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Morphometric Comparison of Blue Catfish *Ictalurus furcatus* (Lesueur, 1840) from Northern and Southern Atlantic Drainages of México

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Abstract.—A morphometric comparison was performed on specimens of blue catfish (*Ictalurus furcatus*) from northern (Lower Río Bravo) and southern (Chiapas) México in order to identify diagnostic characters that allow their discrimination. The discriminant function analysis determined three characters to be highly diagnostic to separate the two groups of specimens: the southern group [SG] has a shorter anal base (mean = 3.4 times in standard length [SL], range = 3.1 to 3.7) *vs* northern group [NG] (mean = 2.9 times in SL, range = 2.7 to 3.1), a lesser head width (mean = 6.0 times in SL, range 5.1 to 6.8) *vs* NG (mean = 5.6 times, range = 5.3 to 6.0), and a lower number of anal rays (mean = 26, range = 24 to 28) *vs* NG (mean = 31, range = 29 to 34). Additionally, 14 other characters were also different ($P < 0.01$) between both groups. All these characters support the taxonomic validation of *Ictalurus meridionalis* (Günther 1864) for the individuals of SG that are currently included in *I. furcatus* Lesueur. Studies on comparative osteology and molecular genetics of both forms are needed for the clarification of their taxonomic status.

Resumen.—Se realizó una comparación morfométrica en el bagre azul (*Ictalurus furcatus*) del norte (Bajo Río Bravo) y sur (Chiapas) de México, con el objetivo de identificar caracteres diagnósticos que permitan su discriminación. El análisis de función discriminante determinó que tres caracteres son altamente diagnósticos para separar los dos grupos geográficos. El grupo sureño [GS] tiene una base anal más corta (promedio = 3.4 veces en longitud patrón [LP], intervalo = 3.1 a 3.7) *vs* grupo norteño [GN] (promedio = 2.9 veces en LP, intervalo = 2.7 a 3.1), una cabeza más angosta (promedio = 6.0 veces en LP, intervalo 5.1 a 6.8) *vs* GN (promedio = 5.6 veces en LP, intervalo = 5.3 a 6.0), y un menor número de radios anales (promedio = 26, intervalo = 24 to 28) vs NG (promedio = 31, intervalo = 29 to 34). Además, otros 14 caracteres también fueron diferentes ($P < 0.01$) entre ambos grupos. Todos estos caracteres sustentan la validación taxonómica de *Ictalurus meridionalis* (Günther 1864) para individuos del GS que son actualmente referidos como *I. furcatus* Lesueur. Estudios sobre osteología comparada y genética molecular de ambas formas son necesarios para clarificar su estatus taxonómico.

The blue catfish *Ictalurus furcatus* (Lesueur 1840) is one of the Nearctic freshwater fish species of the Atlantic slope with a distribution extended to Neotropical localities as far southern as the Rio Usumacinta and the Rio Belize, Belize, where it was originally called *Ameiurus meridionalis* Günther 1864 [= *Ictalurus meridionalis*] (Miller et al. 2005).

This southern form was described on the basis of its lower number of anal rays, its shorter barbels and its smaller eye than the northern form (Günther 1864; Jordan and Evermann 1896–1900; Meek 1904; Alvarez del Villar 1970). However, Lundberg (1992) considered the nominal species *I. meridionalis* from the Rio Usumacinta as conspecific with *I. furcatus*, a situation that Miller et al. (2005) stressed as an interesting theme for additional study.

Our ichthyological explorations to the "Reserva de la Biosfera de Montes Azules" in the Mexican State of Chiapas, during 1979–1985 (Lozano-Vilano and Contreras-Balderas 1987) and 2004–2006 (Lozano-Vilano et al. 2007), had already detected in the field some differences in the body proportions of the southern blue catfish specimens when compared with the northern form, mainly the basal length of the anal fin, as well as the head width and length. Additionally, the geographical distribution of blue catfish in México exhibits a notable disjunct pattern in the drainages of Veracruz, where the northern and southern populations are widely separated (cf. Miller et al. 2005).

