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Morphological Description of Alligator Gar and Tropical Gar Larvae, with an Emphasis on Growth Indicators

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Abstract.—Populations of the alligator gar *Lepisosteus spatula* (also known as *Atractosteus spatula*) and the tropical gar *L. tropicus* are declining as a result of commercial and sport fisheries and habitat alteration. Aquaculture represents a short-term approach to population restoration but requires an understanding of the nutritional requirements of early life stages. This paper describes the larval development and growth rates of the alligator gar and tropical gar and identifies morphological indicators of growth and nutritional condition during early life stages. A light-colored dorsal stripe distinguished alligator gar larvae (23–130 mm total length [TL]), whereas tropical gar larvae (22–60 mm TL) could be identified by a pair of brown and yellow lines on the flanks. Larvae of both species adhered to vegetation through the fourth day after hatching (DAH) and began to swim and feed on the fifth DAH. The growth rate of alligator gar larvae was 1.55 mm/d until 10 DAH and 5.06 mm/d thereafter until 15 DAH, when alligator gar larvae averaged 48.6 ± 1.5 mm TL. The growth rate of tropical gar larvae was 1 mm/d until 15 DAH, when these larvae averaged 20.5 ± 0.7 mm TL. A stepwise discriminant analysis suggested that snout length, body depth at the pectoral fins, caudal peduncle depth, and snout width at the anterior margin of the eyes were the best morphometric characteristics for evaluating the growth of gar larvae. Starved larvae of both species stopped growing by 8 DAH, suggesting that yolk reserves were exhausted by that time and indicating a mixed nutrition phase (i.e., lecithoexotrophic) between 5 and 8 DAH. Stepwise discriminant analysis determined that caudal peduncle depth, head width, and preanal depth measured after 8 DAH were the best morphometric indicators of the nutritional condition of gar larvae. Relatively dark body pigmentation also characterized starved larvae.

Alligator gar *Lepisosteus spatula* (also known as *Atractosteus spatula*) and tropical gar *L. tropicus* populations have recently declined due to pressure by commercial and sport fisheries (Simon and Wallus 1989; Gilbert 1992; Mendoza et al. 2000b). Commercial catches of individual alligator gars weighing from 18 to 56 kg in Lake Texoma, Oklahoma, were common between 1944 and 1954; however, due to serious population declines, no adults were caught in 1964 and 1965 (May and Echelle 1968). The alligator gar has supported a commercial fishery in Louisiana for the last century, and more recently has been highly sought for sport fishing in Louisiana, Arkansas, and Mississippi (Suttkus 1963). In Mexico, alligator gars have traditionally been captured in the northeastern region, where they are valued for their size and the quality of their flesh (Rosas 1976; SEPESCA-INP 1994). Recent fisheries statistics indicate that alligator gar populations have been declining (Mendoza et al. 2000b). Variation in alligator gar population size has been noted in Tamaulipas, where mean annual captures were estimated as 13.2 tons in 1988 and 5.7 tons in 1990. In 1997, fishers in Tamaulipas captured only 1.1 tons.

The tropical gar is still relatively abundant and traditionally has been consumed in Tabasco, Mexico, where the species is one of five main fisheries resources. Captures of the tropical gar peaked at 530.6 tons in 1996, but declined to only 219 tons in 1999. The largest captures of the alligator gar and tropical gar in Mexico occur during the spawning season (Resendez and Salvadores 1983; Rodriguez et al. 2000). Dam construction and urban and agricultural expansion affect the bottomland swamps where gars spawn, producing detrimental effects on juvenile recruitment (Simon and Wallus 1989; Mendoza et al. 2000a).

Management of the alligator gar and tropical gar requires intensive culture, which presents a short-

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term approach to restoration of natural populations. Knowledge of early life stages and larval requirements is essential for successful culture of a species. However, the few available studies of larval gars are limited to the description of some of their developmental stages. A comparative study of the embryonic development of gars and sturgeons *Acipenser* spp. showed that gars have characteristics intermediate to holosteans and teleosteans (Dean 1895). Morphological characteristics of early life stages have been described for the longnose gar *L. osseus*, shortnose gar *L. platostomus*, and spotted gar *L. oculatus* (Netch and Witt 1962; Pearson et al. 1979; Yeager and Bryant 1983; Simon and Wallus 1989; Simon and Tyberghein 1991).

Alligator gars smaller than 15 mm total length (TL) are distinguished by a light-colored arrow located on the snout dorsum; the arrow extends posteriorly to the dorsal fin origin in larger specimens (24–117 mm TL; May and Echelle 1968; Simon and Wallus 1989). However, except for studies by Simon and Wallus (1989) and Simon (1990), yolk sac larvae have not been described. The existing morphological and pigmentation descriptions of larval alligator gars have been completed with only 11 specimens (Suttkus 1963; May and Echelle 1968; Echelle and Riggs 1972; Moore et al. 1973; Simon and Wallus 1989). H. Marquez (Universidad Juarez Autónoma de Tabasco, unpublished) described embryonic and larval stages of tropical gar, but did not include morphometric data.

In this paper, we describe the larval development and growth rates of the alligator gar and tropical gar and provide information about morphological characteristics that can be used as indicators of growth and nutritional condition during early life stages. Morphological characteristics provide simple tools for detecting unfavorable culture conditions during larval development (Dettlaff et al. 1993). The description of larval development under laboratory conditions also has practical significance because it offers a reference for comparing larvae raised under different nutritional conditions and for identifying larvae captured in areas where the alligator gar and tropical gar occur in sympatry.

