MORPHOLOGICAL DEVELOPMENT AND IDENTIFICATION OF PALLID, SHOVELNOSE, AND HYBRID STURGEON LARVAE

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Preface

Original plans for this investigation of pallid, shovelnose, and hybrid pallid x shovelnose sturgeon included more extensive description of hybrid larvae. However, the pure forms are extremely similar, and the larvae develop over a much larger size range than expected. To accommodate the larger size range and avoid unnecessary replication of effort and results, illustrations of a seventh, much later, stage of both pallid and shovelnose sturgeon were substituted for the limited series of illustrations planned for the hybrid (one hybrid drawing was completed before this decision was made). Also, more detailed study of the pure forms, especially mesolarvae and metalarvae, was substituted for planned morphometric analysis of hybrid protolarvae.

Abstract

Pallid and shovelnose sturgeon, *Scaphirhynchus albus* and *S. platorynchus*, 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 (inner-barbel length 61-70% of outer-barbel length for pallid, 77-109% for shovelnose). For protolarvae with yolk and pelvic fin buds, barbel length is no longer diagnostic, although it is still useful as a secondary taxonomic criterion

for some specimens. Instead, these larvae are best distinguished by the number of turns in the spiral valve of the hindgut (5-6 for pallid, 6-8 for shovelnose) and, for specimens at least 17 mm TL, the number of dorsal fin pterygiophores (fin-ray supports; 15-18 for pallid, 14-15 for shovelnose). The latter remains diagnostic for later larvae. Yolk is absorbed by 18 to 19 mm TL and the first median fin rays appear in the dorsal fin between 22 and 26 mm TL, marking transition to the mesolarval phase. For protolarvae without yolk, distance between the lobes of the lower lips becomes a primary taxonomic character (5-11% of mouth width including lips for pallid, 11-20% for shovelnose). Also, inner-barbel length relative to outer-barbel length again becomes diagnostic (57-68% for pallid, 66-129% for shovelnose) and remains so even for adults. Mesolarvae between 25 and 30 mm TL, or smaller, with obvious anal fin rays are shovelnose sturgeon; anal fin rays are not apparent in pallid sturgeon until about 31 to 33 mm TL. 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 not until 76 to 86 mm TL in pallid sturgeon. For metalarvae, caudal fin-ray counts are diagnostic (64-73 for pallid, 51-65 for shovelnose). Pallid and shovelnose sturgeon still retain some preanal finfold, and therefore remain metalarvae, through at least 130 mm TL and 198 mm TL, respectively (the largest specimens examined). In addition to the diagnostic characters mentioned, several secondary taxonomic characters are useful for identifying some larvae during specific intervals of development. These include dorsal and anal fin-rays counts (35-44 and 24-30, respectively, for pallid; 30-39 and 18-25 for shovelnose). Myomere counts among protolarvae with pelvic fin buds were similar for both species (35-37 preanal, 19-22 postanal, and 55-58 total myomeres for pallid; 33-36, 20-22, and 53-57 for shovelnose). Except for intermediate counts of caudal fin rays in metalarvae (58-68), fin-ray and scute counts do not provide sufficient criteria to aid identification of hybrid mesolarvae and metalarvae. Pallid and shovelnose sturgeon larvae are smaller than lake sturgeon relative to state of development and, for specimens over 15 mm TL, lack its 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.[1] 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).

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 distinquish. 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, gillrakers 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, gillrakers 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, and reviews previously reported criteria for distinguishing lake and river sturgeon.

Specimens Examined

Larvae and early juveniles examined in this study 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. All specimens preserved for this study are maintained by the Larval Fish Laboratory 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 specimens preserved for this study 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 and pallid x shovelnose sturgeon hybrids were reared in 1992 by the Missouri Department of Conservation Blind Pony Hatchery, Sweet Springs. Upon reaching about 50 mm total length (TL), hybrids were transferred 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 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 specimens preserved for this study appeared 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 there is concern that they may actually be hybrids or the progeny of hybrids with shovelnose sturgeon (M. Dryer, personal communication). A genetic analysis of the pallid sturgeon brood stock has been undertaken to assess their purity, but results were not available prior to this study.

Methods

Measurements used in this investigation follow Snyder (1981, 1983, 1988) and are diagrammed 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 45 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).

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 1990). 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 approximates 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 extends 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 45 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.

Counts used in this investigation follow Snyder (1981, 1983, 1988) or Bailey and Cross (1954) with some modifications. Only preanal, postanal, and total myomeres were counted (Figure 1). Preanal myomere counts include all myomeres even partially transected 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.

Specimens were analyzed for the above counts and measurements and examined for differences in externally visible morphology, melanophore pigmentation patterns, and developmental state relative to size 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 by BioScan). 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 repeatability within 1 or 2 mm. Notably dissimilar measurements among fish of similar size were rechecked for verification or correction.

Larval phases of development were designated 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 it was no longer externally visible, although some might still have been present internally.

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.

Results and Discussion

Specific data for 149 specimens measuring 9 to 198 mm TL are summarized in Tables 1 to 7. The data are remarkably similar for both species with only a few notable differences. In the following discussion, morphometric and meristic characters are considered diagnostic (primary taxonomic criteria) if the means between species are well separated and their ranges are mutually exclusive or nearly so. Lesser but still useful differences are considered secondary criteria for identification. Identifications should always be based on multiple characters when possible; those based only on a couple of secondary criteria should be considered tentative. Figures 2 through 8 illustrate typical developmental state, morphology, and melanophore pigmentation of pallid and shovelnose sturgeon at comparable stages from recently hatched, 9-mm protolarvae to 40-mm mesolarvae. Figure 9 illustrates a 12-mm hybrid pallid x shovelnose sturgeon protolarva for comparison with the pure forms illustrated in Figure 3.

Morphometric Characters

Yolk-bearing protolarvae prior to pelvic fin bud formation (larvae <13 mm TL).—Shovelnose sturgeon tend to be slightly deeper and wider than pallid sturgeon at many measured locations (Tables 1-2). However, there is extensive overlap in the values for most measurements, many of which are influenced by the amount of yolk, condition of the larvae, and rearing environment.

Differences in measured characteristics of the head are more obvious when considered relative to head length (HL, measured to origin of pectoral fin or fin bud, SN to OP1) than total length (Tables 3-4). The greatest differences, aside from inner-barbel length (BI), are width of mouth opening (MO; only pallid sturgeon measure <22% HL), distance between anterior margin of mouth opening and anterior base of an inner barbel (AM to ABI; only pallid sturgeon measure >18% HL), eye diameter (SN to PE minus SN to AE; only shovelnose sturgeon measure >16% HL), and outer-barbel length (BO; only shovelnose measure >11% HL). Range overlap for these characters is extensive and only the upper or lower ends of the ranges are exclusively characteristic of one or the other species. All four characters can be considered as secondary criteria for identification, but the differences are transitory and either disappear or become much less distinct in yolk-bearing protolarvae with pelvic fin buds. Also, none of the referenced structures are present or very distinct in recently hatched larvae (<10 mm TL; Figure 2).

The only diagnostic character for protolarvae prior to pelvic fin bud formation is the length of the inner barbels (BI) once the buds are sufficiently formed (larvae 10-12 mm TL). As in adults, inner-barbel length is substantially shorter in pallid than in shovelnose sturgeon (Tables 3-4; Figure 3). Ranges for inner-barbel length are mutually exclusive, or nearly so, relative to head length (5-7% with a mean of 6% versus 8-13%, mean 10%, respectively), outer-barbel length (BO) (61-70%, mean 68%, versus 77-109%, mean 88%), and length from snout to anterior margin of the mouth opening (SN to AM) (15-19%, mean 16%, versus 19-31%, mean 24%). 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 3-4).

Yolk-bearing protolarvae with pelvic fin buds (larvae ~13-18 mm TL).— Most of the differences observed prior to pelvic fin bud formation no longer exist or become much less distinct. Eye diameter still tends to be less for pallid than shovelnose sturgeon, but the overlap in ranges is extensive (e.g., 26-37% versus 30-40% SN to AM, respectively; Tables 3-4) making the character unsuitable even as a secondary criterion for identification. Outer-barbel length is now also nearly the same for both species.

Inner-barbel length remains useful for identification of some larvae but is no longer diagnostic (Tables 3-4; Figures 4-5). There is considerable overlap between pallid and shovelnose sturgeon for inner-barbel length relative to head length (11-28%, mean 19%, versus 17-30%, mean 22%, respectively), snout-to-mouth length (25-57%, mean 41%, versus 37-59%, mean 48%), mouth width (25-53%, mean 40%, versus 37-59%, mean 45%), and outer-barbel length (60-91%, mean 71%, versus 55-95%, mean 78%). However, if the two specimens with the greatest inner-barbel lengths for pallid sturgeon and two least inner-barbel lengths for shovelnose sturgeon are excluded from the dataset, range overlap for these relationships is substantially reduced (e.g., ranges for inner-barbel length relative to outer-barbel length are reduced to 60-76% versus 70-95%, respectively, and are similar to the ranges for larvae prior to pelvic fin bud formation except for overlap rather than exclusion between 70% and 76%). The overlap in ranges between species for the full dataset is also obvious in inner-barbel-length ratios similar to those found diagnostic by Bailey and Cross (1954) (Tables 3-4).

Protolarvae without yolk (~19 to >22 but <26 mm TL).—Once all externally visible yolk is absorbed, protolarvae can be diagnosed by inter-lip-lobe distance (ILL) and, again, by inner-barbel length (Tables 3-4, Figure 6). Distance between the lobes (right and left halves) of the medially split lower lip is usually less for pallid than shovelnose sturgeon when considered relative to either head length (1-6%, mean 4%, versus 6-11%, mean 8%) or mouth width (5-11%, mean 7%, versus 11-20%, mean of 15%). Inner-barbel length is only diagnostic relative to outer-barbel length (57-68%, mean 62%, versus 66-129%, mean 92%). If the single highest value for pallid sturgeon and single lowest value for shovelnose sturgeon are deleted from the dataset, the small range of overlap (66-68%) is replaced by a wide zone of mutual exclusion (65-76%). Expressed in terms of Bailey and Cross's (1954) ratio of inner-barbel length in outer-barbel length, the character (using all data) remains diagnostic with approximately the same value for transition between species (1.5) as reported by Bailey and Cross for much larger fish. Accordingly, the diagnostic criteria (point of transition) for this character should remain applicable for later larvae as well as juveniles and adults. Relative to other measurements, inner-barbel length only provides secondary taxonomic criteria. Between species there is much lower-range overlap for inner-barbel length relative to both head length (28-32%, mean 29%, versus 28-40%, mean 32%, respectively) and snout-to-mouth length (51-59%, mean 56%, versus 51-86%, mean 62%).