In the present work, we compared 28 morphologic characters (27 morphometric and 1 meristic) in blue catfish from northern (Lower Río Bravo) and southern (Río Lacantún) México, in order to determine the magnitude and signification of the differences.

Methods

Thirty-four individuals of blue catfish from different sites in southern (Chiapas, B in Fig. 1: 1, Río Lacanjá; 2, Río Tzendales; 3, Arroyo Miranda; 4, Río Lacantún at Estacion Chajul; 5, Río Chajul; 6, Arroyo San Pablo; 7, El Colorado; and 8, Arroyo Manzanares) and northern México (Lower Río Bravo, A in Fig. 1: 1, Rancho Taffinder; 2, Río Alamo; 3, El Astillero; 4, Garceño; 5, La Gloria; 6, Rodríguez de Anáhuac; and 7, Presa Don Martín) were chosen for the comparative analysis (Appendix 1). The range and average length of the two groups of specimens (southern and northern) were similar (Table 1).

Twenty-two body distances based on box truss protocol (Bookstein et al. 1985, Fig. 2) and five distances of the head region and the number of anal rays were considered in the analysis (Hubbs and Lagler 1947). Each specimen was measured with a digital caliper (precision 0.01 mm) connected to a personal computer. The measurements were as follows (landmark number in parenthesis): (1-2), tip snout to mouth commissure; (1-3), tip snout to nostril; (2-3), mouth commissure to nostril; (2-4), mouth commissure to dorsal fin origin; (2-5), mouth commissure to pectoral fin origin; (3-4), nostril to dorsal fin origin; (3-5), nostril to pectoral fin origin; (4-5), dorsal fin origin to pectoral fin origin; (4-6), basal length of dorsal fin; (4-7), dorsal fin origin to pelvic fin origin; (5-6), pectoral fin origin to posterior insertion of dorsal fin; (5-7), pectoral fin origin to pelvic fin origin; (6-7), posterior insertion of dorsal fin to pelvic fin origin; (6-8), posterior insertion of dorsal fin to posterior insertion of adipose fin; (6-9), posterior insertion of dorsal fin to anal fin origin; (7-8), pelvic fin origin to posterior insertion of adipose fin; (7-9), pelvic fin origin to anal fin origin; (8-9), posterior insertion of adipose fin to anal fin origin; (8-10), posterior insertion of adipose fin to posterior insertion of anal fin; (8-11), posterior insertion of adipose fin to mid caudal base; (9-10), basal length of anal fin; and (10-11), posterior insertion of anal fin to mid caudal base. Other lineal measures and counts were: head length, head width (at level of occipital), eye diameter, internostril width, interorbital width, and the number of anal rays.