Methods

Alligator gar eggs were obtained via captive spawning of wild-caught adults at the aquaculture facilities of the Environment, Natural Resources, and Fisheries Ministry of Mexico, located in Tancol, Tamaulipas. The breeders were sexed by external characteristics and comprised 16 males (mean [±SD] weight, 22.6 ± 3.2 kg; mean length, 105 ± 13 cm) and 9 females (mean weight, 30.1 ± 7.5 kg; mean length, 125 ± 16.3 cm). On 31 May 1998, the broodstock was placed into two 30-m × 20-m earthen ponds with an average water depth of 95 cm. Casuarina branches (*Cassuarina* spp.) were spread over the ponds for use as gar spawning substrate (Mendoza et al. 2000a). Courtship and spawning took place the first night after fish were placed in the ponds, at a water temperature of 30°C and a dissolved oxygen concentration of 2.9 mg/L. The next day, the eggs (which adhered to the casuarina branches) were collected and transferred in oxygenated plastic bags to the facilities of the Ecophysiology Laboratory of Universidad Autónoma de Nuevo León, Monterrey.

Tropical gar eggs attached to grass (*Synodon* spp.) were collected on 5 September 1998 from natural spawning habitat in the bottomland swamp area of Comalcalco, Tabasco. The tropical gar is the only gar species in this area. The attached eggs were transferred to and incubated in the facilities of the Aquaculture Section of the Universidad Juarez Autónoma de Tabasco, Villahermosa Tabasco.

Experimental conditions.—Eggs of both species were maintained adhered to branches or grass and incubated in fiberglass tanks (480 L) at 31°C and a dissolved oxygen concentration of 6.0 mg/L. After hatching, larvae were distributed among four fiberglass tanks (230 × 70 × 30 cm; volume = 480 L) at an initial density of 500 larvae per tank (approximately 1 larva/L). The tanks were previously conditioned with branches or grass to facilitate larval adherence. Water temperature was maintained at 27 ± 1°C, and an air compressor maintained dissolved oxygen levels above 6 mg/L.

Branches were removed from tanks as soon as larvae began swimming. Fish were fed ad libitum with nauplii and adults of brine shrimp *Artemia salina* in two daily rations. However, larvae in one tank for each species were deprived of food to allow evaluation of the effect of starvation on growth and morphological characteristics.

Experimental design.—A sample of 10 larvae per tank was taken every 12 h until 4 days after hatching (DAH), every 24 h from 4 to 15 DAH, and on alternating days from 15 to 30 DAH. Larvae were individually weighed to the nearest 0.1 mg with an Ohaus balance and then fixed in Bouin's solution (Theilacker 1978). Morphometric characteristics were measured with an ocular micrometer and vernier calipers (nearest 0.1 mm).

Larval pigmentation was described from both live and preserved specimens. Twenty morphometric characters (standard length, snout length, eye diameter, head length, predorsal length, preanal length, yolk sac length, pectoral fin length, pelvic fin length, head depth at eyes, head depth at pectorals, preanal depth, mid-postanal depth, caudal peduncle depth, yolk sac depth, snout width at nares, mid-snout width, snout width at anterior margin of eyes, head width, and suctorial disk width) and five meristic characters (number of finrays in pectoral, pelvic, dorsal, anal, and caudal fins) were measured or counted for each specimen based on the criteria defined and illustrated by Simon and Wallus (1989) and Simon and Tyberghein (1991) for lepisosteid larvae.

Analysis.—For each species, six TL intervals were designated by the presence of specific larval structures. Stepwise discriminant analysis (SDA; Ferran 1996) was used to identify the morphometric characteristics that best distinguished among larvae of different length interval. The SDA allows one to distinguish between two or more groups based on variables that measure characteristics expected to differ among the groups. In this respect, SDAs serve to identify the variables that contribute most to differentiation among groups, classify the original cases to determine the rate of correct classification, and permit the classification of new cases of unknown membership (Theilacker 1978, 1986; Ferran 1996).

Student's *t*-test was used to compare the total lengths of starved and fed larvae of the same age. Morphometric characters of fed and starved larvae belonging to the same TL interval were analyzed by SDA to determine which characters could be used to evaluate larval nutritional condition (Theilacker 1978, 1986).

Results

Incubation time for alligator gar eggs was 48 h at 31°C; the incubation time for tropical gar eggs could not be determined because the eggs were collected from the natural spawning habitat. Average egg diameter was 4.3 ± 0.3 mm (n = 25) for alligator gars and 3.8 ± 0.2 mm (n = 25) for tropical gars.

Alligator Gar

Recently hatched larvae ranged from 6.6 to 8.8 mm TL (Table 1) and from 11.4 to 12.8 mg. The mouth cavity (stomodeum) was present, and an unpigmented optic cup covered the eyes. The snout primodium was modified as an adhesive papillose suctorial disk, which allowed larvae to remain adhered to vegetation in tanks until the yolk sac was absorbed. The head was slightly deflected over the oval-shaped yolk sac. The dorsal finfold extended posteriorly beyond the yolk sac, and pectoral fin buds were located above the yolk sac. Recently hatched larvae were only sparsely pigmented, and the white yolk sac was prominent (Figure 1A, B). However, dark pigmentation could be observed on the head, and a dark line extended laterally from the operculum, continued above the yolk sac, and turned into diffuse pigmentation at the pectoral fin buds. Behind the yolk sac, the pigmented line became increasingly defined, simulating the future anal and caudal fins.