Several other characters also provide secondary criteria for identification (Tables 1-4, Figure 6). Eye diameter is again smaller for most pallid than shovelnose sturgeon when considered relative to both head length (13-14%, mean 13%, versus 14-17%, mean 15 %, respectively) and snout-to-mouth length (23-27%, mean 26%, versus 26-36%, mean 29%). Pelvic fin length relative to total length is generally less for pallid than shovelnose sturgeon (11-13%, mean 12%, versus 13-15, mean 14%). Reversing the condition for protolarvae prior to pelvic fin bud formation, length of the outer barbels is now usually greater for pallid than shovelnose sturgeon. The differences in ranges for outer-barbel length relative to head length (45-50%, mean 47%, versus 24-46%, mean 36%) are greater and should be more useful than those relative to total length (9-10%, mean 10%, versus 5-10%, mean 7%). As would be expected based on pterygiophore counts discussed below, length of the base of the dorsal fin (origin OD to insertion ID) is slightly greater for pallid (9-10%, mean 10% TL) than shovelnose sturgeon (7-9%, mean 8%TL). Based on differences in percentage total length measured from the snout (Tables 1-2), origin of the dorsal fin is immediately over or slightly behind the posterior margin of the vent in pallid sturgeon (0-2%, mean 1% TL) and somewhat further behind in shovelnose sturgeon (2-3%, mean 3% TL).

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. Some ranges are nearly identical to those reported herein for both species combined, but most others are greater: snout length (AS to AE), prepectoral length (SN to OP1), predorsal finfold length (SN to ODF) and head width for 14- to 19-mm larvae and predorsal finfold length and preanal length (Sn to PV) for 7- to 12-mm larvae. Values for preanal length for 14- to 19-mm larvae and head width for 7-12-mm larvae were less than reported herein. I have no explanation for these differences but none of the characters are discussed in the preceding section as 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 are greater 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 12-16% TL, respectively), and eye diameter (3-5% TL versus 2-3% TL, respectively). A similar comparison data for larvae prior to pelvic fin bud formation reveals no notable differences between lake and river sturgeon

Meristic Characters

Myomere counts.—Myomere counts between species are quite similar (Table 5). Preanal and total myomere counts are slightly higher for pallid than shovelnose sturgeon, but differences between means are never greater than two myomeres. Myomere counts for protolarvae without pelvic fins or fin buds are a bit higher than for later larvae (see Methods for possible explanations).

Preanal and total myomere counts are generally a myomere or two greater for pallid protolarvae than shovelnose sturgeon (Table 5), but the differences are not great enough for identification purposes. Combining data for protolarvae after pelvic fin bud formation, pallid sturgeon have 35 to 37 preanal, 19 to 22 postanal, and 55 to 58 total myomeres whereas shovelnose sturgeon have 33-36 preanal, 20-22 postanal, and 53 to 57 total myomeres. Counts for protolarvae prior to pelvic fin bud formation are more variable and higher at the upper extreme of each range, but the mean counts are only a myomere or two higher than for later larvae. Myomere counts reported by Carlson (1983) for wild-caught river sturgeon protolarvae (8-19 mm TL) are lower by about two preanal, two postanal and four total myomeres (32 to 34 preanal, 16-20 postanal, and 50-53 total). Assuming that his counts should be are similar to at least those reported herein for shovelnose sturgeon, Carlson may have missed the two most anterior and two most posterior myomeres.

Turns of the spiral valve.—The spiral valve was readily observed in most protolarvae examined in this study, but Carlson (1983) was less successful with wild-caught river sturgeon. If clearly observed, the number of turns in the spiral valve of the hindgut (as observed without dissection) is useful for at least tentative identification of protolarvae, especially after the pelvic fin buds form (Table 5, Figures 2-4). Specimens with five spiral-valve turns are probably pallid sturgeon, whereas those with seven are probably shovelnose sturgeon (Table 5). Specimens with six spiral-valve turns could be either species, although among the limited number of protolarvae without yolk examined, pallid sturgeon (n=5) always had six spiral-valve turns and shovelnose sturgeon (n=3) always had seven turns.

Fin meristics.—The full complement of dorsal fin pterygiophores in river sturgeon is established by a few millimeters before all yolk is absorbed (Table 7, Figures 6-7). At that size (~17 mm TL), the number of dorsal fin pterygiophores becomes useful for at least tentatively identifying most larvae. Based on protolarvae without yolk (Table 5) and several mesolarvae through about 55 mm TL, pallid sturgeon have 15 to 18 dorsal fin pterygiophores with a mean of 16, whereas shovelnose sturgeon have 14-15 with a mean of 14.

Full complements of fin-ray counts except for all but the caudal fin are established during the mesolarval phase at total lengths greater than 34 mm depending on the specific fin and species of concern (Tables 6 and 7, Figure 8). All fin-ray counts for pallid sturgeon reared in 1992 are higher than those for shovelnose sturgeon. Relative to shovelnose sturgeon that were reared in 1989 at a similar incubation temperature (~17°C), the ranges of counts for each fin are mutually exclusive. However, the 1992 shovelnose sturgeon were reared at a lower incubation temperature (13°C) and their fin-ray counts are notably higher than for the 1989 shovelnose sturgeon and substantially overlap the still higher pallid sturgeon ranges for all fins except the caudal fin where the overlap is slight and does not include mean (or modal) values. Fin-ray counts for pallid sturgeon are quite similar to those reported by Bailey and Cross (1954) and Carlson et al. (1985), except caudal fin-ray counts which had not been reported for either river sturgeon (Table 6). 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).

Combining all available data on fin-ray counts, only those for the caudal fin are diagnostic (64-73 with means of 68-69 for pallid sturgeon versus 51-65 with means of 58-61 for shovelnose sturgeon) (Table 6). Dorsal fin-ray counts with their mutually exclusive means (35-44, means 38-41, for pallid versus 30-39, means 31-35, for shovelnose) and anal fin-ray counts with slightly overlapping means (24-30, means 24-28, for pallid and 18-25, means 20-24, for shovelnose) can be considered secondary taxonomic criteria.

Dorsal, anal, pectoral, and pelvic fin-ray counts for late mesolarvae and metalarvae of hybrid pallid x shovelnose sturgeon reared in 1992 (along with pallid sturgeon; incubation temperature ~17°C) are similar to the combined counts for pallid sturgeon and higher than those for shovelnose sturgeon (Table 6). The hybrid's caudal fin-ray counts, however, are intermediate to pallid and shovelnose sturgeon counts. Mean dorsal and anal fin-ray counts reported by Carlson, et al. (1985) for wild-caught specimens believed to be hybrids are just slightly lower. In contrast, the mean pectoral and pelvic fin-ray counts reported by Carlson et al. (1985) were still lower with the mean pectoral count intermediate to pallid and shovelnose sturgeon and the mean pelvic count matching the means for shovelnose sturgeon.

Scutes.—Counts for scutes in the dorsal and ventral (ventrolateral) rows are similar for both species and closely match counts previously reported by Bailey and Cross (1954), Clay (1975), and Williams and Clemmer (1991) (Table 6). In contrast, mean lateral row scute counts for both 1989 and 1992 broods of shovelnose sturgeon were notably lower (38-41) than observed for pallid sturgeon (45) or reported by the above authors for either species (42-46). As revealed by the number of lateral scutes anterior to the origin of the dorsal fin (including scutes transected by a vertical line from that point), most of the difference between original and previously reported lateral scute counts for shovelnose sturgeon occurs in that anterior region. Combining all available data, the ranges for lateral scute counts are similar for both species (39-49 with means of 43-45 for pallid and 37-50, means 40-46, for shovelnose sturgeon).

Comparisons with descriptions of lake sturgeon larvae.—Carlson (1983) reported diagnostic differences in myomere counts between river sturgeon and lake sturgeon (34-37 preanal, 20-25 postanal, and 55-59 total for 11- to 21-mm lake sturgeon; Table 5). However, the lake sturgeon counts are quite similar to river sturgeon counts reported herein. Jude (1982) reported even greater numbers of preanal (40-43) and total (57-64) myomeres, but fewer postanal myomeres (17-22) 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 original observations within the ranges reported by Jude (1982). If Jude's counts are accurate, then myomere counts are diagnostic for distinguishing river sturgeon from lake sturgeon. However, until the source of discrepancies between Carlson's and Jude and Wallus's counts are resolved, or additional myomere count data for lake sturgeon becomes available, this character should probably not be used for distinguishing river sturgeon from lake sturgeon.

Based on previously published data by Vladykov and Beaulieu (1946), Clay (1975), Jollie (1980), and Jude (1982), fin-ray counts distinguish some pallid or shovelnose sturgeon from lake sturgeon in much the same way they distinguish pallid and shovelnose sturgeon, but the specific relationship varies with the fin under consideration. For lake sturgeon, dorsal and anal fin-ray counts (35-44, mean 38, and 25-30, mean 28, respectively) are nearly identical to those for pallid sturgeon and higher than for shovelnose sturgeon. The situation is reversed for lake sturgeon pectoral and pelvic fins (40-45 and 27-30, respectively) wherein the counts are similar to those for shovelnose and lower than for pallid sturgeon. The only caudal fin-ray count reported for lake sturgeon (80; Jude 1982) is notably higher than for either pallid or shovelnose sturgeon. This could be considered a diagnostic character for separating lake sturgeon from both species of river sturgeon, but additional data is needed to verify the single observation and document variation in the count.

Lake sturgeon scute counts reported by Vladykov and Beaulieu (1946) and Jollie (1980) are generally lower than those for river sturgeon and are useful for distinguishing some lake sturgeon. However, due to more than slight range overlap, scute counts, with one exception, cannot be considered diagnostic. The exception is the lateral scute count between lake and pallid sturgeon (28-42, mean 35, and 39-49, mean 43-45).