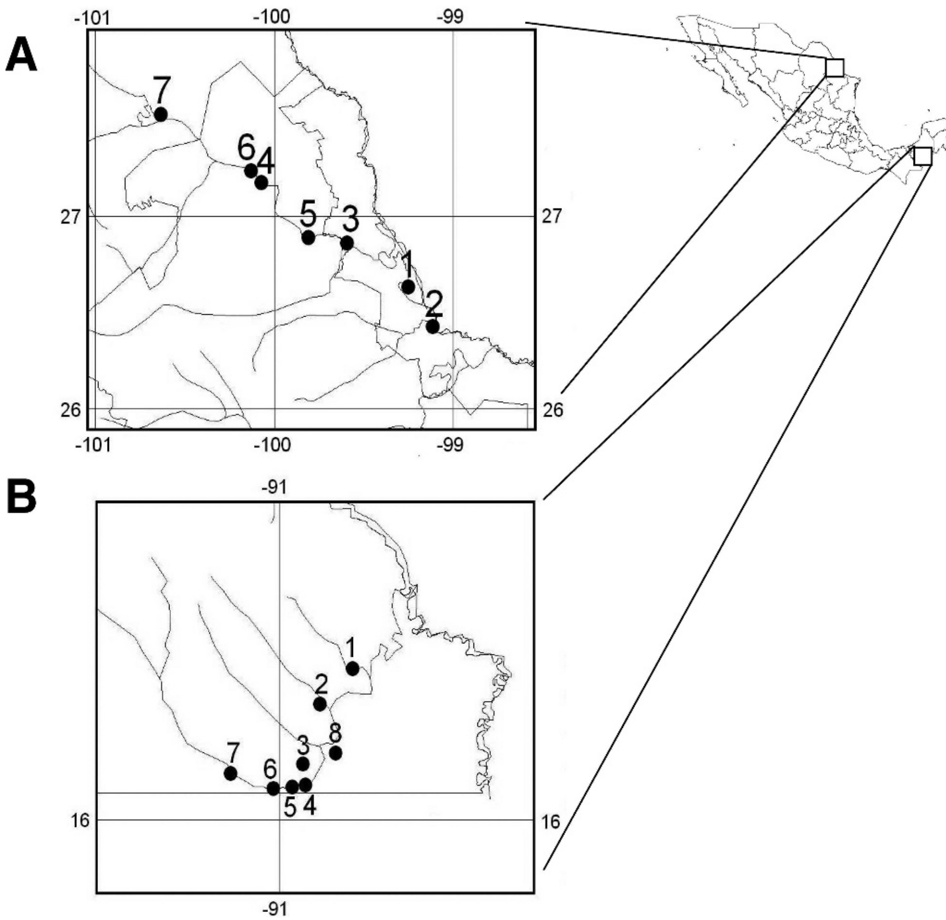

Fig. 1. Study sites for blue catfish in northern and southern México. (A) Lower Río Bravo of Coahuila, Nuevo León and Tamaulipas; (B) Río Lacantún at Reserva de la Biosfera de Montes Azules, Chiapas. Names of sites are indicated in the text.

The original body measurements were standardized by means of the regression of Elliott et al. (1995), which removes the size component from the shape measurements (allometry), and is calculated for each character by the following equation:

$Ms = Mo\ (Ls/Lt)^b$; where Ms = standardized measurement of the character, Mo = original measurement of the character (mm), Ls = average standard length (mm) of all the specimens from the two groups examined, Lt = standard length (mm) of specimen, and "b" was estimated for each character from the observed data using the non-linear regression equation, $M = aL^b$. Parameter "b" was estimated as the slope of the regression log Mo on log Lt using all fish.

The standardized morphometric values of the 34 examined specimens were analyzed between groups (northern: Lower Río Bravo basin, and southern: Río Lacantún basin) by means of "forward stepwise discriminant" function analysis (DFA) using Statistica 5.0 (StatSoft, Inc., Tulsa, OK, 1995). The DFA allowed us to detect which combination of characters discriminated best between groups. Finally, each character was compared statistically between groups using a Student's "t" test.

Table 1. Descriptive statistical values of 27 standardized morphological characters plus one meristic (anal rays), with their respective levels of significance (P), for individuals of blue catfish from northern and southern, México. Significant characters are shown in bold.