The yolk sac depth was reduced by 50% in larval sizes from 9.2 to 13.5 mm TL (2–4 DAH), as compared with the previous stage. The anterior section of the yolk sac appeared slightly rounded, while the posterior section adopted an angular shape (Figure 1C, D). Veins were arranged in a visible network along the yolk sac. The head acquired a horizontal position. The mouth was formed, and the adhesive suctorial disk decreased in size. The large opercula covered the anterior sides of the pale-yellow yolk sac. The base of the dorsal finfold was slightly displaced backwards. The head and opercula were black, with the exception of a midventral white line ending at the yolk sac. A mid-dorsal gray stripe with white margins extended from the head to the posterior region of the yolk sac. The black lateral bands in larvae 2–4 DAH were wider and more conspicuous than in recently-hatched larvae and included a projection simulating the dorsal fin.

The adhesive suctorial disk completely disappeared when alligator gar larvae were 14.2–19.2 mm TL (5 DAH); the yolk sac was considerably reduced, and larvae appeared more elongated (Figure 1E, F). At this size, the larvae detached from the vegetation and began exogenous feeding. Pelvic fin buds were evident, and fin rays began forming in the pectoral and caudal fins. The operculum covered the base of the pectoral fins, and the snout began to adopt its characteristic elongated shape. The origin of the dorsal finfold was positioned over the anus. Remnants of the dorsal finfold were observable between the developing dorsal, caudal, and anal fins, but a more conspicuous finfold remained between the anal and pelvic fins. Pigmentation consisted mostly of dark areas on the sides of the body. The ventral region was gray, and the dorsal region was gray with white margins. The extension and contrast of white areas in the dorsal

TABLE 1.—Morphometric characters (mean; SD in parentheses) of alligator gar larvae grouped by selected total length intervals (N = sample size). Characters are expressed as percentages of total length or head length. Fin ray counts are also listed for each interval.

Measure	Total length intervals (mm)					
	6.6–8.8 (N = 10)	9.2–13.5 (N = 17)	14.2–19.2 (N = 13)	19.5–22.5 (N = 11)	23.0–32.0 (N = 6)	34.8–50.0 (N = 5)
	5.8 (0.3)	6.0 (0.5)	7.4 (0.8)	9.9 (0.6)	14.2 (1.6)	15.3 (0.4)
	4.9 (0.9)	6.8 (0.5)	6.1 (0.2)	5.8 (0.2)	5.6 (0.5)	6.2 (0.6)
	17.3 (4.5)	25.6 (3.2)	26.0 (1.2)	27.8 (1.5)	29.5 (1.3)	30.7 (0.7)
	41.5 (4.2)	47.3 (8.1)	60.4 (1.7)	61.6 (2.1)	64.4 (1.0)	67.0 (1.5)
	74.5 (2.4)	66.4 (2.9)	61.7 (1.0)	62.7 (1.5)	65.1 (1.2)	67.5 (1.1)
	98.8 (0.9)	99.0 (0.3)	96.6 (3.7)	91.7 (1.3)	95.5 (1.8)	95.1 (0.8)
	37.7 (1.7)	31.0 (6.0)				
	2.4 (0.2)	3.5 (1.5)	7.6 (1.0)	7.9 (0.3)	6.7 (0.5)	6.0 (0.3)
			1.6 (0.6)	3.6 (0.6)	5.1 (0.9)	5.8 (0.3)
	10.3 (3.2)	12.0 (1.9)	13.6 (1.2)	11.2 (0.9)	8.1 (1.5)	8.8 (0.6)
	38.8 (1.4)	21.3 (4.6)	13.8 (1.8)	11.5 (0.8)	11.3 (0.7)	11.3 (0.5)
	9.6 (1.8)	9.4 (0.8)	7.4 (2.0)	7.7 (0.6)	8.5 (0.8)	9.3 (0.4)
	7.3 (0.7)	7.6 (0.6)	5.5 (1.4)	6.7 (1.2)	6.8 (0.9)	7.3 (0.4)
	4.8 (0.9)	6.8 (1.0)	4.6 (1.4)	6.3 (0.7)	7.5 (0.7)	7.5 (0.7)
	28.9 (1.5)	14.3 (6.7)				
	44.3 (9.9)	22.3 (2.9)	22.7 (5.1)	18.6 (2.7)	14.8 (0.4)	16.9 (1.8)
	36.9 (7.7)	21.4 (2.9)	26.1 (4.2)	26.6 (1.6)	22.8 (2.1)	24.2 (1.7)
	44.4 (9.9)	25.4 (2.7)	33.1 (3.3)	31.3 (1.8)	29.1 (2.9)	30.3 (1.7)
	47.3 (7.5)	30.7 (5.6)	38.6 (4.8)	36.2 (1.7)	33.4 (2.4)	33.2 (1.1)
	44.3 (9.9)	20.2 (4.2)				
	0	0	2–6	6	6	6
	0	0	0	0	1–4	4–5
	0	0	0	1–5	5–6	7–8
	0	0	0	3–6	5–7	7–8
	0	0	3–8	8–10	10	10

region was variable. The dorsal and ventral sides of the snout were gray with black margins, with a more intense contrast on the dorsal side. The pectoral and pelvic fins and remnant finfolds were unpigmented, whereas the caudal, dorsal, and anal fins were black, with unpigmented margins. Along the sides, a white stripe with irregular margins extended from the eyes to the pelvic fins. The width of this stripe varied among individuals and was partially or totally fused with the white margins of the dorsal region.