Size Relative to Developmental State

Original observations.—Size of pallid sturgeon is similar to or slightly greater than that of shovelnose sturgeon for onset of most developmental events considered (Table 7, Figures 1-7). Exceptions are a notably greater size (TL) among pallid sturgeon for acquisition of: the full complement of fin-ray supports in the dorsal (17 mm versus 14 mm for shovelnose), anal (17 versus 12 mm), pectoral (20 versus 15 mm), and pelvic (16 versus 20 mm) fins; the first fin rays in the anal fin (>30 versus <26 mm) and caudal fin (>26 versus <26 mm); the full complement of fin rays in the caudal fin (>75 versus < 61 mm), pectoral fin (>56 versus <55 mm), and pelvic fin (45-46 versus < 43 mm); and the first ventral scutes (45-46 versus 40-43 mm). In contrast, pallid sturgeon acquire the full complement of scutes in the ventral row at a smaller size than shovelnose sturgeon (>46 to <56 versus >55 to < 61, respectively). Transition from the protolarval to mesolarval phases for both species occurs with acquisition of first fin rays in the dorsal fin between 21 and 26 mm. Transition to the metalarval phase occurs with acquisition of the full complement of caudal fin rays between 75 and 87 mm for pallid sturgeon and between 55 and 61 mm for shovelnose sturgeon. After acquisition of all caudal fin rays, the only character maintaining the fish as metalarvae rather than juveniles is the preanal finfold which is still present on the largest specimens examined, a 130-mm pallid and a 198-mm shovelnose sturgeon. These differences in size at the onset of selected developmental events are useful for identification but only onset of first anal fin rays and full acquisition of caudal fin rays (transition to the metalarval phase) are sufficiently different to consider as primary taxonomic criteria.

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," the striations or radial support structures of the finfold (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 published no such statement; the comment was probably based on Jude's drawing of a 31-mm specimen which appears to have a full complement of dorsal fin pterygiophores but no fin rays. Jude (1982) apparently mistook developing fin-ray supports (median fin pterygiophores and paired fin radials) for developing fin rays which he inappropriately called "actinotrichia" (in Table 7, Jude's data 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 but this aspect of their description and the existence of a "lateral finfold" appear to be in error. 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, the dorso-anterior portion 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 first portion to be completely absorbed (Figure 4). The remaining yolk, which is associated with the stomach, then divides ventrally leaving portions visible only on the right and left sides. In the latter case, there might still be internal yolk above the stomach 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 apparent in the stomach region, although some internal yolk might still remain (Table 7).

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 a few millimeters larger relative to developmental state than either species of river sturgeon (Table 7). 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 loose all finfold and acquire the full complement of fin rays in dorsal, anal, pectoral and pelvic fins before all caudal fin rays are formed. As a result, lake sturgeon, and 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.

Pigmentation

Pigmentation is quite variable but similar for both species (Figures 2-8). 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. No consistent differences were observed except for a strong tendency for shovelnose sturgeon mesolarvae (at least through 40 mm, Figures 7 and 8) to have a dark "Y" pattern of pigment over the hindbrain. 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. This pigment pattern is sometimes also apparent on pallid sturgeon but is never very intense.

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 white. The boundary between between the dark lateral band and the white surfaces below it is quite sharp. In contrast, the lateral pigmentation of river sturgeon extends over the ventrolateral to the ventral surface and the boundary is less distinct boundary. Also the white ventral surface of river sturgeon ends at the vent but continues to well behind the anal fin in lake sturgeon. These differences in the pigmentation of lake and river sturgeon persist in larvae at least as large as 31 mm TL. The size at which these differnces breakdown is unknown but, according to Wallus (1990), by 122 mm TL, the bicolor pattern on lake sturgeon 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, pigmentation is more uniform (no blotches) with that on the dorsal surface being darker than that on the lateral surface between the lateral and ventral series of scutes.

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 the river sturgeons have been reported as April through mid June, and possibly July, but specific seasons are not well documented

(Gilbraith et al. 1988). The pallid sturgeon examined for this study were artificially spawned in mid April whereas both broods of shovelnose sturgeon were spawned in mid June. If there is a strong temporal difference in spawning season for sympatric populations, the identity of protolarvae, and possibly mesolarvae, can be correlated with spawning season.

Conclusions

As expected, the larvae of pallid and shovelnose sturgeon are extremely similar. However, except for recently hatched specimens less than 10 mm TL, many larvae can be at least tentatively identified to species. Table 8 provides a summary of morphological criteria for identification. Beyond recently hatched specimens, the most difficult larvae to identify are protolarvae with yolk and pelvic fin buds (~13-18 mm TL). 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 adult. A couple diagnostic characters were unexpected–the number of spiral-valve turns and inter-lip-lobe distance.

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 highly probable that other specimens in these broods, specimens from other rearings, 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, criteria presented here will be inadequate for positive identification and they will remain "unidentified river sturgeon" (*Scaphirhynchus* sp.). 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.

Under the section Specimens Examined, it was noted that there is concern about the purity of the brood stock used for the pallid sturgeon series examined for this study.

However, if character state intermediacy is assumed for hybrids, any hybrid influence does not appear to be very strong. Inner-barbel length relative to outer-barbel length and dorsal and anal fin-ray counts were found to be diagnostic for juveniles and adults by Bailey and Cross (1954). The values of those characters for the questioned pallid sturgeon mesolarvae and metalarvae in this study are nearly the same as those previously reported for metalarvae, juveniles, and adults by Bailey and Cross (1954). In fact, when considering fin-ray counts, the greatest discrepancies between original observations reported here and previously published data are for shovelnose sturgeon. The two broods of shovelnose used for this study were reared at different temperatures and their fin meristics reflect that difference.

As expected, the larvae of hybrid pallid x shovelnose sturgeon are also very similar to the two parental forms (Figure 9). Among the characters closely examined were fin and scute meristics in late mesolarvae and early metalarvae (Table 6). The only intermediate fin-ray counts for specimens reared at similar temperatures are those for the caudal fin. All other fin-ray counts match those for pallid sturgeon and are at least slightly higher than reported by Carlson et al. (1985). Except for counts of caudal fin rays, neither fin-ray nor scute counts provide suitable criteria for identification of hybrids.

Based on the limited descriptive information available, lake sturgeon larvae should 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 never develop a caudal 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.

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) additional sets of morphometric data for protolarvae without yolk; (3) head and barbel measurements for mesolarvae and metalarvae, including hybrids; (4) determination of the size range 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.–Summary of morphometrics for pallid sturgeon protolarvae reared at Blind Pony Hatchery. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to nearest integers.

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

TABLE 2.– Summary of morphometrics for shovelnose sturgeon protolarvae reared at Gavins Point National Fish Hatchery. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to nearest integers.

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

TABLE 3.--Summary of selected morphometric relationships for pallid sturgeon protolarvae reared at Blind Pony Hatcher including ratios Bailey and Cross (1954) found diagnostic for larger fish. See Figure 1 for abbreviations and diagram of measurements. 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 ± SD	Range	N	Mean ± SD	Range	N	Mean ± SD	Range	N
TL, mm	10 ± 1	9 - 12	9	15 ± 2	12 - 19	13	20 ± 1	19 - 22	5
% of Head Length (snout to origin of pectoral fin, OP1)									
SN to AE	18 ± 4	13 - 23	8	27 ± 4	21 - 35	13	36 ± 5	29 - 42	5
SN to ABI	27 ± 1	26 - 30	6	23 ± 5	16 - 31	13	15 ± 2	13 - 17	5
SN to ABO	29 ± 2	27 - 32	6	25 ± 4	20 - 32	13	19 ± 2	16 - 20	5
SN to AM	37 ± 2	32 - 39	8	47 ± 2	43 - 51	13	52 ± 4	48 - 57	5
AM to ABI	16 ± 11	8 - 36	8	24 ± 5	15 - 33	13	36 ± 2	34 - 40	5
Head Width at AM	49 ± 3	43 - 53	8	65 ± 4	57 - 72	13	78 ± 2	74 - 80	5
M Width				48 ± 4	40 - 54	13	55 ± 2	51 - 57	5
MO Width	21 ± 6	13 - 30	8	37 ± 4	29 - 43	13	43 ± 3	39 - 46	5
ILL Width				6 ± 2	3 - 9	13	4 ± 1	2 - 6	5
IOR Width	25 ± 4	19 - 31	8	41 ± 6	31 - 49	13	50 ± 3	45 - 52	5
BI Length	6 ± 1	5 - 7	6	19 ± 5	11 - 28	13	29 ± 2	28 - 32	5
BO Length	9 ± 1	8 - 11	6	27 ± 9	17 - 44	13	47 ± 2	45 - 50	5
Eye Diameter	14 ± 1	13 - 16	8	15 ± 1	13 - 17	13	13 ± 0	13 - 14	5
% of SN to AM Length (snout to anterior margin of mouth opening)									
SN to ABI	73 ± 4	67 - 78	6	49 ± 11	33 - 66	13	30 ± 2	26 - 32	5
BI Length	16 ± 2	15 - 19	6	41 ± 11	25 - 57	13	56 ± 3	51 - 59	5
Eye Diameter	38 ± 5	30 - 44	9	32 ± 3	26 - 37	13	26 ± 2	23 - 27	5
% of SN to ABO Length (snout to anterior base of barbel, outer)									
SN to ABI	96 ± 3	92 - 100	6	93 ± 6	79 - 103	13	83 ± 6	74 - 88	5
% of BO Length (barbel, outer)									
BI Length	68 ± 3	61 - 70	6	71 ± 9	60 - 91	13	62 ± 5	57 - 68	5
% of M Width (mouth, between outer limits of lips)									
ILL Width				14 ± 4	8 - 21	13	7 ± 2	5 - 11	5
AM to ABI				49 ± 9	33 - 66	13	67 ± 4	62 - 70	5
BI Length				40 ± 9	25 - 53	13	53 ± 3	50 - 56	5
Measurement Ratios "Similar" to Those of Bailey and Cross (1954) Given Below									
AM to ABI in SN to ABO	2.9 ± 0.5	2.2 - 3.7	6	1.1 ± 0.5	0.6 - 2.0	13	0.5 ± 0.0	0.5 - 0.6	5
AM to ABI in M Width				2.1 ± 0.4	1.5 - 3.0	13	1.5 ± 0.1	1.4 - 1.6	5
AM to ABI in SN to PO	5.1 ± 2.8	1.5 - 8.9	9	4.0 ± 0.6	3.1 - 5.1	13	3.0 ± 0.2	2.8 - 3.2	5
BI Length in SN to ABO	4.8 ± 0.4	4.2 - 5.2	6	1.5 ± 0.7	0.7 - 2.8	13	0.6 ± 0.0	0.6 - 0.7	5
BI Length in BO Length	1.5 ± 0.1	1.4 - 1.6	6	1.4 ± 0.2	1.1 - 1.7	13	1.6 ± 0.1	1.5 - 1.8	5
BI Length in SN to PO	11.6 ± 0.8	10.3 - 12.6	6	5.1 ± 1.0	3.7 - 7.0	13	3.7 ± 0.2	3.4 - 3.8	5