	Río Lacantún N=21		Lower Río Bravo N=13			
Variables	Ave.	SD	Ave.	SD	Student's "t"	P
SL (mm)	211	43.3	219	44.8	0.517	0.609
1-2	15.21	0.92	15.28	1.59	0.163	0.871
1-3	13.34	1.09	12.35	1.07	2.591	**0.014**
2-3	9.46	1.15	9.36	1.39	0.228	0.821
2-4	68.25	6.89	76.83	7.64	3.386	**0.002**
2-5	35.62	2.88	34.57	1.64	1.196	0.241
3-4	66.29	5.46	68.75	3.00	1.486	0.147
3-5	38.24	5.55	38.54	4.78	0.257	0.797
4-5	47.27	11.07	53.09	10.48	1.52	0.138
4-6	17.02	1.15	15.77	1.00	3.231	**0.003**
4-7	54.63	4.26	56.63	5.08	1.236	0.225
5-6	55.37	3.68	57.60	3.04	1.83	0.077
5-7	57.48	5.28	52.19	3.45	3.204	**0.003**
6-7	44.63	4.50	47.44	3.26	1.952	0.060
6-8	85.53	6.77	89.57	5.31	1.828	0.077
6-9	57.52	3.05	53.45	2.04	4.247	**<0.001**
7-8	82.47	5.07	95.17	4.19	7.562	**<0.001**
7-9	28.71	2.82	24.26	1.70	5.125	**<0.001**
8-9	60.50	3.99	77.45	6.32	9.62	**<0.001**
8-10	25.67	1.59	21.98	1.21	7.166	**<0.001**
8-11	45.94	1.94	42.90	1.69	4.656	**<0.001**
9-10	60.74	3.64	78.64	4.27	13.045	**<0.001**
10-11	34.60	3.02	27.35	2.11	7.567	**<0.001**
Head width	34.11	3.27	42.67	1.69	8.711	**<0.001**
Internostril width	16.24	0.75	14.67	0.65	6.23	**<0.001**
Head length	49.99	2.18	54.08	3.11	4.512	**<0.001**
Interorbital width	26.15	1.10	28.05	0.92	5.196	**<0.001**
Eye diameter	9.13	0.56	9.23	0.81	0.426	0.673
Anal rays	26	1	31	2	9.719	**<0.001**

SL (mm) = no transformed standard length.

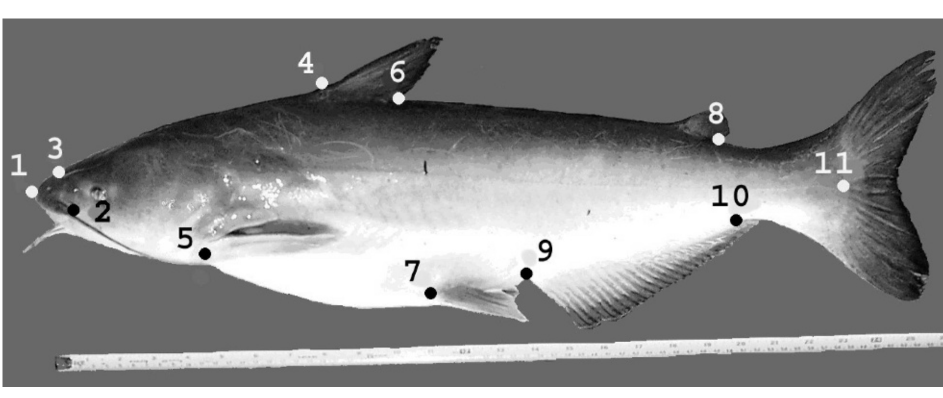

Fig. 2. Landmarks based on Bookstein et al. (1985) box truss protocol for the morphometric comparison of groups of blue catfish from northern and southern México. Photograph by María de Lourdes Lozano-Vilano.

Table 2. Summary of the discriminate function analysis (forward stepwise type) applied for standardized measurements of blue catfish from northern (Lower Río Bravo basin) and southern (Río Lacantún basin). Number of steps: 9; number of variables in the model: 9; grouping: 2.

Character	Wilks	Partial	F-remove	p-level	Toler.	1-Toler.
9-10	0.036161	0.831570	4.86106	0.037299	0.522359	0.477641
8-10	0.057616	0.521912	21.98478	0.000092	0.352112	0.647888
Head width	0.043603	0.689646	10.80049	0.003113	0.363757	0.636243
6-7	0.032274	0.931708	1.75914	0.197216	0.552287	0.447713
Internostril width	0.032742	0.918411	2.13209	0.157211	0.709333	0.290667
Interorbital width	0.033956	0.885572	3.10113	0.090976	0.764098	0.235902
Anal rays	0.032556	0.923661	1.98355	0.171840	0.882346	0.117654
2-5	0.032599	0.922422	2.01848	0.168258	0.458300	0.541700
7-9	0.031405	0.957506	1.06513	0.312338	0.706935	0.293065

Overall Wilks' Lambda: 0.03007. $F_{approx.\ (9,\ 24)} = 86.014$, $p < 0\ .0001$.

