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Range expansion of the genus *Sicydium* (Teleostei: Gobiidae) to coastal mountain streams of southwestern Ecuador and possibly northwestern Peru

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Abstract: We report collections of several specimens of *Sicydium* in 2013 and 2014 from the Jubones and Santa Rosa Rivers in southwestern Ecuador. These collections substantially expand the known range of the genus southward. The specimens are tentatively identified as *Sicydium* cf. *rosenbergii* based on their morphology. Small differences in morphology among specimens from the two rivers are noted, as are discrepancies with the type description. A museum database search uncovered two additional records of the genus south of their previously recognized range including one record from northwestern Peru.

Key words: Biodiversity; Neotropics; Pacific Ocean; South America; *Sicydium rosenbergii*

Sicydium Valenciennes, 1837 is an amphidromous genus of goby that inhabits fast-flowing portions of Neotropical streams draining into both the Pacific and Atlantic oceans (Bussing 1998; Kullander 2003). Adult *Sicydium* spawn in freshwater rivers and embryos drift to the ocean, where they undergo a planktonic phase, before swimming back upstream to grow and eventually reproduce (Keith & Lord 2011; Keith et al. 2011). Their amphidromous life histories make them very good at colonizing new streams and the genus exhibits relatively high rates of endemism in some areas (KEITH et al. 2011). However, this life history also puts them at risk given the challenges that migratory species can face in Neotropical streams (Fievet & Le Guennec 1998; Bell 1999; Anderson & Maldonado-Ocampo 2010; Keith & Lord 2011). *Sicydium* are relatively easy to identify to the level of genus because it is one of only two genera of gobies regularly found in Neotropical streams beyond areas of tidal influence (Kullander 2003). The other genus, *Awaous*, is typically found in areas with slower moving waters than *Sicydium*, and is quite distinct morphologically, differing substantially in general body form and color pattern (e.g., Bussing 1998; Jiménez et al. 2015).

Along the Pacific coast of the Americas, the genus *Sicydium* has been reported to occur from near Mazatlan, Mexico (Kullander 2003; Miller 2005) to the Esmeraldas river basin in northwestern Ecuador (Kullander 2003; Barriga 2012; Jiménez et al. 2015; Eschmeyer et al. 2016). There are presently six species considered valid from this area: *S. salvini* Ogilvie-Grant, 1884 from Mexico to Panama (Eschmeyer et al. 2016), *S. altum* (Meek, 1907) from Costa Rica, *S. cocoensis* (Heller & Snodgrass, 1903) from the Cocos Islands, Costa Rica, *S. fayae* Brock, 1942 described from the Tres Marias Islands of Mexico, *S. hildebrandi* Eigenmann, 1918 from Colombia, and *S. rosenbergii* (Boulenger, 1899) collected from 1,067 m of elevation in Paramba, northwestern Ecuador. *Sicydium multipunctatum,* historically described as occurring from Mexico to Honduras, was recently synonymized with *S. salvini* based on an analysis of morphological and genetic data (Chabarria & Pezold 2013). One additional species, *S. condotense* Regan, 1914 described from the Condoto River in southwestern Colombia, has uncertain status (Eschmeyer et al. 2016).

Unfortunately, there has been very little published on the genus from the southern portion of its range in Ecuador. As a consequence, there is uncertainty regarding where the southern limit for the range of the genus is and what species actually occur in Ecuador. The two recent lists of freshwater fishes from western Ecuador both indicate a southern limit for the genus in the Esmeraldas River drainage in northwestern Ecuador, near Colombia (Barriga 2012; Jiménez et al. 2015), as do general references on the genus (e.g., Kullander 2003; Eschmeyer et al.

Figure 1. Photographs of *Sicydium* specimens collected in Ecuador and type specimens for species reported from Ecuador. **A**: Female specimen collected in the Santa Rosa River. **B:** Male (top) and female (bottom) specimens collected in the Jubones River at 136 m site. **C:** Photo voucher of male specimen collected in the Jubones River at 434 m. **D:** Specimen of *Sicydium* sp. collected in the Esmeraldas River drainage showing live colors (ROM 93697). **E:** Syntypes of male (top) and female (bottom) *Sicydium rosenbergii* (BMNH 1899.6.29.26-27). **F:** Holotype of *Sicydium hildebrandi* from Río Dagua, Colombia (FMNH-58465). Scale bars are 10 mm.