Measurement Ratios Found Diagnostic by Bailey and Cross (1954, Fig. 9, Table 4)[a]

	Sm. Juveniles, 100 to 200 mm SL		Juveniles & Adults,>200 mm SL		
Mouth to inner barbel in snout to outer barbel (b in a)	2.4	1	2.9	2.3 - 3.3	12
Mouth to inner barbel in mouth width (including lips, b in e)	1.7	1	1.8	1.6 - 2.0	12
Mouth to inner barbel 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	3.3	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

[a] 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 4.--Summary of selected morphometric relationships for shovelnose sturgeon protolarvae reared at Gavins Point National Fish Hatchery, including ratios Bailey and Cross (1954) found diagnostic for larger fish. See Figure 1 for abbreviations and diagram of measurements. 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 ± SD	Range	N	Mean ± SD	Range	N	Mean ± SD	Range	N
TL, mm	10 ± 1	9 - 12	8	15 ± 2	13 - 17	12	19 ± 1	18 - 21	6
% of Head Length (snout to origin of pectoral fin, OP1)									
SN to AE	19 ± 3	14 - 22	6	29 ± 4	23 - 34	12	36 ± 4	31 - 40	6
SN to ABI	28 ± 3	24 - 34	6	21 ± 3	16 - 26	12	16 ± 2	14 - 17	6
SN to ABO	30 ± 3	27 - 34	6	23 ± 3	18 - 28	12	18 ± 1	16 - 19	6
SN to AM	40 ± 4	35 - 45	6	46 ± 2	42 - 51	12	52 ± 3	47 - 56	6
AM to ABI	12 ± 5	7 - 18	6	26 ± 5	20 - 34	12	36 ± 4	31 - 42	6
Head Width at AM	53 ± 6	43 - 59	8	64 ± 3	59 - 68	12	76 ± 5	69 - 82	6
M Width				49 ± 2	45 - 53	12	52 ± 5	46 - 59	6
MO Width	29 ± 4	22 - 35	8	38 ± 3	34 - 43	12	41 ± 3	36 - 45	6
ILL Width				7 ± 2	3 - 11	12	8 ± 2	6 - 11	5
IOR Width	29 ± 4	23 - 36	8	41 ± 5	33 - 49	12	50 ± 4	46 - 55	6
BI Length	10 ± 2	8 - 13	6	22 ± 4	17 - 30	12	32 ± 5	28 - 40	6
BO Length	11 ± 3	8 - 15	6	29 ± 8	18 - 41	12	36 ± 8	24 - 46	6
Eye Diameter	17 ± 3	13 - 20	6	16 ± 1	14 - 18	12	15 ± 1	14 - 17	6
% of SN to AM Length (snout to anterior margin of mouth opening)									
SN to ABI	71 ± 10	58 - 81	6	45 ± 8	33 - 55	12	30 ± 4	25 - 34	6
BI Length	24 ± 4	19 - 31	6	48 ± 7	37 - 59	12	62 ± 12	51 - 86	6
Eye Diameter	42 ± 2	38 - 45	6	36 ± 3	30 - 40	12	29 ± 3	26 - 36	6
% of SN to ABO Length (snout to anterior base of barbel, outer)									
SN to ABI	93 ± 4	88 - 99	6	89 ± 3	81 - 93	12	87 ± 7	77 - 97	6
% of BO Length (barbel, outer)									
BI Length	88 ± 11	77 - 109	6	78 ± 12	55 - 95	12	92 ± 23	66 - 129	6
% of M Width (mouth, between outer limits of lips)									
ILL Width				14 ± 4	8 - 21	12	15 ± 3	11 - 20	5
AM to ABI				52 ± 8	42 - 68	12	69 ± 8	58 - 78	6
BI Length				45 ± 7	37 - 59	12	62 ± 14	50 - 88	6
Measurement Ratios "Similar" to Those of Bailey and Cross (1954) Given Below									
AM to ABI in SN to ABO	2.9 ± 1.2	1.6 - 4.5	6	0.9 ± 0.3	0.6 - 1.3	12	0.5 ± 0.1	0.4 - 0.6	6
AM to ABI in M Width				2.0 ± 0.3	1.5 - 2.4	12	1.5 ± 0.2	1.3 - 1.7	6
AM to ABI in SN to PO	6.8 ± 2.1	4.5 - 9.6	6	3.8 ± 0.5	3.0 - 4.3	12	3.0 ± 0.3	2.6 - 3.4	6
BI Length in SN to ABO	3.2 ± 0.7	2.1 - 3.9	6	1.1 ± 0.3	0.7 - 1.6	12	0.6 ± 0.1	0.4 - 0.7	6
BI Length in BO Length	1.2 ± 0.1	0.9 - 1.3	6	1.3 ± 0.2	1.1 - 1.8	12	1.1 ± 0.3	0.8 - 1.5	6
BI Length in SN to PO	7.6 ± 1.1	6.1 - 9.3	6	4.4 ± 0.5	3.4 - 5.1	12	3.4 ± 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		
Mouth to inner barbel in snout to outer barbel (b in a)	1.5	1.3 - 1.7	6	1.6	1.3 - 2.2	47
Mouth to inner barbel in mouth width (including lips, b in e)	1.3	1.2 - 1.4	6	1.3	1.1 - 1.4	47
Mouth to inner barbel 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 5.--Summary of meristics for pallid sturgeon protolarvae reared at Blind Pony Hatchery and shovelnose sturgeon protolarvae reared at Gavins Point National Fish Hatchery with comparable myomere counts for river sturgeon (probably shovelnose) and lake sturgeon from published accounts. See Figure 1 for abbreviations and diagram of measurements. Data are rounded to nearest integers.

	Protolarvae with yolk, no pelvic buds			Protolarvae with yolk and pelvic buds			Protolarvae without yolk		
	Mean ± SD	Range	N	Mean ± SD	Range	N	Mean ± SD	Range	N
Pallid Sturgeon									
TL, mm	10 ± 1	9 - 12	9	15 ± 2	12 - 19	13	20 ± 1	19 - 22	5
Myomeres									
Preanal	37 ± 1	36 - 39	9	36 ± 1	35 - 37	13	36 ± 1	36 - 37	3
Postanal	21 ± 2	19 - 24	9	21 ± 1	20 - 22	13	20 ± 1	19 - 21	3
Total	59 ± 2	56 - 63	9	57 ± 1	56 - 58	13	56 ± 1	55 - 57	3
Fin Ray Supports									
D	11 ± 1	10 - 11	2*	14 ± 2	11 - 17	13	16 ± 1	15 - 18	5
A	4 ± 1	3 - 5	2*	9 ± 1	6 - 10	13	10 ± 1	9 - 11	5
P1				7 ± 1	4 - 8	11*	9 ± 1	8 - 10	5
P2				7 ± 1	6 - 8	5*	9 ± 1	8 - 10	5
Spiral Valve Turns	5 ± 0	5 - 6	8	5 ± 1	5 - 6	13	6 ± 0	6 - 6	5
Shovelnose Sturgeon									
TL, mm	10 ± 1	9 - 12	8	15 ± 2	13 - 17	12	19 ± 1	18 - 21	6
Myomeres									
Preanal	36 ± 0	35 - 36	8	34 ± 1	33 - 36	12	35 ± 0	34 - 35	6
Postanal	21 ± 2	20 - 25	8	21 ± 1	20 - 21	12	21 ± 1	20 - 22	6
Total	57 ± 2	55 - 60	8	55 ± 1	53 - 57	12	56 ± 1	55 - 57	6
Fin Ray Supports									
D	11 ± 2	9 - 12	3*	13 ± 1	12 - 15	12	14 ± 0	14 - 15	6
A	6 ± 3	4 - 9	3*	9 ± 1	7 - 10	12	10 ± 1	9 - 10	6
P1				10 ± 0	9 - 10	7*	10 ± 0	9 - 10	6
P2				8 ± 1	7 - 9	6*	9 ± 0	8 - 9	6
Spiral Valve Turns	6 ± 1	5 - 7	8	7 ± 1	6 - 8	12	7 ± 0	7 - 7	3
Published Myomere Counts for Comparison									
	River (Shovelnose?) Sturgeon (Carlson 1983)			Lake Sturgeon (Carlson 1983)			Lake Sturgeon (Jude 1982 & Wallus 1990))		
TL, mm		8 - 19	10		11 - 21	15		11 - 12	
Preanal	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	

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

TABLE 6.—Summary of fin-ray and scute (bony-plate) counts for shovelnose, pallid, pallid x shovelnose hybrid, and lake sturgeons from original observations[a] (Orig.) and published accounts (Lit). Where appropriate and notable, mean and modal counts are underlined and rare or questionable extremes are enclosed in parentheses.

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

[a] 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).

[b] 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 - Vladykov and Beaulieu (1946); f - Jollie (1980); g - Jude (1982); h - Dadswell et al. (1984); i - Scott and Crossman (1973); j - Smith (1985); k - Vladykov 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.

[c] 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).

[d] 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).

[e] 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).

[f] Comparable caudal fin ray counts for pallid sturgeon mesolarvae 67-75 mm TL (N=4) were 55-57-59 and for hybrid mesolarvae 58-68 mm TL (N=4), 52-54-57; these counts suggest that the adult complement, and therefore transition to the metalarval phase, is achieved between 75 and 87 mm TL for pallid sturgeon and between 68 and about 72 mm TL for the hybrid initially reared under similar conditions. Transition appears to occur at < 61mm TL for shovelnose sturgeon.

[g] Comparable lateral and ventral scute counts for hybrid sturgeon 58-68 mm TL (N=4) were 39-41-43 and 8-9-10, respectively; apparently incomplete.

