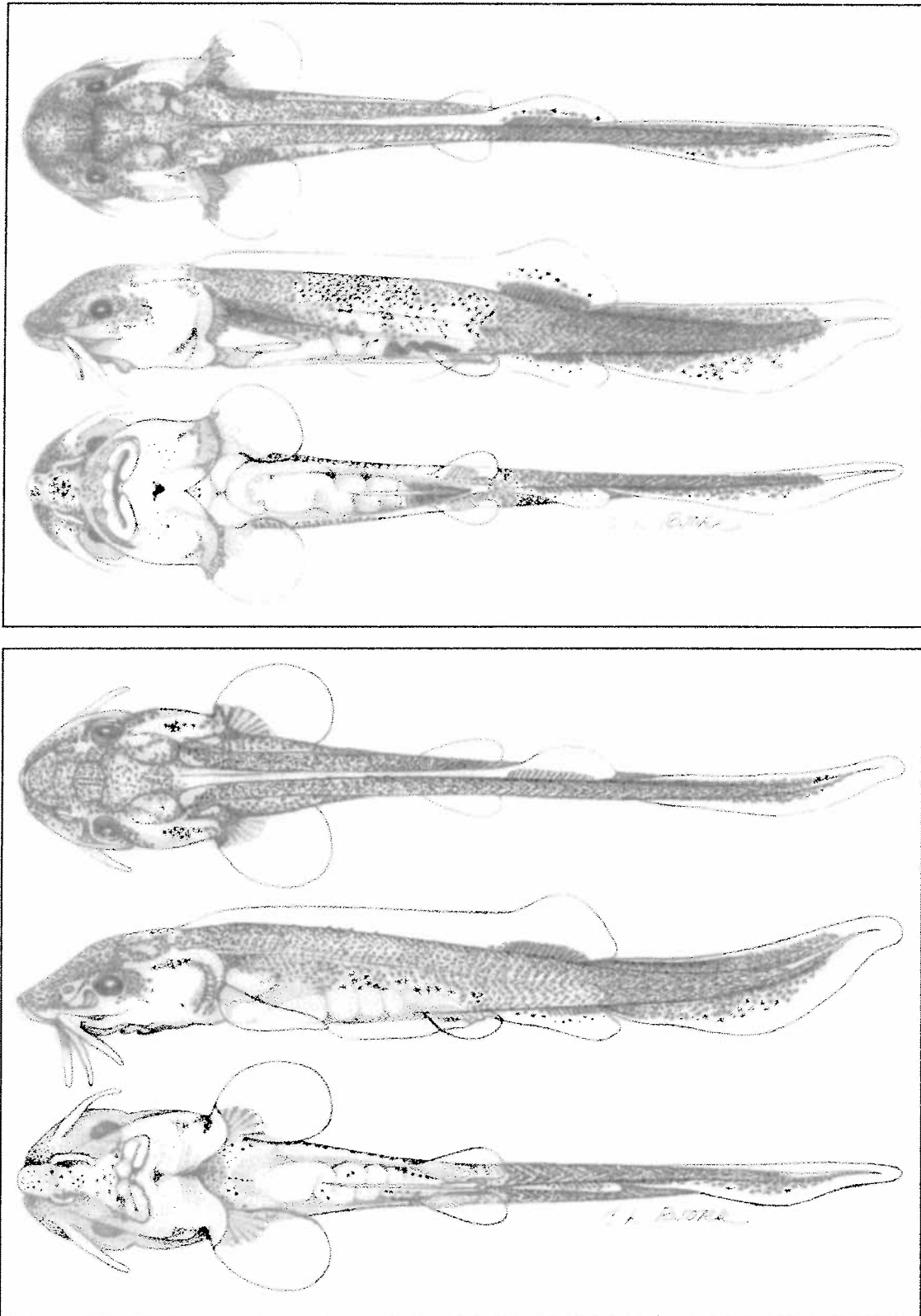


FIGURE 6.—Sturgeon protolarvae without yolk, 11 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 19.1 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 7 May 1992. **Below:** shovelnose sturgeon, 19.1 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched 17 June, and preserved 28 June, 1989.