When the larvae reached 19.5–22.5 mm TL (8 DAH), snout length increased to 10% of TL. Fin rays began forming in the dorsal and anal fins. The general pigmentation pattern remained similar to that of the previous length interval, but the intensity of black and gray areas was reduced, as was the contrast between unpigmented and dark areas. The white stripe along the sides sometimes extended to the caudal fin as irregular and interrupted white areas.

The formation of pelvic fin rays began when larvae were 23–32 mm TL (10–12 DAH), at which time the unpigmented margins of the dorsal region tended to disappear and the whole body turned gray with different intensities. Some areas remained unpigmented, such as the pectoral and pelvic fins and the margins of the dorsal, caudal, and anal fins. An unpigmented line existed beneath the eyes, and a white stripe on the dorsum of the snout sometimes continued to the dorsal fin (Figure 2A, B).

Snout length reached the adult alligator gar proportion (15% of TL) when larvae were 34.8–50.0 mm TL (15 DAH). Ray formation in the dorsal and anal fins was complete at this stage. The white dorsal stripe was brilliant and easily distinguishable against the gray pigmentation of the dorsum (Figure 2C, D). The ventral region was unpigmented, as were some areas in the dorsal, caudal, and anal fins. Individuals longer than 130 mm TL,

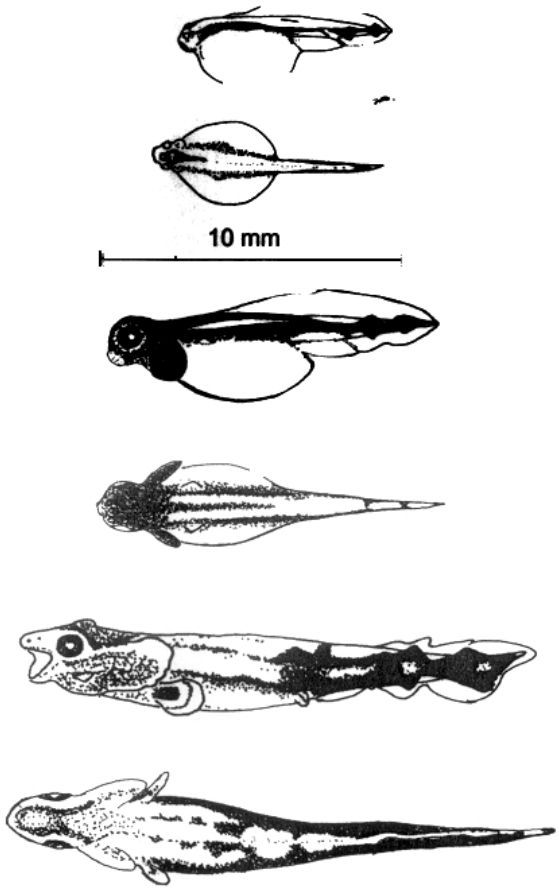

FIGURE 1.—Morphology and pigmentation of an alligator gar. From top to bottom, the figure shows the lateral and dorsal views of a 7-mm TL yolk sac larva, the lateral and dorsal views of an 11-mm yolk sac larva, and the lateral and dorsal views of a 17-mm larva.

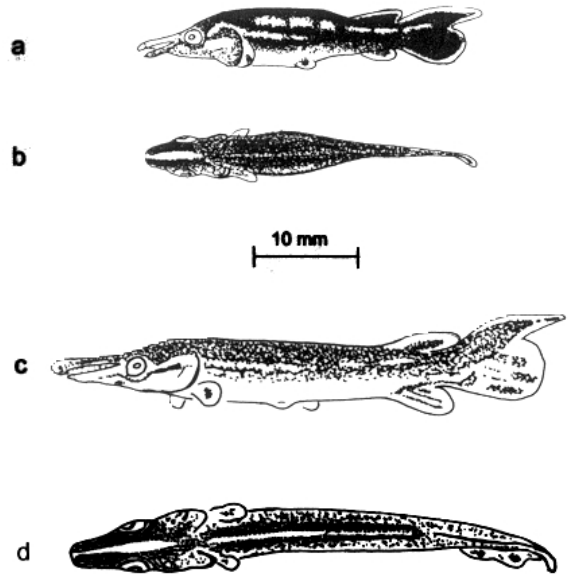

FIGURE 2.—Morphology and pigmentation of an alligator gar: (a) lateral and (b) dorsal views of a 32-mm TL larva; and (c) lateral and (d) dorsal views of a 50-mm larva.

observed after ending the experimental period, did not possess the white dorsal stripe.

Tropical Gar

The morphology of recently hatched tropical gar larvae (6.8–9.0 mm TL) was similar to that of alligator gars of the same stage (Table 2). The finfold of dorsal, caudal, and anal fins was continuous. Pectoral fin buds were apparent just above the yolk sac. Just after hatching, larvae were almost completely white and transparent. However, by the time the fish were 9.0 mm TL, a black stripe was evident on the sides (Figure 3A). This stripe began at the base of the head, continued across the opercula, the dorsal side of the yolk sac, and around the pectoral fin buds, and outlined the dorsal, caudal, and anal fins. Gray spots appeared on the dorsal region and turned progressively darker.