TABLE 7.—Size (mm TL, total length) and age (from hatching)[a] at apparent onset of selected developmental events for shovelnose, pallid, and lake sturgeons. Except as footnoted, data for shovelnose and pallid sturgeons are original observations of specimens reared respectively by Gavins Point National Fish Hatchery in 1989 (<22 mm TL) and 1992 (>25 mm TL) and by Blind Pony Hatchery in 1992. 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 Size (mm TL)	Pallid Sturgeon Age (d)[a]	Shovelnose Sturgeon Size (mm TL)	Shovelnose Sturgeon Age (d)[a]	Lake Sturgeon Size (mm TL)	Lake Sturgeon Age (d)[a]
Hatching	(7)8-9	0	7[b]- 9	0	(7)8-12[b,c,d]	0
Eyes Well Pigmented	10	2	10, (12[b])	2	14[b,c]	
Barbel Buds Formed	10	2	9	1	12-13[e],14[b],15[c]	2-3[d],3-4[e]
Pectoral Buds Formed	9	0-1	9, (13[b])	0	11[e]-12[c]	2-3[d]
Pelvic Buds Formed	12	5	12-13, (<15[b])	4	16[c], <18[b]-18[d]	4[e]
All Yolk Absorbed[f]	19	11	(12[b,f]), 18	11	(17[b,f]),19[g]-21[c], 23[e]	<9-10[c,d],8-39[g]
All Finfold Absorbed	>130	>71	>140[e], >198	>73	>75[c,e]	
			First Element(s) Present			
Fin Ray Supports,						
Dorsal	12	4	11, (<14[b])	3	15-17[b,c]	
Anal	12	4	11	3	18-19[c]	
Pectoral	13	6	15	6	>19[c], ≤22[c]	
Pelvic	16	8	15	6		
Fin Rays,						
Dorsal	>22, <26	>14, <17	(19[b]), >21, <26	>15, <21	>31[c], <75[c,h]	
Anal	>30, <34	>19, <22	>21, <26	>15, <21	>31[c], <75[c,h]	
Caudal	>26, <30	18	>21, <26	>15, <21	>31[c], <75[c,h]	
Pectoral	>22, <26	>14, <17	>21, <26	>15, <21	>31[c], <42[c]	7-8[d]
Pelvic	>30, <34	>19, <22	>31, <34	>21, <24	>31[c], <75[c,h]	13-14[d]
Scute Series,						
Dorsal	>22, <26	>14, <17	>21, <26	>15, <21	>27[c], <31[c]	
Lateral	>26, <30	18	>26, <31	>21, <24	>31[c], <75[c,h]	
Ventral	45-46	33	40-43	24	>31[c], <75[c,h]	
			Full Complement Present			
Fin Ray Supports,						
Dorsal	17	9	14	5	<31[c]	
Anal	17	9	12	3	<31[c]	
Pectoral	20	10	15	6		
Pelvic	20	11	16	7		
Fin Rays,						
Dorsal	>34, <40	>22, <26	>34, <40	>21, <24	(<31[b]), >31[c]	
Anal	>41, <45	>26, <33	>40, <43	24	>31[c], <123[e]	
Caudal	>75, <87	>43,<71	>55,<61	>31, <35	>31[c], <123[e]	
Pectoral	>56, <67	>36, <43	>48, <55	>24, <31	>75[c], <123[e]	
Pelvic	45-46	33	>40, <43	24	>31[c], <123[e]	
Scute Series,						
Dorsal	>22, <26	>14, <17	>21, <26	>15, <21	>27[c], ≤31[c]	
Lateral	>41, <45	>26, <33	>43, <48	24	>31[c], <123[e]	
Ventral	>46, <56	34	>55, <61	>31, <35	>31[c], <123[e]	

[a] 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.

[b] Carlson (1983).

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

[d] Harkness and Dymond (1961).

[e] Wallus (1990).

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

[g] Wang et al. (1985), age data based on specimens reared at 10, 15 and 20°C

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

(continued)

TABLE 8.—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 or slightly behind vent)	2%	≥3% (dorsal fin a bit further behind vent)
Spiral Valve Turns			
Count	5	6[c]	7
Mesolarvae (23, 24, or 25 to between 55 and 87 mm TL)			
Inner Barbel Length (BI)[e]			
as % outer barbel length (BO)	*≤65%*	*66-68%*	*≥69%*
times in outer barbel length (BO)	*≥1.6*	*1.5*	*≤1.4*
Dorsal Fin Pterygiophores			
Count	*≥16*	*15*	*≤14*
First Anal Fin Rays[h]			
Total length when first present	*≥31, ≤33 mm*		*≥22, ≤25 mm*
Dorsal Fin Rays (only larvae >between 34 and 40 mm TL)			
Count	≥40	35-39[f]	≤34
Anal Fin Rays (only larvae >between 40 and 45 mm TL)			
Count	≥26	24-25[f]	≤23
First Caudal Fin Rays[h]			
Total length when first present	≥27, ≤29 mm		≥22, ≤25 mm
Full Complement of Pectoral Fin Rays[h]			
Total length when first present	≥57, ≤66 mm		≥49, ≤54 mm
Full Complement of Pelvic Fin Rays[h]			
Total length when first present	45-46 mm		≥41, ≤42 mm
First Ventral (Ventrolateral) Scutes[h]			
Total length when first present	45-46 mm		40-43 mm
Full Complement of Ventral Scutes[h]			
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)	Moderate to Dark		Absent to Light
Metalarvae and Older Fish (>between 55 and 87 mm TL)			
Inner Barbel Length (BI)[g]			
as % outer barbel length (BO)	*≤63%*		*≥67%*
times in outer barbel length (BO)	*≥1.6*		*≤1.5*
Caudal Fin Rays			
Count	*≥66*	*64-65*	*≤63*
Full Complement of Caudal Fin Rays[h] *(beginning of metalarval phase)*			
Total length when first present	*≥76, ≤86 mm*		*≥56, ≤60 mm*
Dorsal Fin Rays			
Count	≥40	35-39[f]	≤34
Anal Fin Rays			
Count	≥26	24-25[f]	≤23

[a] Specimens less than 10 mm TL are not distinguishable by morphological criteria.
[b] Includes the mean values for both species.
[c] Includes the mean value for pallid sturgeon.
[d] Includes the mean value for shovelnose sturgeon.
[e] Extension of measurements for protolarvae without yolk justified on basis of similar results for older fish by Bailey and Cross (1954).
[f] Includes at least some mean or modal values for both species.
[g] Data from or calculated from Bailey and Cross (1954).
[h] 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.

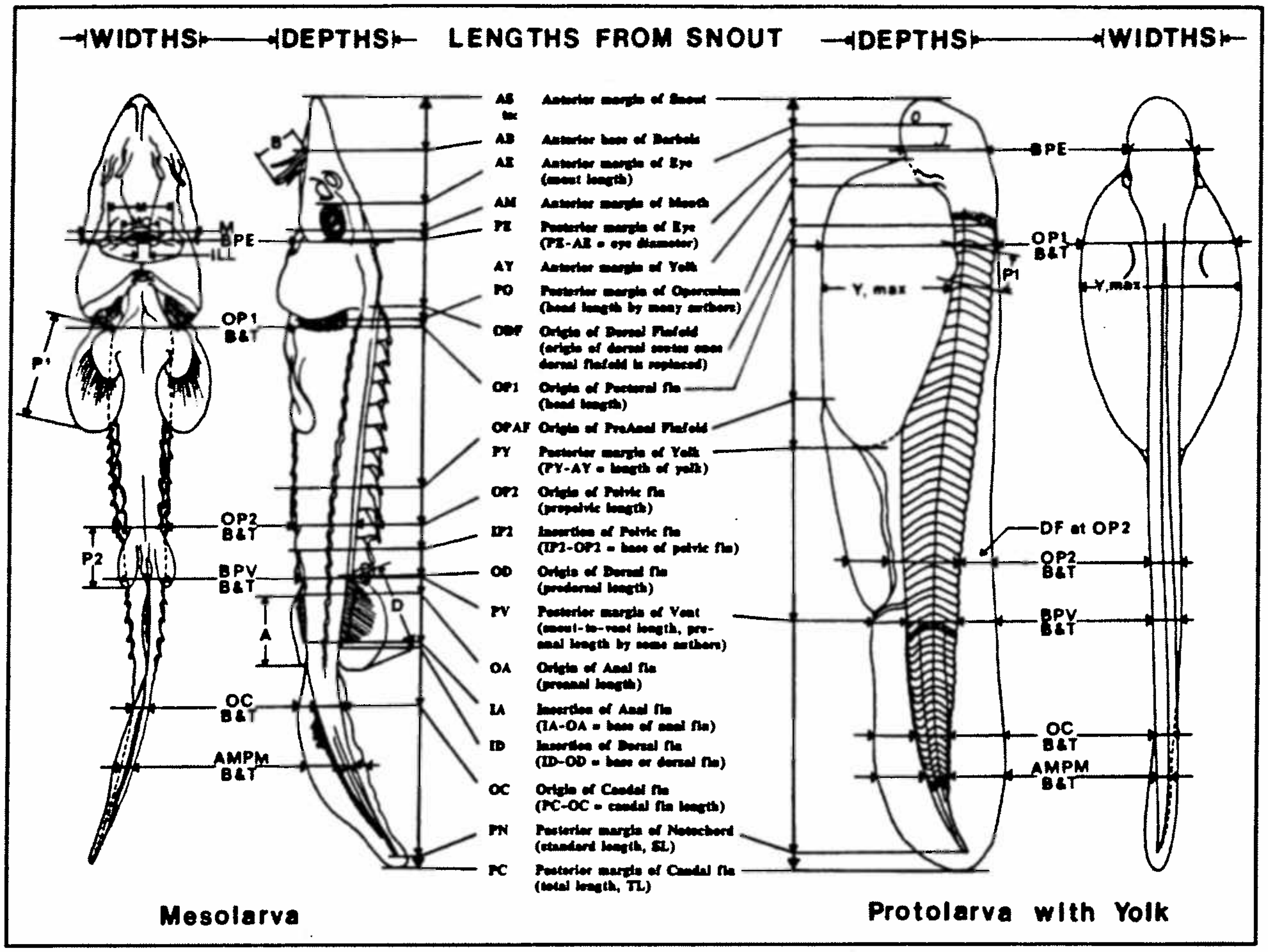

FIGURE 1.—Measurements used in morphometric analysis of sturgeon larvae. First preanal and first and last postanal myomeres stippled in lateral view of protolarva. Abbreviations not defined above are: **B**–barbel (length, BI for inner barbel, BO for outer barbel); **A**, **D**, **P1**, and **P2**–anal, 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.