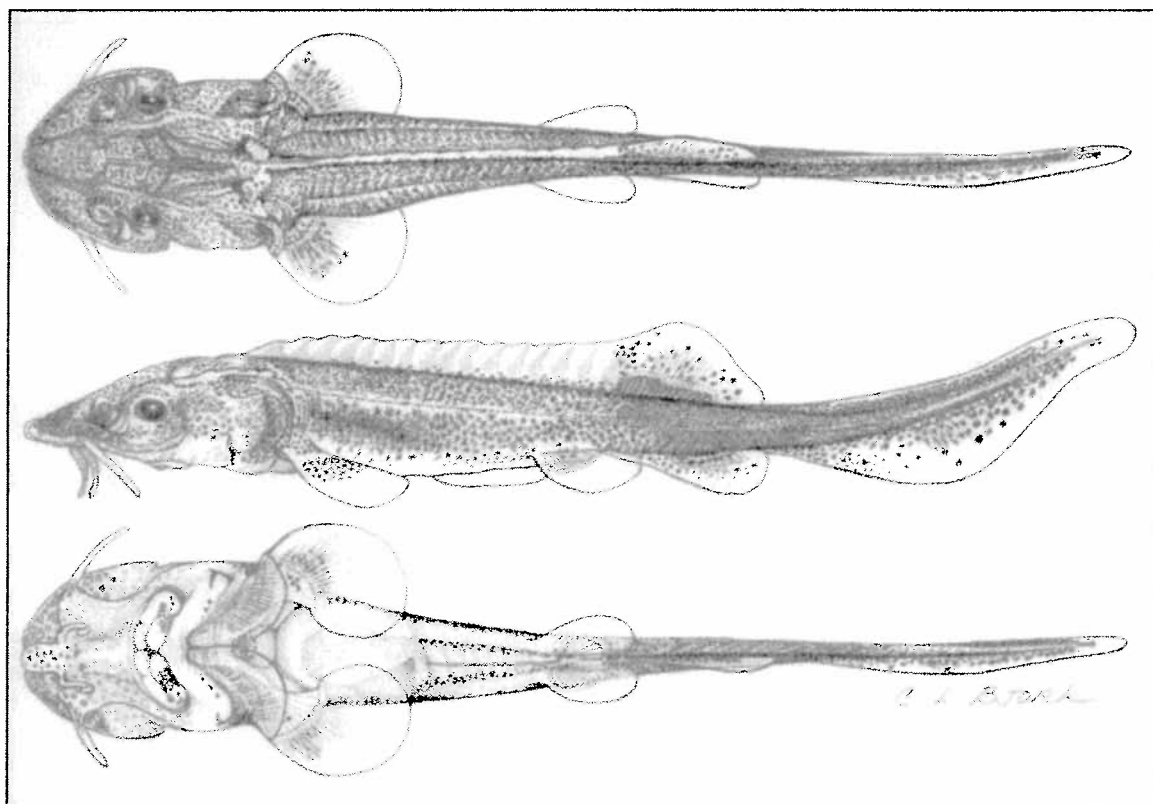
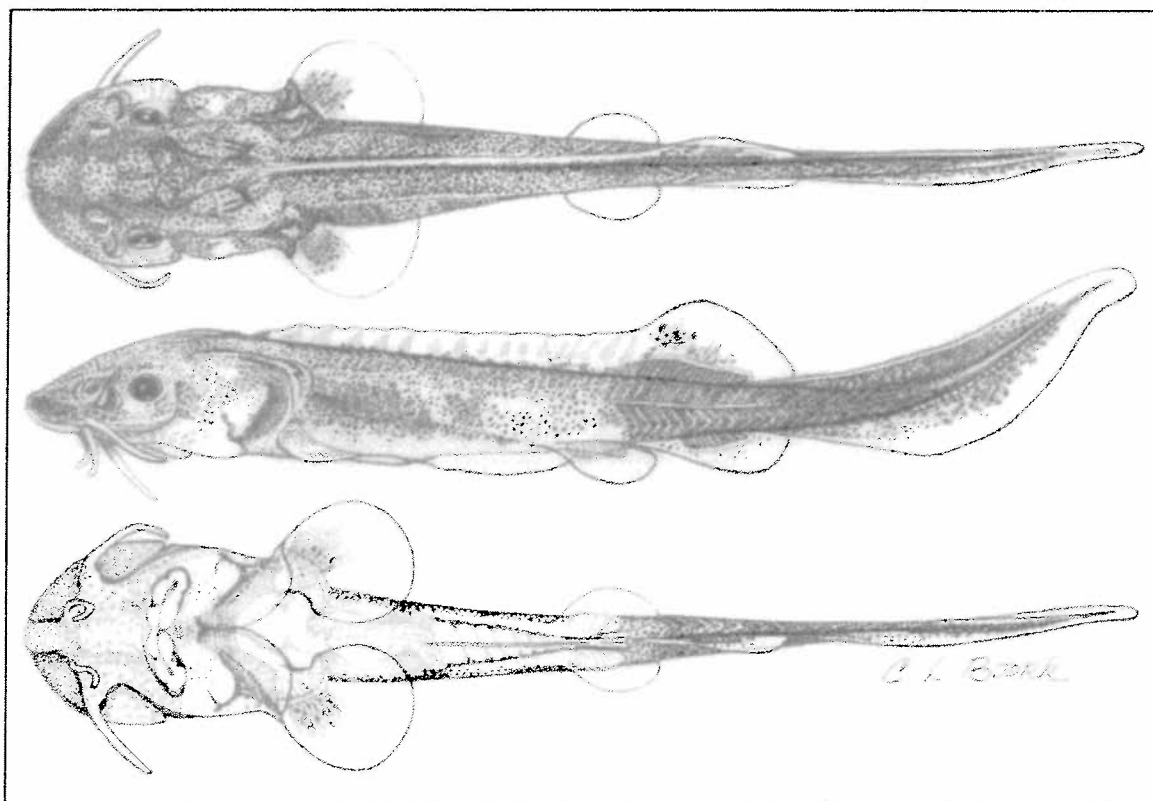