The yolk sac depth was reduced by 50% in larvae 9.6–12.1 mm TL (3–4 DAH), as compared with recently hatched larvae (Figure 3B). The opercula increased considerably in size and covered the pectoral fins. The base of the dorsal finfold was displaced posteriorly. The pigmentation of the dorsal region darkened and fused with the dark stripe at the sides, close to the pigmented area simulating the dorsal fin. A yellow line was situated between these dark areas.

Tropical gar larvae between 12.5 and 13.8 mm TL (5–6 DAH) began swimming freely. Pelvic fin buds were present, and fin rays began to form in the pectoral and caudal fins. The yellow line between the dark dorsal and side regions became increasingly conspicuous and extended to the caudal fin. The opercula, the ventral region of the body, and the dorsal region of the snout were gray.

Rays began forming in the dorsal and anal fins when larvae reached 14.5–21.8 mm TL (7–14 DAH). The snout length increased to10% of TL. The color pattern was similar to that of fish from the previous size interval; however, the lateral yellow line varied in width and contrast. The dark pigmentation of the sides was more intense than that of the dorsal region. Pectoral and pelvic fins and finfolds were unpigmented. The snout was yellow dorsally and ventrally, with diffuse gray to black margins.

When tropical gar larvae reached 22.0–36.0 mm TL (15–22 DAH), pelvic fin ray formation began

TABLE 2.—Morphometric characters (mean; SD in parentheses) of tropical gar larvae grouped by selected total length intervals (N = sample size). Characters are expressed as percentages of total length or head length. Fin ray counts are also listed for each interval.

	Total length intervals (mm)					
Measure	6.8–9.0 (N = 12)	9.6–12.1 (N = 14)	12.5–13.8 (N = 10)	14.5–21.8 (N = 18)	22.0–36.0 (N = 6)	38.3–60.3 (N = 10)
Length						
Snout	5.0 (1.6)	6.8 (0.4)	7.5 (0.4)	10.6 (1.2)	13.8 (2.2)	18.4 (1.0)
Eye diameter	6.0 (0.7)	6.8 (0.4)	6.8 (0.2)	5.9 (0.7)	5.9 (0.5)	5.8 (0.3)
Head	23.4 (2.9)	29.4 (1.2)	28.3 (1.2)	27.6 (1.6)	29.4 (1.9)	32.2 (1.1)
Predorsal	37.0 (4.0)	51.6 (3.5)	57.3 (1.0)	62.9 (4.5)	67.0 (3.2)	70.4 (1.6)
Preanal	66.4 (2.0)	63.9 (1.7)	61.8 (2.0)	64.1 (3.6)	67.0 (3.2)	69.7 (1.4)
Standard	98.3 (0.8)	98.1 (0.4)	98.0 (0.6)	95.6 (3.6)	96.0 (1.6)	95.6 (3.5)
Yolk sac	38.3 (3.5)	26.3 (2.4)				
Fin length						
Pectoral	1.4 (0.4)	4.9 (1.9)	7.6 (0.2)	6.7 (0.9)	6.0 (0.7)	5.1 (0.4)
Pelvic			0.7 (0.02)	1.5 (0.9)	4.3 (0.4)	5.3 (1.0)
Body depth						
Head at eyes	8.6 (2.0)	14.0 (3.1)	14.9 (0.2)	11.8 (0.9)	9.9 (0.9)	8.2 (0.9)
Head at pectoral	31.5 (2.8)	21.4 (2.9)	16.2 (0.6)	12.3 (0.9)	11.5 (0.8)	9.5 (1.0)
Preanal	6.4 (1.2)	7.6 (0.6)	9.0 (0.7)	10.0 (0.7)	8.9 (0.5)	8.4 (1.5)
Mid-postanal	5.2 (1.2)	7.0 (0.7)	8.0 (0.5)	8.8 (0.5)	7.6 (0.8)	6.4 (0.5)
Caudal peduncle	3.6 (1.3)	5.8 (1.0)	7.3 (0.8)	8.5 (0.6)	8.2 (0.7)	7.2 (0.7)
Yolk sac depth	25.0 (2.2)	11.0 (3.3)				
Body width						
Snout at nares	35.7 (9.7)	24.8 (4.1)	24.5 (1.9)	18.8 (1.3)	14.4 (1.6)	11.2 (1.3)
Mid-snout	35.7 (9.7)	29.5 (4.3)	28.8 (2.5)	26.6 (2.3)	20.2 (2.3)	17.4 (1.9)
Snout at anterior margin of eyes	35.7 (9.7)	30.4 (3.4)	37.3 (4.6)	34.2 (5.6)	25.8 (3.1)	22.8 (1.9)
Head	35.7 (9.7)	43.8 (8.7)	51.5 (3.9)	44.2 (4.0)	36.6 (4.1)	26.9 (2.2)
Suctorial disc	23.9 (9.7)	18.8 (5.1)				
Fin ray counts						
Pectoral	0	0	2–3	3–5	5	
Pelvic	0	0	0	0	1–4	5–6
Dorsal	0	0	0	1–5	3–6	6–7
Anal	0	0	0	1–5	5–7	6–7
Caudal	0	0–2	3–6	7–10	10	10

and pectoral and caudal fin ray formation was complete. The dark lateral pigmentation was reduced in width and intensity and appeared as a thin, brown line initiating just behind the posterior end of the snout, continuing through the eyes, and ending at the caudal fin (Figure 3C).

At 38.3 mm TL, the formation of rays in the dorsal and anal fins was complete. Adult tropical gar snout proportion (18% of TL) was reached in 60-mm TL (30 DAH) larvae. The ventral region was white (Figure 3D). The snout had a brown hue dorsally due to diffuse brown spots. A pair of conspicuous brown and yellow lines was evident along the sides.