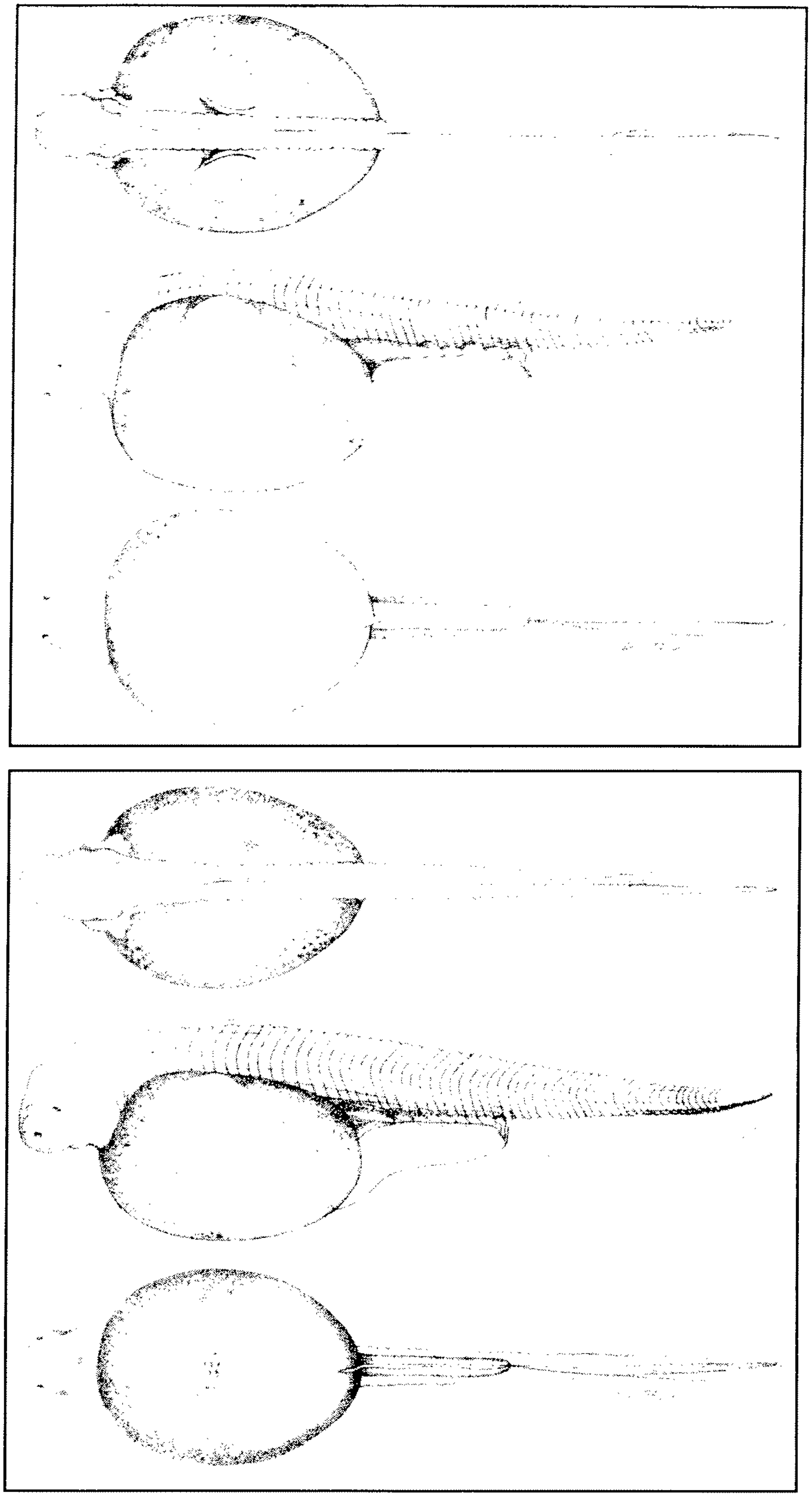

FIGURE 2.—Sturgeon protolarvae with yolk, 0 to 1 d after hatching. **Above:** pallid sturgeon, 8.7 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 27 April 1992. **Below:** shovelnose sturgeon, 9.1 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched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

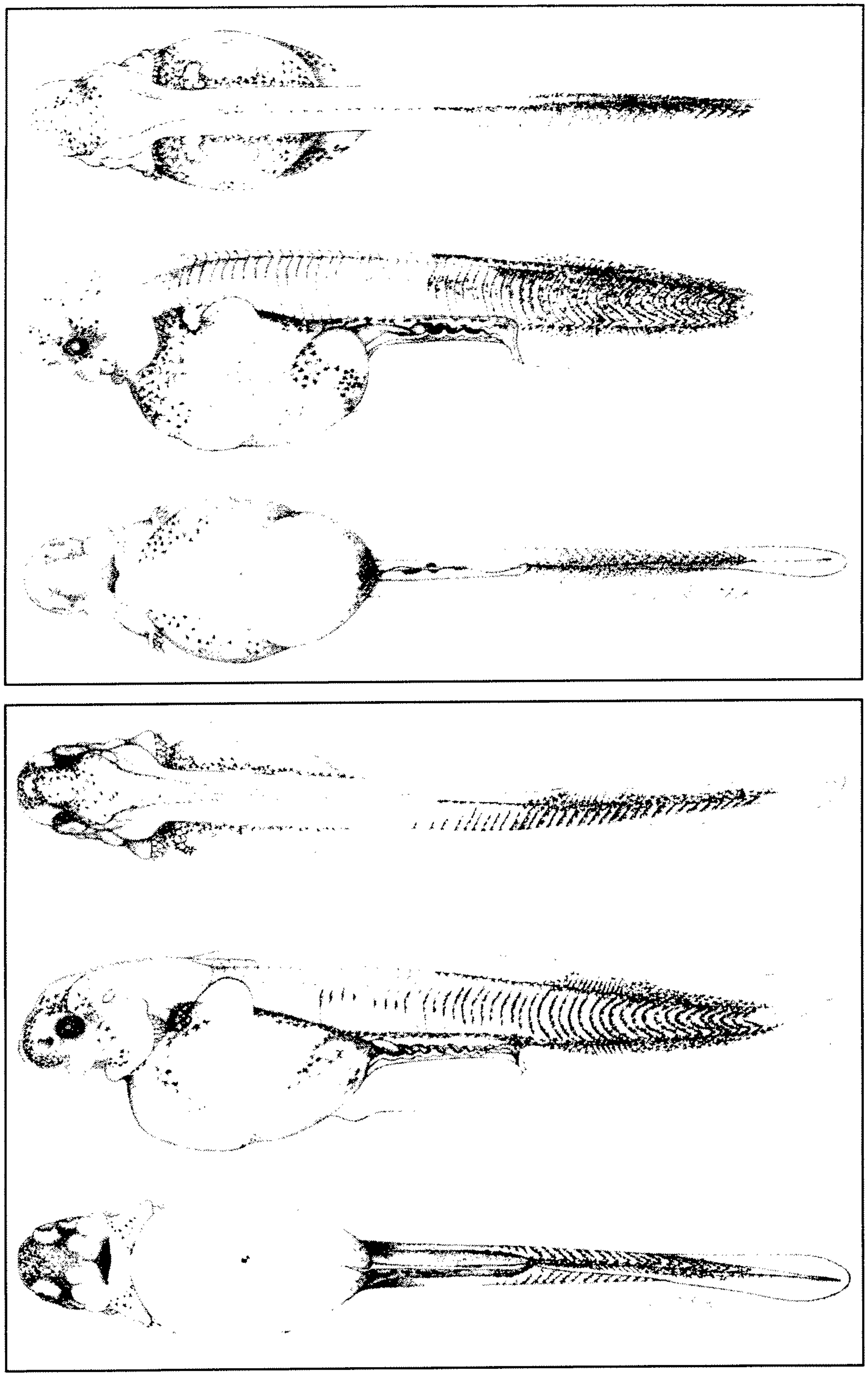

FIGURE 3.—Sturgeon protolarvae with yolk, 3 to 4 d after hatching. **Above:** pallid sturgeon, 11.7 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 30 April 1992. **Below:** shovelnose sturgeon, 11.6 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched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

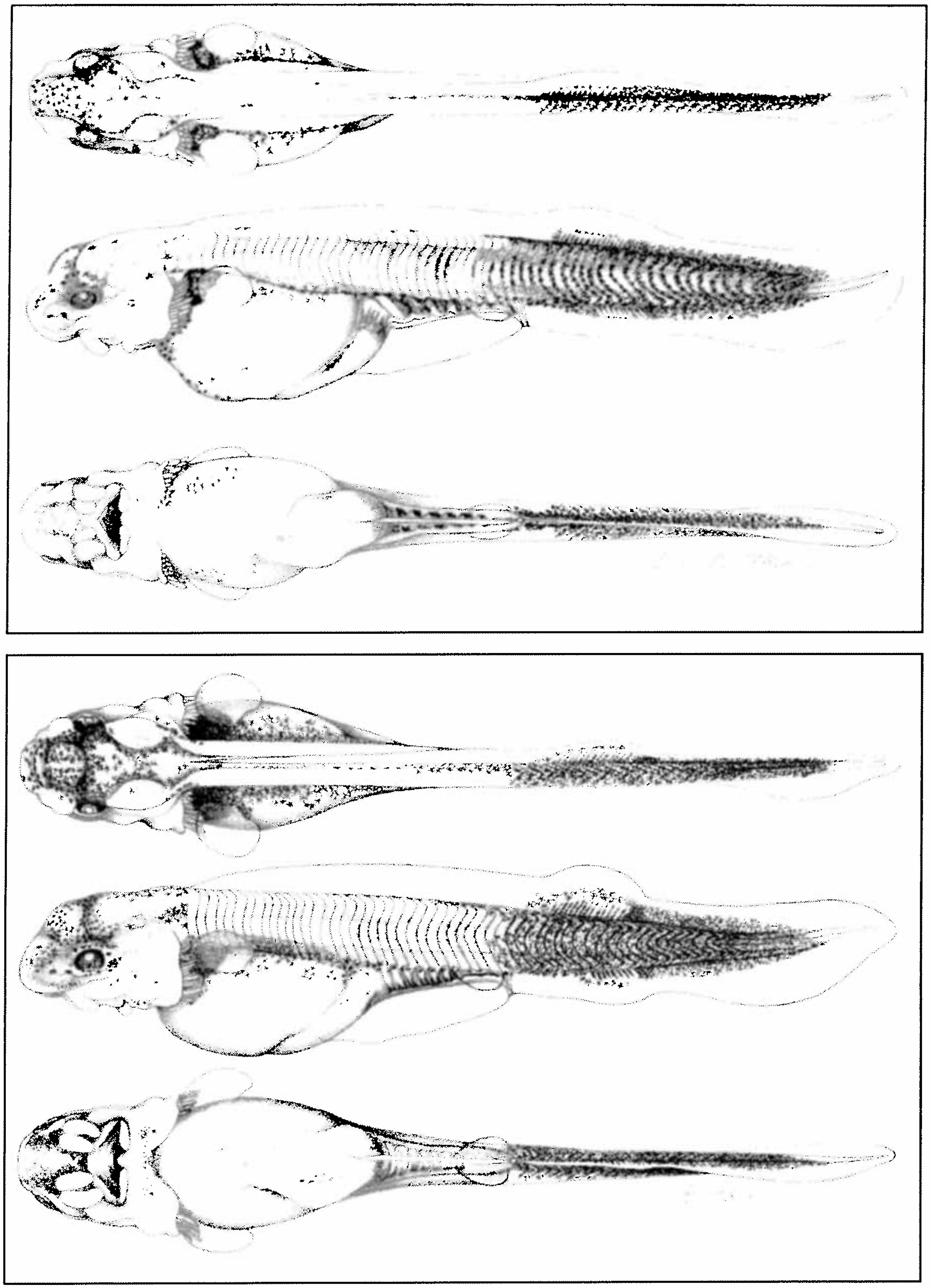

FIGURE 4.—Sturgeon protolarvae with yolk and pelvic buds, 5 to 6 d after hatching. **Above:** pallid sturgeon, 13.9 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 2 May 1992. **Below:** shovelnose sturgeon, 13.6 mm TL, reared at Gavins Point NFH, fertilized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