2016). A recent comprehensive fish species list for Peru also does not include the genus *Sicydium* (e.g., Ortega et al. 2011). In terms of the species that occur in Ecuador, Barriga (2012) reported two species, *S. rosenbergii* and *S. salvini*, from the Santiago-Cayapas and Esmeraldas drainages in northwestern Ecuador. However, the type locality for *Sicydium salvini* is Panama and it is reported by most authors to occur in Costa Rica and Panama (e.g., Bussing 1998; kullander 2003). Bussing (1998) suggested that reports of this species occurring in South America may be erroneous, bringing into question whether it really occurs in Ecuador. Jiménez et al. (2015) also reported two species of *Sicydium* from the same drainages in northwestern Ecuador. Like Barriga (2012), they reported *S. rosenbergii*, whose type locality is in Ecuador. However, the second species that they listed is *S. hildebrandi*, not *S. salvini*. The type locality for *S. hildebrandi* is the Dagua River in western Colombia, making its occurrence in Ecuador more likely given the geographic proximity. These three species reported for Ecuador are generally similar in morphology and the original species descriptions do not provide interspecific comparisons or specify distinguishing characters, further complicating their identification.

In this paper, we report collections of several specimens of *Sicydium* from two water sheds of southwestern Ecuador close to Peru, the Jubones River and the Santa Rosa River (Figures 1–2), substantially expanding the range for the genus southward. We specifically describe the location and environmental conditions at the collection sites, present meristic and morphometric data on the specimens collected to identify the species, and conduct a search of museum collections to identify other potential unpublished records for the genus in Ecuador and Peru.

The specimens of *Sicydium* (Figure 1) were collected with a Smith Root LR24 Electrofisher backpack and seine and voucher specimens were deposited in museum collections (Table 1). Sampling in the Santa Rosa River was conducted under permit 015-IC-FAN-DPEO-MAE and in the Jubones River under permit 013-14-IC-FAU-DNB/MA from the Ministry of the Environment of Ecuador (Figure 2). All

Table 1. Museum records for *Sicydium* spp. in southwestern Ecuador (south of the Esmeraldas River drainage) and Peru based on searches of Vertnet, Fishnet, and several of the most relevant museums (USNM, FMNH, AMNH, MCZ, FLMNH, SIO, BMNH, MNHN). Records are ordered from north to south.

Species	Drainage	Country	Locality	Latitude	Longitude	Elevation	Year	Museum record[A]	Number of specimens
Sicydium hildebrandi	Taura	Ecuador	Cutuguay Riv.	02°18.207′ S	079°10.399′W	~300 m[B]	2012	ROM 93779	1
Sicydium cf. *rosenbergii*	Jubones	Ecuador	Casacay	03°19.8033′ S	079°42.6817′W	136 m	2014	FMNH 126159 [C]	2
Sicydium cf. *rosenbergii*	Jubones	Ecuador	Río Vivar	03°17.9160′ S	079°36.7524′W	434 m	2014	Photo Voucher [C]	2
Sicydium cf. *rosenbergii*	Santa Rosa	Ecuador	Playon	03°34.8833′ S	079°54.7467′W	189 m	2013	MECN-DP 3511 [C]	1
Sicydium rosenbergii	Chancay	Peru	Carhuaquero[D]	06°36.554′ S	079°15.091′W	~350 m[B]	2007	ROM 91180	1

[A] ROM is the Royal Ontario Museum, FMNH is the Field Museum of Natural History, and MECN is the Museo Ecuatoriano de Ciencias Naturales.
[B] Elevation estimated from latitude and longitude of location on Google Maps™.
[C] Reported in this study.
[D] No locality listed for record. Name taken from closest locality on map.