Standardized coefficients for canonical variables

Variable	Root 1
9-10	0.57657
8-10	−1.18316
Head width	0.93789
6-7	−0.35705
Internostril width	−0.34437
Interorbital width	0.39294
Anal rays	0.29866
2-5	0.41776
Distance 7-9	−0.24895
Eigenval	32.25540
Cum. Prop.	1.00000

Results and Discussion

The means and standard deviations of the 28 morphological characters of 34 examined specimens of blue catfish are depicted in Table 1. The "t" student test for each character between groups (northern *vs*. southern) revealed 17 characters to be statistically different.

The DFA applied to 34 specimens of blue catfish from both groups selected 9 of 28 morphologic variables examined (Table 2). Overall value of Wilks' lambda was 0.03007, indicating a significant discrimination ($p<0001$) between groups. The highest Wilks' values were associated with the basal length of anal fin (0.0361), posterior insertion of adipose fin to posterior insertion of anal fin (0.0576), and the head width at level of occipital (0.0436). The contribution of each one of the nine characters selected by the model to the overall discrimination appears in the Table 2. The characters with high weight to the discrimination between groups were the variables: 8-10 ($Y_1 = -1.18316$), head width ($Y_1 = 0.93789$) and 9-10 ($Y_1 = 0.57657$). Predicted or correct classification of individuals was 100% in both groups, which indicates that the individuals maintain the identity of each group as shown in figure 3.

The count of anal rays was statistically different between groups, with the lowest number (mean = 26, range = 24 to 28) for the southern group (SG) and the highest for the northern group (NG, mean = 31, range = 29 to 34) (Table 1). When both groups

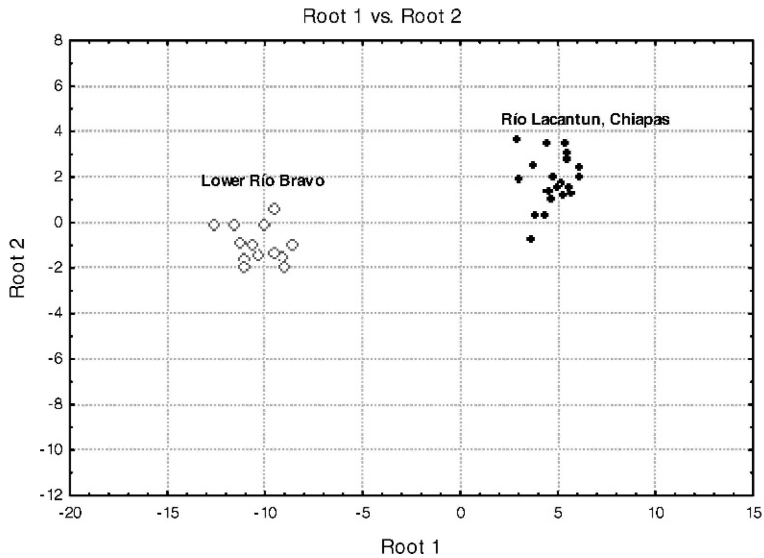

Fig. 3. Discriminant function analysis for northern and southern blue catfish specimens from México. Axis 1 vs. axis 2. Pooled data.

were compared without transformation of the body measurements, the following body proportions were obtained: in the NG, the head width contained in average 5.6 times in standard length [SL] (range 5.3 to 6.0), while in that of the SG 6.0 times (range 5.1 to 6.8). The head of the NG specimens was notably longer and wider than in those SG specimens (Fig. 4). The basal length of anal fin in the NG specimens contained in average 2.9 times (range = 2.7 to 3.1) in SL in comparison with that of the SG (3.4 times, range = 3.1 to 3.7).