The SDA results among TL intervals for alligator gar larvae (λ = 0.000; χ^2 = 540.85; df = 40; P = 0.001) and tropical gar larvae (λ = 0.000; χ^2 = 520.52; df = 45; P = 0.001) showed that the selected intervals were differentiated best by snout length, body depth at the pectoral fins, caudal peduncle depth, and snout width at the anterior margin of the eyes (Table 3). The SDA analyses revealed that 96.8% of alligator gar specimens (n = 62) and 92.9% of tropical gar specimens (n = 70) were adequately classified by designated TL intervals on the basis of morphometric characteristics.

Growth

Larvae of both species remained adhered to vegetation until 4 DAH and began to swim and feed exogenously at 5 DAH. The growth rate of alligator gar larvae during the first 10 DAH was 1.55 mm/d (Figure 4). The growth rate increased to 5.06 mm/d during the next 5 d, with larvae reaching 50 mm TL by 15 DAH. The growth curve was defined by the following equation: $y = 6.019e^{0.3122x}$ (r^2 = 0.938), where y is total length and x is DAH.

For tropical gar larvae, the growth rate was 1 mm/d until 15 DAH and 2.5 mm/d between 15 and 30 DAH. The growth curve was defined by the following equation: $y = 6.001e^{0.2794x}$ (r^2 = 0.907).

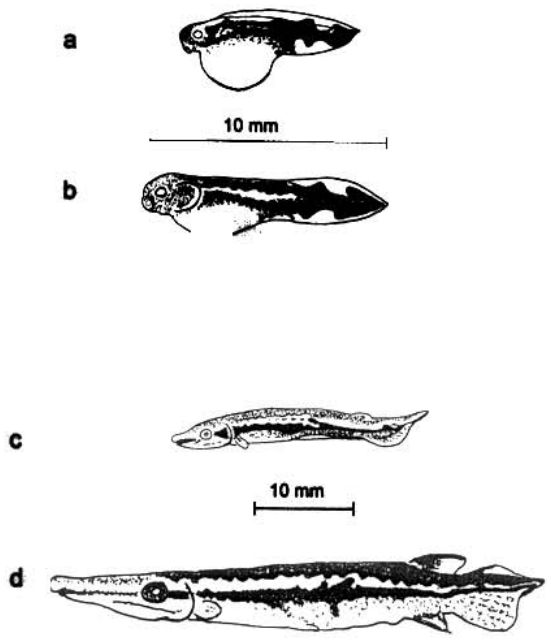

FIGURE 3.—Lateral views of a tropical gar, showing the morphology and pigmentation of (a) a 7.5-mm TL yolk sac larva, (b) a 9.8-mm yolk sac larva, (c) a 25-mm larva, and (d) a 50-mm larva.

Major changes in the snout length of alligator gars occurred between 19.5 and 32.0 mm TL (8–12 DAH), whereas for tropical gar larvae, snout length changed between 22.0 and 60.3 mm TL (15–30 DAH) (Figure 5). The relationship between snout length and total length was defined by the linear regression equations $y = -3.907 + 2.482x$ ($r^2 = 0.839$) for alligator gar larvae and $y = -8.943 + 2.821x$ ($r^2 = 0.867$) for tropical gar larvae.

Effect of Starvation

Unfed alligator gar larvae stopped growing by 8 DAH, averaging 19.6 ± 0.5 mm TL. Based on Student's *t*-test, significant differences in total length ($t = 2.073$; df = 8; $P = 0.032$) were detected between unfed and fed larvae (20.64 ± 0.097 mm TL). Similarly, growth of unfed tropical gar larvae stopped at 8 DAH, when the fish averaged 15.9 ± 0.43 mm TL. For both species, high mortality (50–80%) was observed in unfed larvae between 10 and 13 DAH, and no larvae survived beyond 15 DAH.

The SDA results of fed and starved larvae for alligator gars belonging to the 19.5–22.5-mm interval ($\lambda = 0.004$; $\chi^2 = 100.93$; gl = 2; $P = 0.001$) and tropical gar larvae belonging to the 14.5–17.0-mm interval ($\lambda = 0.031$; $\chi^2 = 45.17$; gl = 2 ; $P = 0.001$) showed that caudal peduncle depth, head width, and preanal depth were the morphometric characteristics that best differentiated fed and starved larvae (Table 4). Unfed larvae of both species showed mostly black or gray pigmentation, and the contrast with the unpigmented areas was reduced.

Discussion

Our measured incubation time for alligator gar eggs (48 h at 31°C) was similar to that reported by Morales (1987; 50–62 h at 27°C). Although it was not possible to determine the incubation time

TABLE 3.—Results of stepwise discriminant analyses among total length (TL) intervals for alligator gar and tropical gar larvae. See Tables 1 and 2 for length intervals.