FIGURE 7.—Sturgeon mesolarvae, 17 to 21 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 26 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 13 May 1992. **Below:** shovelnose sturgeon, 26 mm TL, reared at Gavins Point NFH, fertilized 12 June, hatched ~23 June, and preserved 14 July, 1992.



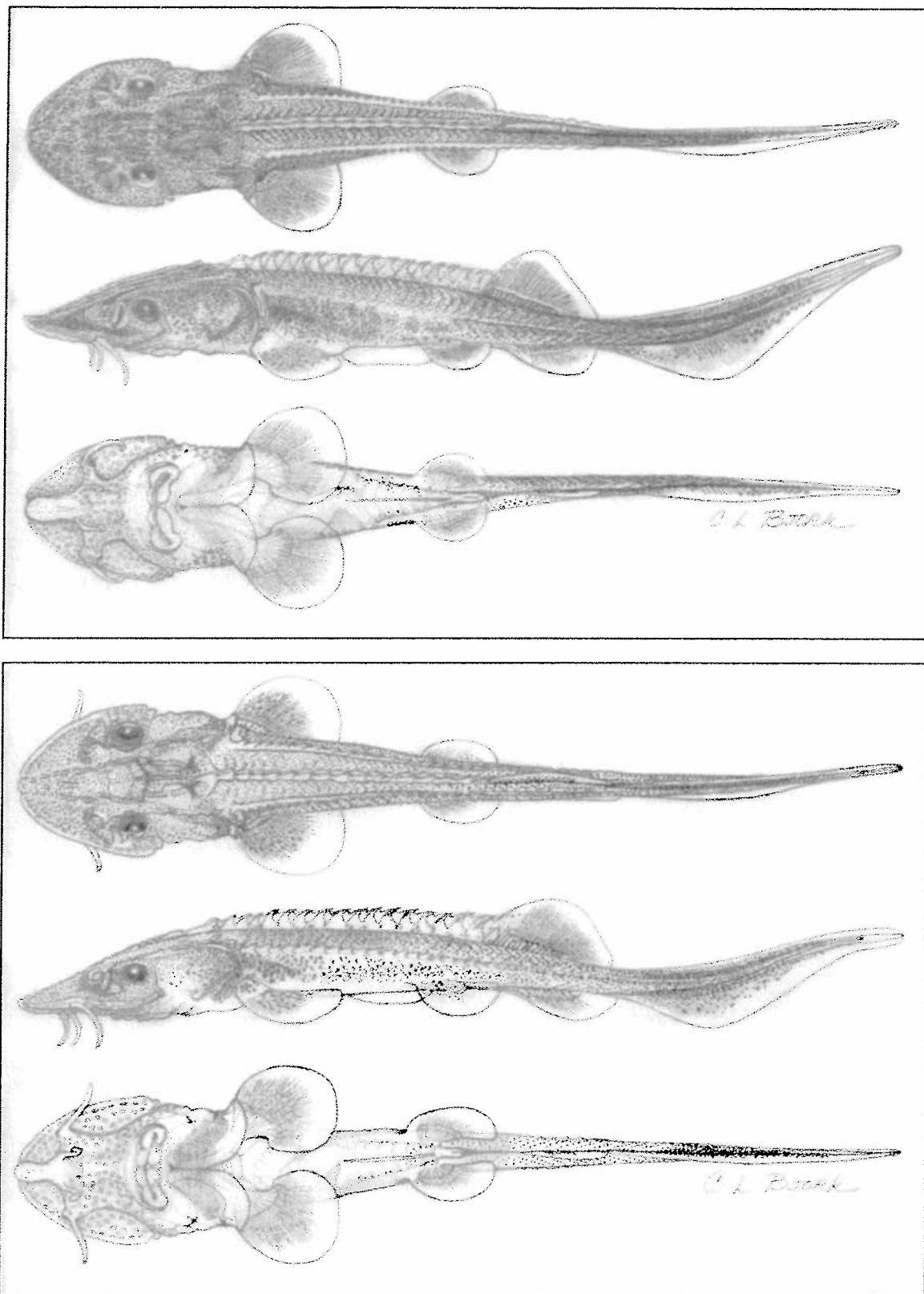


FIGURE 8.—Sturgeon mesolarvae, 24 to 26 d after hatching. **Above:** pallid sturgeon, based on nearly