In the comparative analysis of blue catfish between specimens from the northern and southern populations of México (Lower Río Bravo and Río Lacantún, respectively) 17 morphological characters were found to be significantly different (Table 1). Several of these differences had already been referred in the literature (e.g., Günther 1864; Jordan and Evermann 1896–1900; Meek 1904; Alvarez del Villar 1970), such as a lower number of anal rays and a smaller head in southern populations (*I. '' meridionalis''*) in comparison with those of northern populations (*I. furcatus*). Also, the length of the barbels is different between these two populations; being longer in northern specimens (reaching the origin dorsal fin) and shorter in southern specimens (reaching the end of head or slightly beyond).

We also detected that the coloration of live specimens of ''*I. meridionalis*'' is gray silvery on the dorsal part of the body with steel reflections and whiter ventrally; however, this coloration pattern is different than that reported by Jordan & Evermann (1896) and Meek (1904), which was brownish with steel blue reflections on the dorsum, and silvery on the ventral region. Of the 17 characters found to be significant by means of the student's ''t'' test, three of them were highly useful for separating both groups and were associated with distances in the anal region and the head width. Although the number of anal rays could be a character with latitudinal clinal variation, we did not detect this trend because specimens examined here from an intermediate area (Rio Tanquilin, San

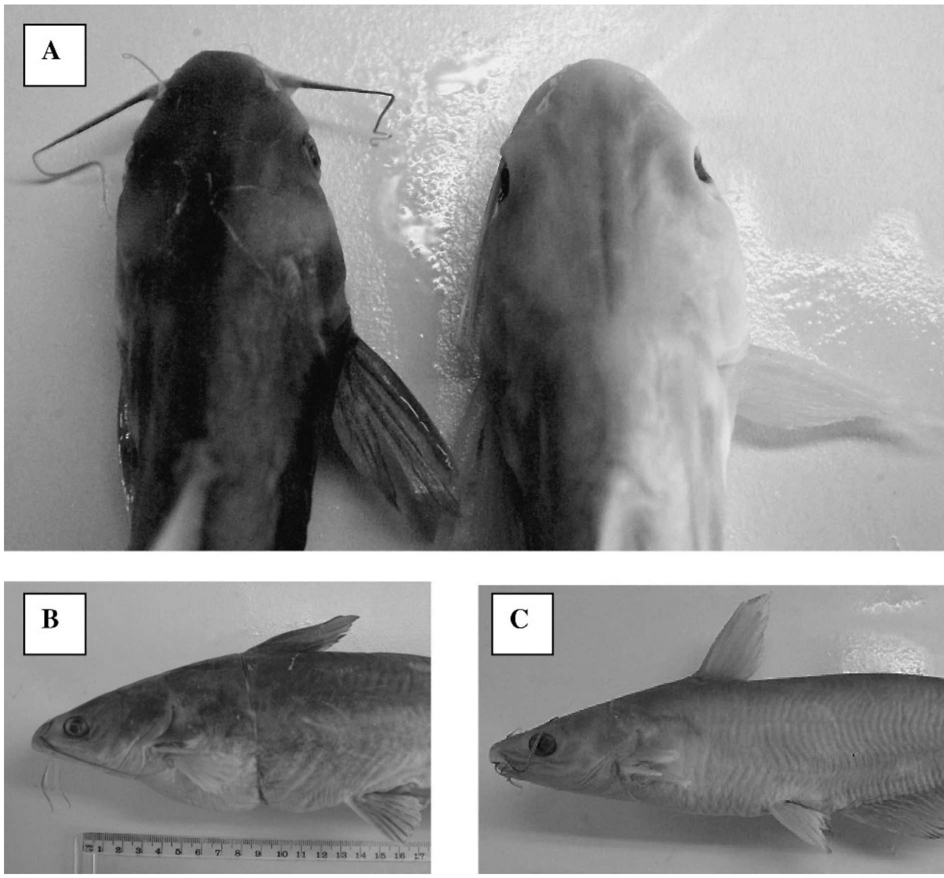

Fig. 4. (A) Dorsal cephalic views of blue catfish for southern specimen (left) and northern (right). Lateral cephalic views of southern specimen (B) and northern specimen (C). Photographs by Gorgonio Ruiz-Campos.