Function 1	TL intervals 1–6 for alligator gar larvae	TL intervals 1–6 for tropical gar larvae
Eigenvalue		30.132
% of variance		66.4
Canonical correlation		0.984
Standardized canonical discriminant function coefficients		
Snout length	−0.136	−0.843
Body depth at the pectoral fins	2.611	0.378
Caudal peduncle depth	−3.195	0.554
Snout width at anterior margin of eyes	−0.040	0.717
Functions at group centroids		
TL interval 1	19.963	6.727
TL interval 2	0.205	3.955
TL interval 3	−0.264	2.849
TL interval 4	−7.648	−2.317
TL interval 5	−11.031	−5.517
TL interval 6	−9.874	−8.978

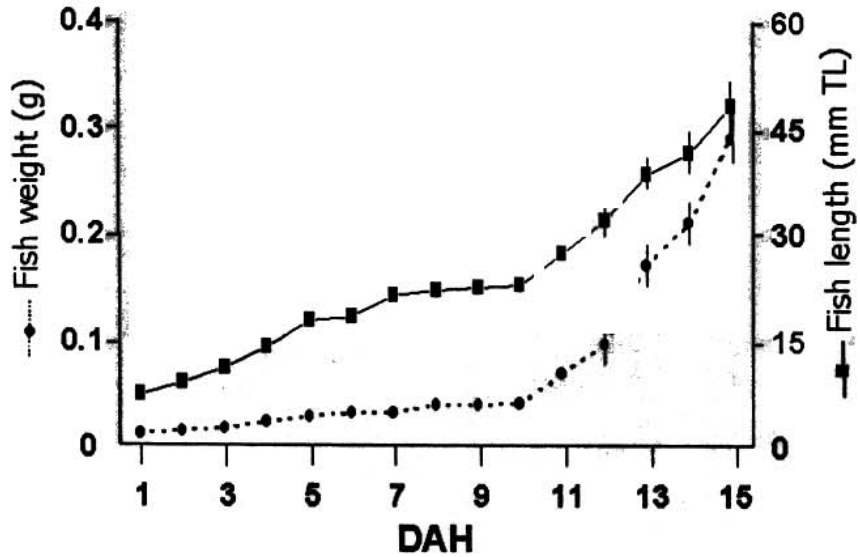

FIGURE 4.—Growth in weight (left scale) and total length (right scale) of alligator gar larvae from hatching until 15 d after hatching (DAH).

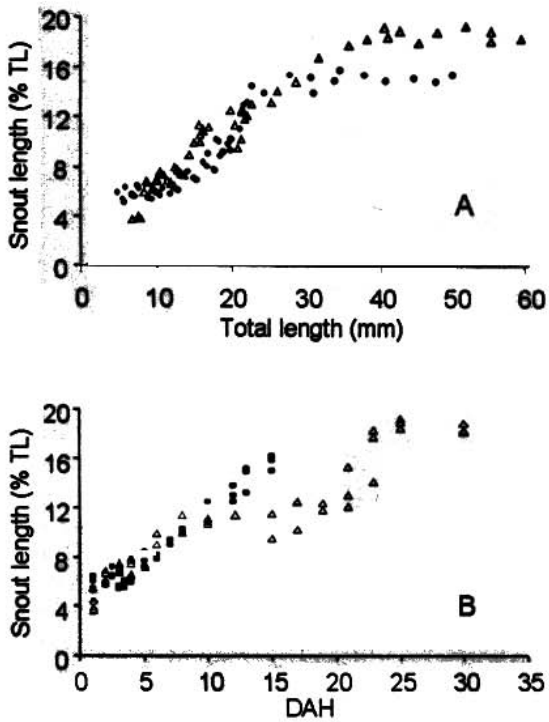

FIGURE 5.—Relationships between (A) snout length and total length and (B) snout length and days after hatching (DAH) during the development of alligator gar (circles) and tropical gar (triangles) larvae.

for tropical gars because eggs were collected from natural spawning habitats, Marquez (Universidad Juarez Autónoma de Tabasco, unpublished) reported an incubation time of 48 h for tropical gars held at 30°C. The egg diameters of alligator and tropical gars were similar to those reported for longnose gars (3–5 mm; Simon and Wallus 1989). Gar eggs are moderately large, and larvae have an extended yolk sac period. Consequently, gar larvae are relatively large and developed at the start of exogenous feeding. Because eggs and yolk sac larvae remain adhered to vegetation, these stages may incur a relatively high risk of predation. However, gar species have developed the defense of incorporating cardiotoxic substances in the eggs; of the gar species, alligator gar eggs are the most toxic (Netch and Witt 1962; Burns et al. 1981).

The developmental intervals based on TL were similar for alligator gar and tropical gar larvae. For each species, the first two TL intervals correspond to the yolk sac or prelarval phase, whereas the next two TL intervals correspond to the larval phase (Dettlaff et al. 1993). Morphometric changes between TL intervals for alligator gar and tropical gar larvae demonstrate allometric growth throughout larval development for both species. The change in growth proportions during development has been suggested as a general feature of fish larvae and could be correlated with functional demands (e.g., feeding or swimming) that change according to priorities during early growth (Osse et al. 1997; Osse and van den Boogaart 1999).

TABLE 4.—Results of stepwise discriminant analyses of fed and starved larvae for alligator gar (19.5–22.5 mm total length) and tropical gar (14.5–17.0 mm total length).