identical impure specimen, 41 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 22 May 1992. **Below:** shovelnose sturgeon, 40 mm TL, reared at Gavins Point NFH, fertilized 12 June, hatched ~23 June, and preserved 17 July, 1992.

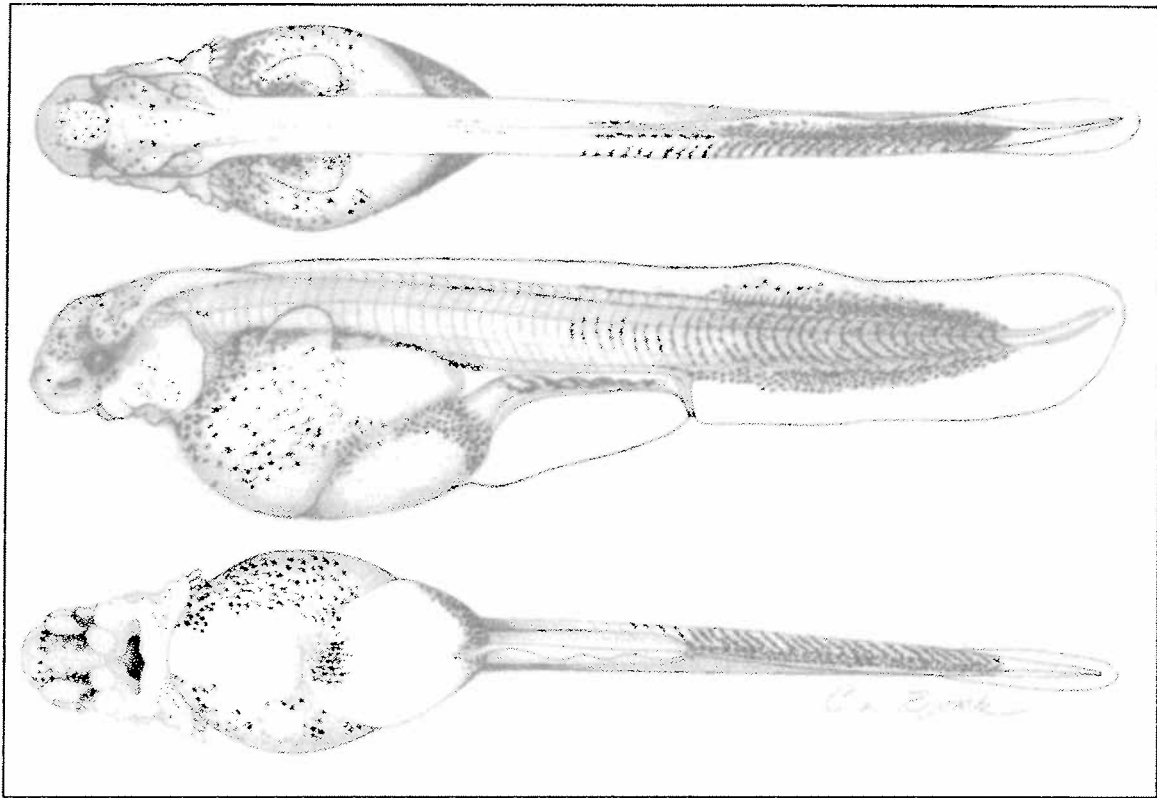


FIGURE 9.—Hybrid pallid x shovelnose sturgeon protolarva with yolk, 5 d after hatching. Specimen 11.8 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 1 May 1992.