Luis Potosí) had a lower number of anal rays (mean = 22) when compared with southern specimens of Chiapas (mean = 26).

In spite of the range and average of length for both species examined being statistically similar, we expect that the variation of each character compared will decrease as the sample size increases. We suggest that a larger sample size for each southern and northern group, including intermediate populations, as well as a detailed study on the osteology and molecular genetic analysis should be conducted to evaluate the taxonomic status of the southern form "*Ictalurus meridionalis.*"

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Appendix 1

The material examined of blue catfish for the comparative analysis is deposited in the Colección Ictiológica del Laboratorio de Ictiología, Facultad de Ciencias Biológicas, Universidad Autónoma de Nuevo León (UANL). CHIAPAS: UANL-15739, Río Tzendales, 16°17′52″ N, 90°53′12″ W, 24 Aug. 2004; UANL-15718, Arroyo San Pablo, 16°06′07″ N, 91°00′52″ W, 23 Aug. 2004; UANL-15790, *idem*, 30 Nov. 2004; UANL-16984, Arroyo San Pablo, *idem*, 10 Dic. 2005, 30 Nov. 2004; UANL-16883, Río Manzanares, 16°10′14″ N, 90°50′36″ W, 14 Sep. 2005; UANL-15760, Arroyo Miranda exit to Lacantún, 16°08′44″ N, 90°55′50″ W, 25 Aug. 2004; UANL-15822, Río Lacantún at Estación Chajul, 16°06′35″ N, 90°56′23″ W, 1–2 Dec. 2004; UANL-15993, Río Lacanjá, 16°24′14″ N, 90°47′52″W, 10 Feb. 2005; UANL-16698, Río Lacanjá, *idem*, 9 Jun. 2005; UANL-16726 (ex UANL 16716), El Colorado, 16°07′13″ N, 91°07′50″ W, 9 Jun. 2005; UANL-16883, Río Manzanares, 16°10′14″ N, 90°50′36″ W, 14 Sep. 2005; UANL-17046, Río Chajul, 16°06′11″ N, 90°57′22″ W, 11 Dec. 2005. TAMAULIPAS: UANL-826, Rancho Taffinder, 8 km NNW Nueva Ciudad Guerrero, 26°37′42″N, 99°14′59″W, 14 Oct. 1966; UANL-4226, mouth of the Río Alamo, 5.2 km E Ciudad Mier, 26°25′34″N, 99°06′41″W, 15 Feb. 1982; UANL-8968, Río Salado at El Astillero, 26°51′30″N, 99°35′28″W, 6 Jun. 1985; NUEVO LEON: UANL-8157, Río Salado at Garceño, 27°10′19″N, 100°04′10″ W, 7 Ago. 1984; UANL-8557, Río Salado at La Gloria, 26°53′14″N, 99°48′20″W, 10 Nov. 1984; UANL-8935, Río Salado at La Gloria, *idem*, 6 Jun. 1985; UANL-11628, Río Salado at Rodríguez de Anáhuac, 27°13′59″N, 100°07′43″W, 1982 [no date]; COAHUILA: UANL-15179, Presa Venustiano Carranza (Don Martín), 27°31′24″N, 100°37′51″W, 9 May 2002. Other material examined. VERACRUZ: UANL-1823, Río Papaloapam at Los Amates, 18°17′00″ N, 95°52′00″ W, 14 Dec.1972. TABASCO: UANL-2911, Río Sonapa 18 Km W Huimanguillo, 17°52′00″N 93°28′00″W ,14 Feb. 1978. SAN LUIS POTOSI: UANL-1269, Río Tanquilin SW Camoca, 21°16′00″ N, 99° 03′ 00″ W, 28 Oct., 1971.