Function 1	Alligator gar	Tropical gar
Eigenvalue		
% of variance		
Canonical correlation		
Standardized canonical discriminant function coefficients		
Caudal peduncle depth	−1.320	1.082
Head width	1.691	0.538
Preanal body depth	0.219	0.709
Functions at group centroids		
Fed larvae	14.942	3.528
Starved larvae	−16.437	−7.763

A diagnostic difference between alligator gars and tropical gars was snout formation. Alligator gar larvae approached the snout length proportion of adults at an earlier size and age than did tropical gar larvae. The earlier change in alligator gar snout length suggests a faster metamorphosis in alligator gars, which could contribute to earlier changes in feeding habits and earlier onset of cannibalism (Dabrowski and Bardega 1984; Hecht and Pienaar 1993; Busch 1996). Similar changes in feeding habits of young gars were studied by Echelle and Riggs (1972), who reported a progressive increase in the frequency of fishes in the diet with increasing gar size. Echelle and Riggs (1972) also found that piscivory started at smaller sizes for the longnose gar (17–36 mm TL) than for the shortnose gar and spotted gar. Pearson et al. (1979) found that longnose gars began to consume fish larvae very early (at 20–42 mm TL), although piscivory did not limit the intake of other, more readily available prey (i.e., cladocerans). Such results indicate that larval gars are opportunistic feeders.

The pigmentation pattern observed for alligator gar larvae in this study agrees with other descriptions made from larvae of the same size (Suttkus 1963; May and Echelle 1968; Echelle and Riggs 1972; Moore et al. 1973; Simon and Wallus 1989). The light-colored arrow on the snout dorsum of 14.2–22.5-mm alligator gar larvae had well-defined margins, whereas in 14.5–21.8-mm tropical gar larvae, the arrow on the snout dorsum had diffuse margins. The distinctive, light-colored dorsal stripe seen in 23–130-mm alligator gars was absent in tropical gars. The dorsal stripe tended to disappear in alligator gars longer than 130 mm TL. The loss of the dorsal stripe in alligator gars could be considered an indicator of transformation to the juvenile stage, which would take place at approximately 30 DAH, based on our growth rate data.

In the tropical gar, the principal diagnostic pigmentation characteristic was the yellow stripe situated between the dark areas of the flank. The stripe had well-defined margins, whereas in alligator gar larvae a similar white stripe had irregular margins that were partially fused with the white of the dorsal region. A lateral stripe similar to that of alligator gar larvae was reported for spotted gar larvae (Simon and Wallus 1989).

The growth rate observed in tropical gar larvae (1.0 mm/d) is very close to that reported by Marquez (Universidad Juarez Autónoma de Tabasco, unpublished) for the same species (0.86 mm/d) and is similar to that reported for larvae of longnose gar (0.8 mm/d) and spotted gar (0.83 mm/d) (Pearson et al. 1979; Simon and Tyberghein 1991). The slightly faster growth observed for the tropical gar than for the longnose gar or spotted gar may be due to the warmer water that this species inhabits. The fastest growth observed in our study was for alligator gar larvae during the first 10 DAH (1.55 mm/d). Growth in alligator gars also was rapid after 10 DAH (5.6 mm/d), exceeding juvenile growth rates reported for spotted gars (1.3–1.7 mm/d) and longnose gars (2.33–4.5 mm/d; Netch and Witt 1962; Echelle and Riggs 1972; Simon and Wallus 1989). The alligator gar reaches the longest size among lepisosteids (up to 3 m TL), likely accounting for its rapid juvenile growth.

Nutritional stages for alligator gar and tropical gar larvae could be distinguished according to the criteria established by Beccaria et al. (1991). By these criteria, larvae between 6.8 and 13.5 mm TL (1–4 DAH) belong to the lecithotrophic stage, in which the larvae remain attached to the vegetation and are nourished only from the yolk sac. Larvae between 12.5 and 22.5 mm TL (5–8 DAH) are included in the lecithoexotrophic stage, when exogenous feeding begins but fed and unfed larvae show no differences in growth, indicating that yolk reserves are still present. Finally, the exotrophic

stage begins in larvae at 22 mm TL, the size at which morphological alterations observed in unfed larvae indicated a total dependence on exogenous food. Our observations concur with those of Pearson et al. (1979) who, based on the fullness of the larval intestinal tract, estimated that longnose gars less than 20 mm TL were lecithotrophic, larvae ranging from 20 to 30 mm TL were lecithoexotrophic, and larvae longer than 30 mm TL were exotrophic.

Results derived from the SDA among TL intervals indicated that the degree of development for alligator gar and tropical gar larvae could be mainly differentiated by snout length, body depth at the pectoral fins, caudal peduncle depth, and snout width at the anterior margin of the eyes. The results suggest that these four morphometric characteristics may be used to evaluate growth of gar larvae.

The SDA of fed and unfed gar larvae indicated that caudal peduncle depth, head width, and preanal depth were the morphometric characteristics that contributed most to differentiation between fed and starved fish. According to the SDA, the three variables may be used to compare the nutritional condition of gar larvae of similar developmental stages. Similarly, Theilacker (1978), based on SDA, found that standard length, head length, eye diameter, body depth at the pectoral fin, and body depth at the anus were the best morphometric characteristics for estimating nutritional condition of laboratory-reared jack mackerel *Trachurus symmetricus* larvae. The SDA method was also used to determine starvation for wild-caught jack mackerel larvae by comparing laboratory-reared and wild fish of the same developmental stage (Theilacker 1986). In addition, the darker pigmentation observed in starving alligator gar and tropical gar larvae has a practical significance, because this observation can easily distinguish individuals in poor condition from among large numbers of cultured larvae.

Morphological descriptions of alligator gar and tropical gar larvae are valuable to the culture of these species, allowing discrimination among larvae with differing nutritional conditions. Such descriptions can also be useful for planning the timing of feeding and the selection of feed sizes when weaning fish onto artificial diets. In addition, the results of the present study may contribute to the identification of larval alligator gars and tropical gars within areas of sympatry.

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