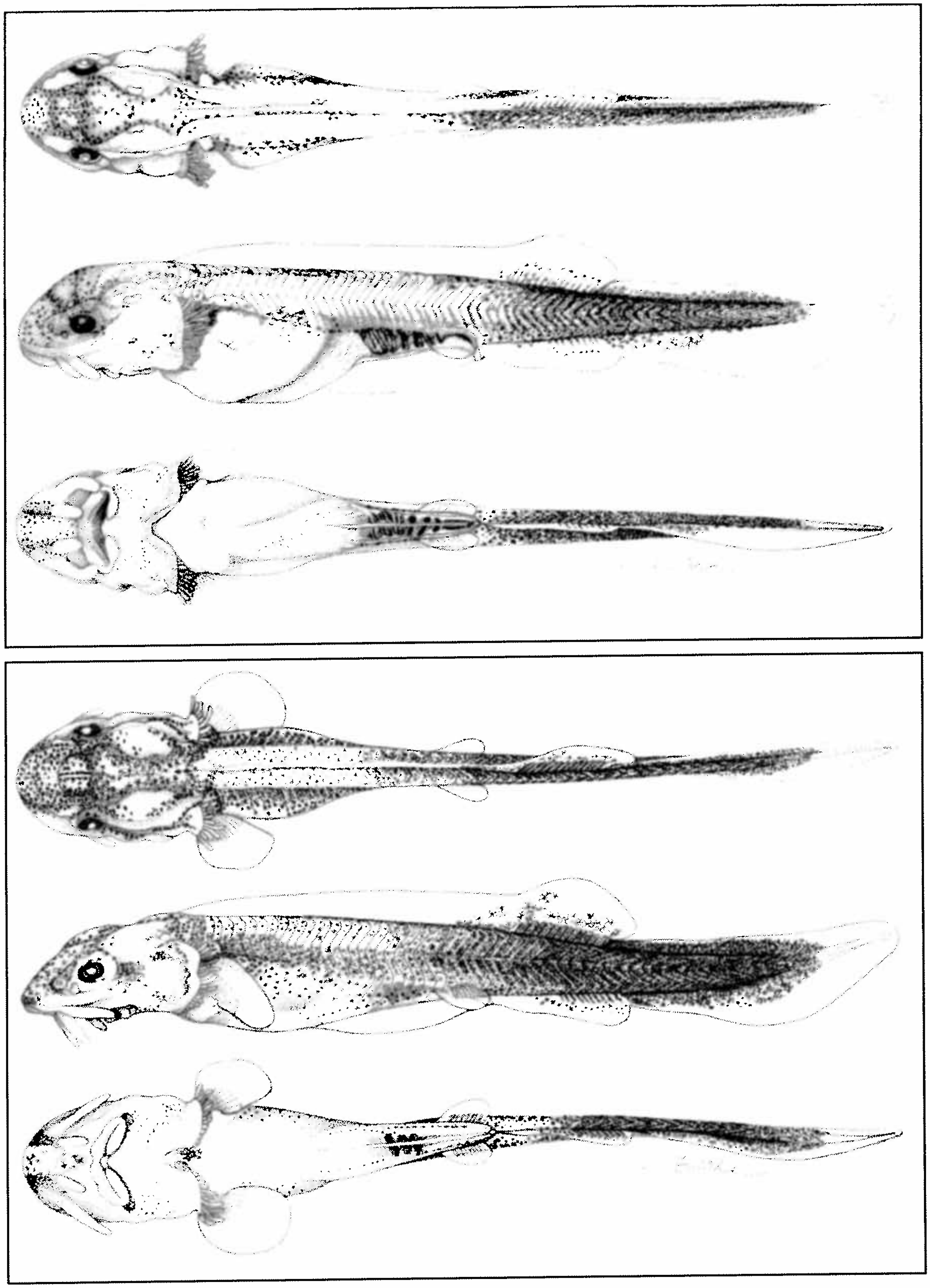

FIGURE 5.—Sturgeon protolarvae with yolk and pelvic fin buds, 7 to 8 d after hatching. **Above**: pallid sturgeon, 16.2 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 4 May 1992. **Below**: shovelnose sturgeon, 15.9 mm TL, reared at Gavins Point NFH, fertilized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

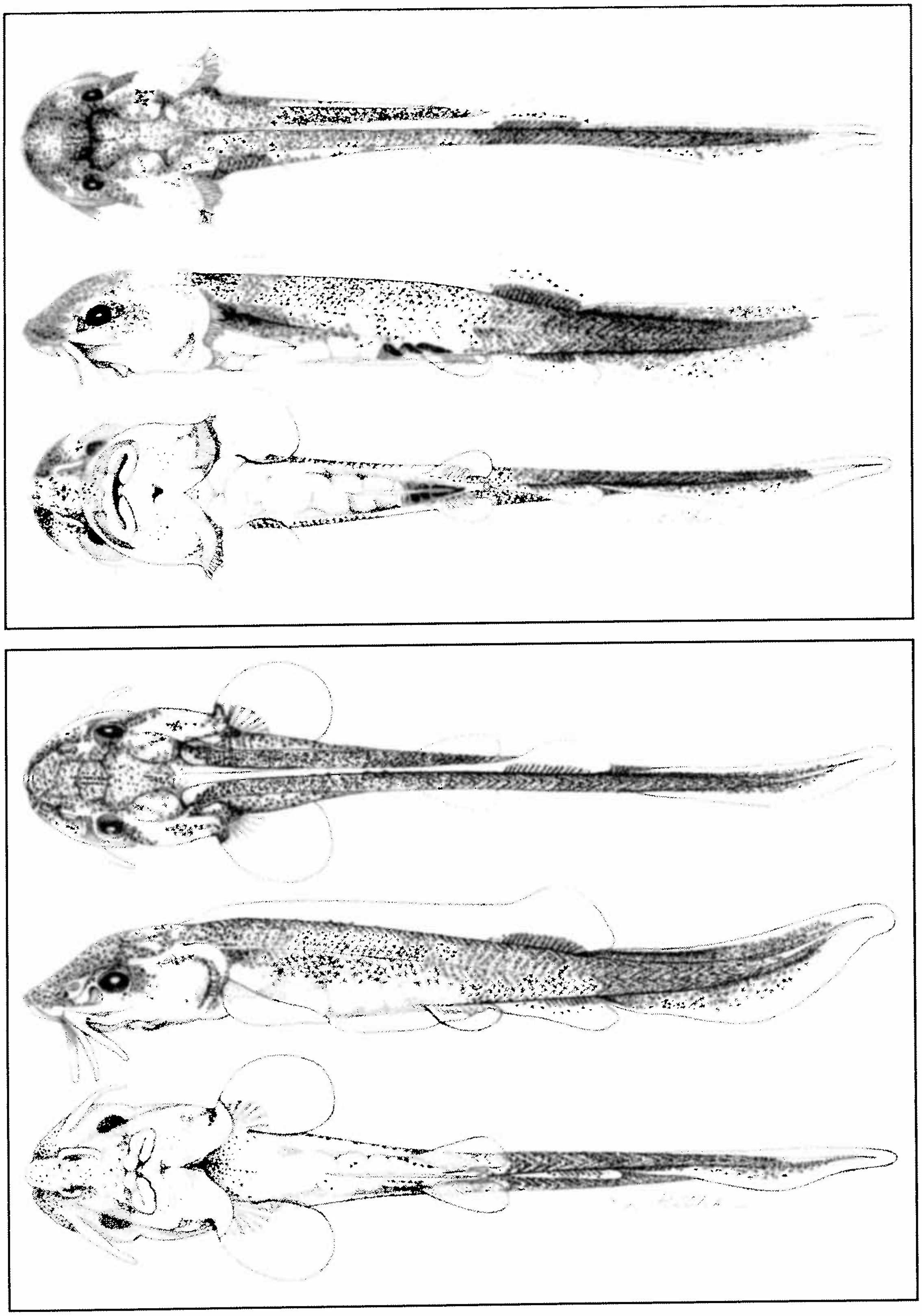

FIGURE 6.—Sturgeon protolarvae without yolk, 11 d after hatching. **Above:** pallid sturgeon, 19.1 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 7 May 1992. **Below:** shovelnose sturgeon, 19.1 mm TL, reared at Gavins Point NFH, fertilized 10 June, hatched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

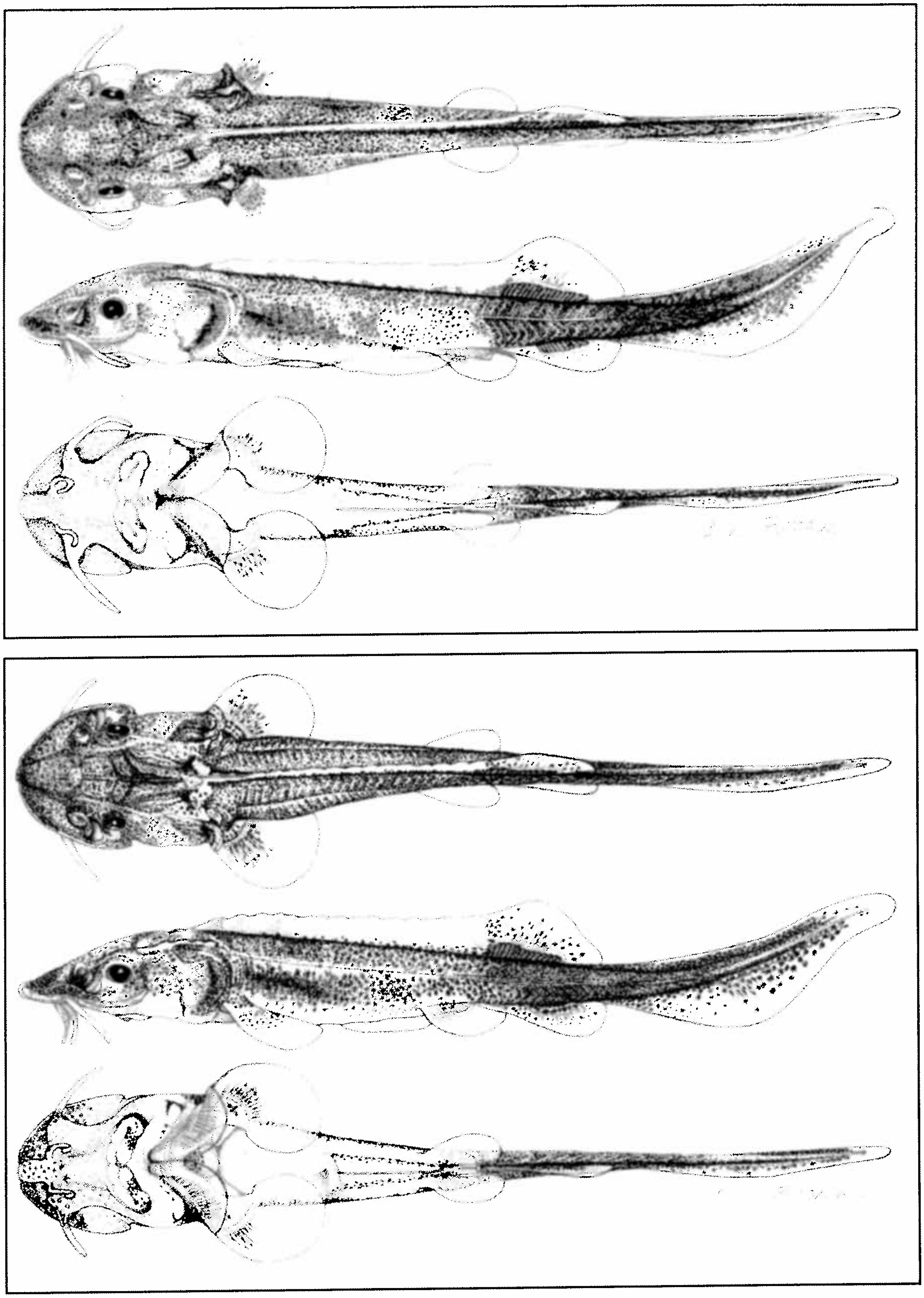

FIGURE 7.—Sturgeon mesolarvae, 17 to 21 d after hatching. **Above:** pallid sturgeon, 26 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 13 May 1992. **Below:** shovelnose sturgeon, 26 mm TL, reared at Gavins Point NFH, fertilized 12 June, hatched ~23 June,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

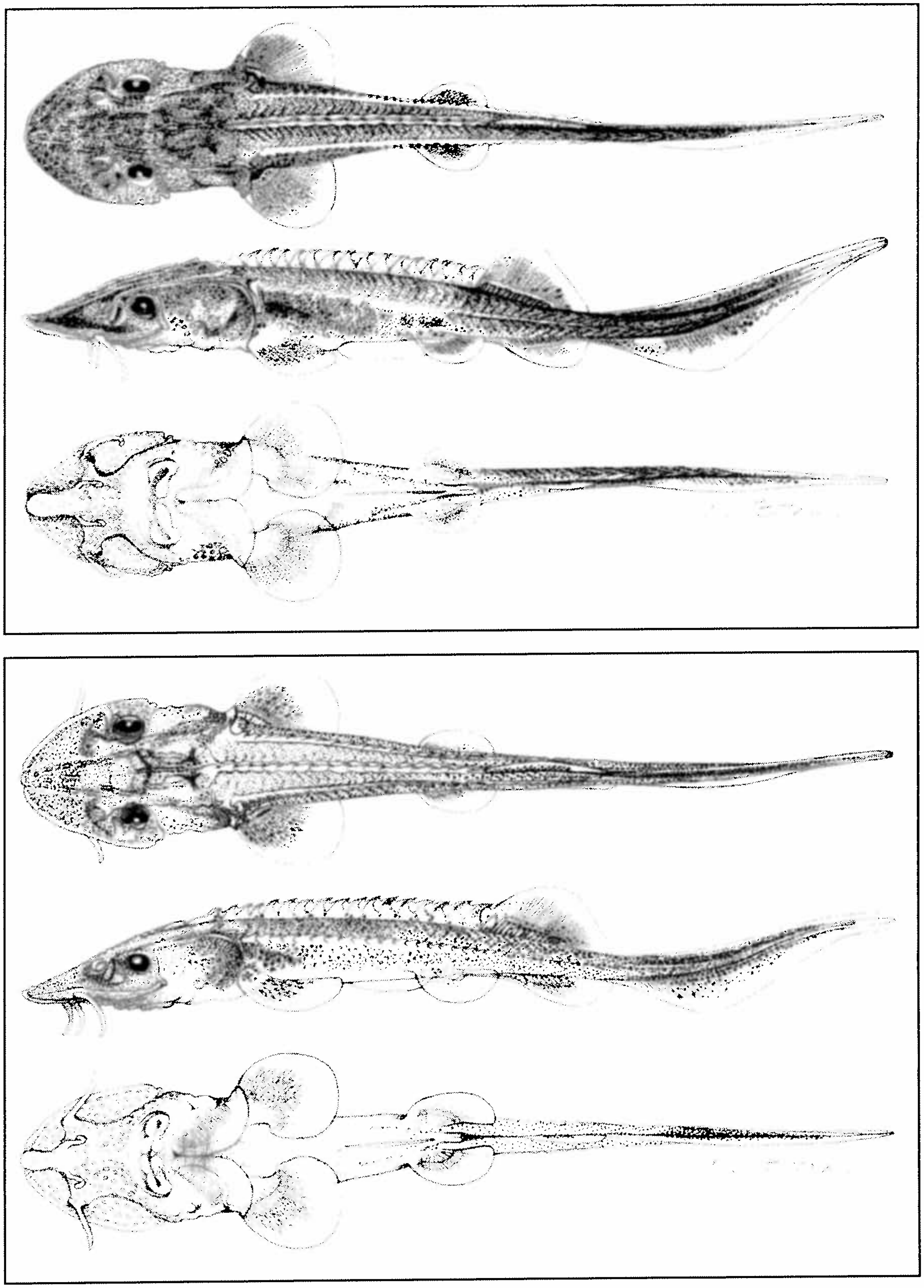

FIGURE 8.—Sturgeon mesolarvae, 24 to 26 d after hatching. **Above:** pallid sturgeon, 41 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 22 May 1992. **Below:** shovelnose sturgeon, 40 mm TL, reared at Gavins Point NFH, fertilized 12 June, hatched ~23 June,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

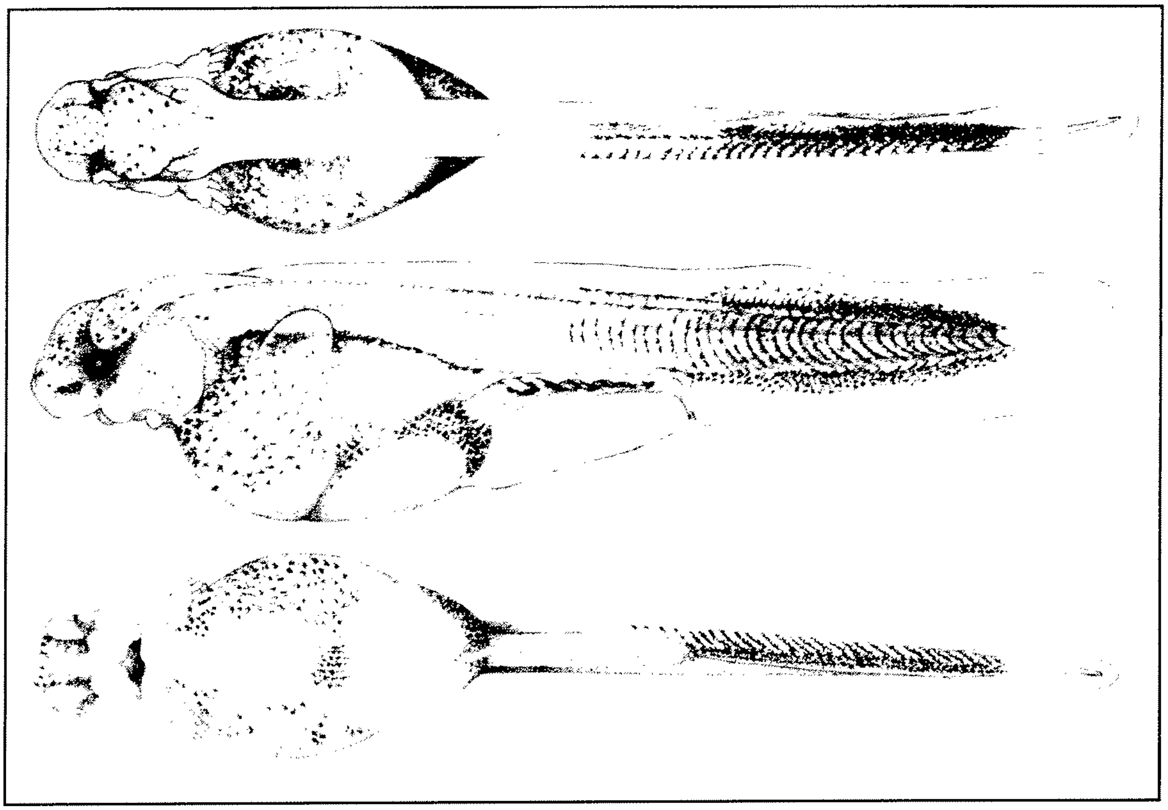

FIGURE 9.—Hybrid pallid x shovelnose sturgeon protolarva with yolk, 5 d after hatching. Specimen 11.8 mm TL, reared at Blind Pony Hatchery, fertilized 19 April, hatched 26 April, and preserved 1 May 1992.