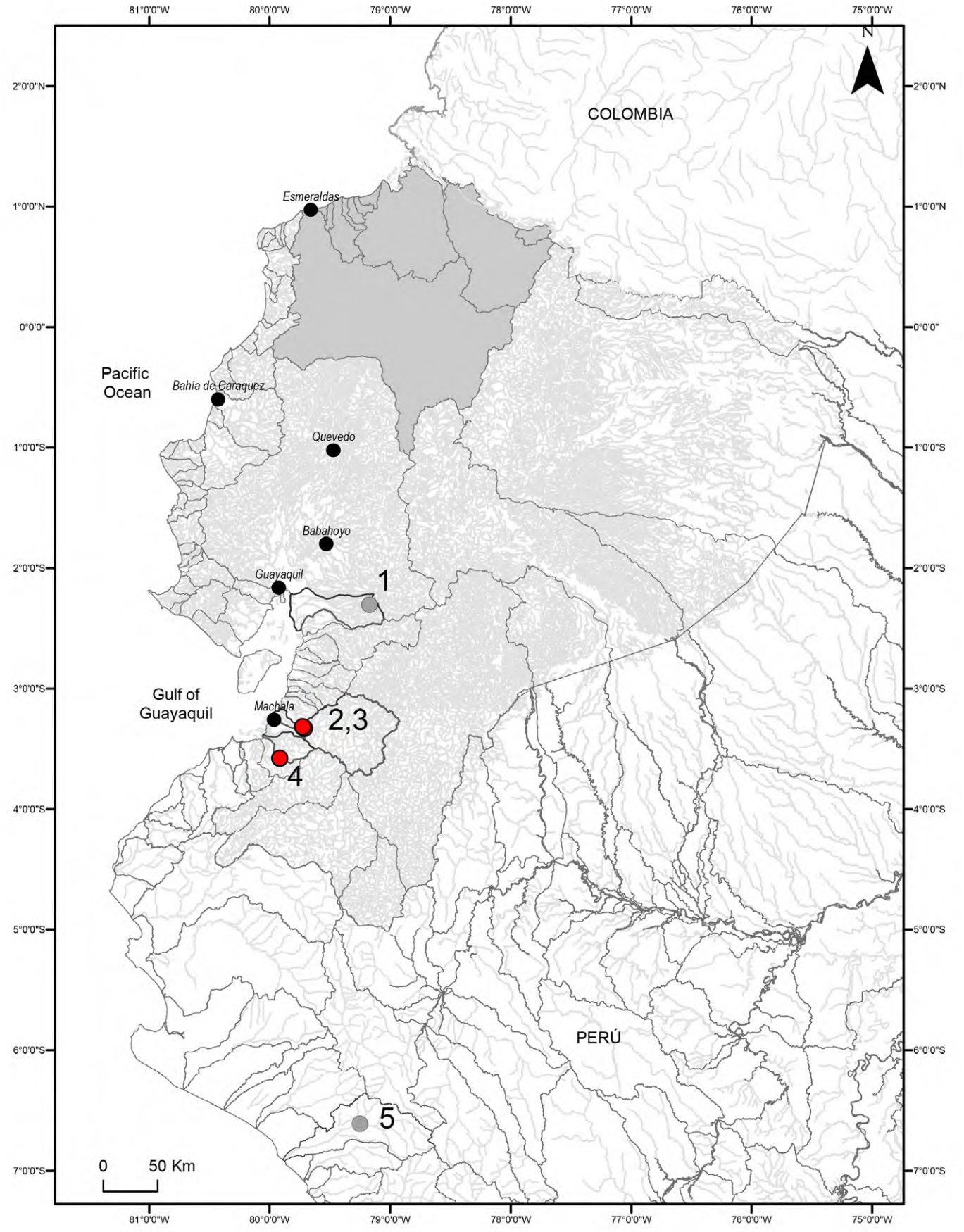

Figure 2. Map of collection localities of *Sicydium* in southwestern Ecuador and northwestern Peru that are south of the previously described southern limit for the genus. Shaded area at the top of the map indicates the previous southern limit for the genus in northwestern Ecuador (Esmeraldas drainage and drainages to the north). Site 1 indicates the site in the Taura River (from the museum database search, ROM 93779), Sites 2 and 3 indicate the two sites in the Jubones River (this study, FMNH 126159), Site 4 indicates the site in the Santa Rosa River (this study, MECN-DP 3511), and Site 5 indicates the site from the Chancay River in northwestern Peru (from the museum database search, ROM 91180). A few major cities included for reference.

Figure 3. Representative habitat in which *Sicydium* cf. *rosenbergii* was collected in southwestern Ecuador. Photo of Jubones River 434 m collection site.

specimens were collected in relatively shallow riffle habitat (Figure 3). Our sampling efforts in the Santa Rosa and Jubones rivers were relatively intense. For the Santa Rosa River, we sampled fish at sites located at 31, 86, 189, 382, and 613 m above sea level and each site was sampled for at least an hour using electrofishing gear and seines in December 2012 and July 2013 (Aguirre et al. 2014; Aguirre et al. 2016). For the Jubones River we sampled sites located at 69, 136, 251, 909, and 1095 m above sea level in July 2014 using the same methods and with approximately similar intensity as for the Santa Rosa River (Aguirre unpublished data). The low number of *Sicydium* specimens collected (total of five) suggests that they are not very abundant in these rivers.

The single specimen from the Santa Rosa River (MECNDP 3511) was collected on 30 July 2013 at an elevation of 189 m at a site located at 03°34.8833′ S, 079°54.7467′ W (Figure 2). *Sicydium* are sexually dimorphic with males typically having greatly extended rays in the first dorsal fin (e.g., Bussing 1998). Based on its dorsal fin length, the Santa Rosa specimen appears to be a female (Figure 1A). At the time of collection, mean water depth was approximately 41.3 cm, velocity was 1.66 m/s, water temperature was 20.3°C, salinity was 0.1 ppt, conductivity was 113.7 µS, oxygen was at saturation (8.28 mg/L), and the bottom consisted primarily of boulder and cobble with some sand, gravel, leaves, and wood debris. No *Sicydium* were collected at the site in December 2012.

A total of four specimens were collected in the Jubones River in July 2014. Two specimens (FMNH 126159) were collected at 136 m in elevation close to the town of Casacay on 27 July 2014 at a site located at 03°19.8033′S, 079°42.6817′W (Figure 2). Based on their dorsal fin lengths (e.g., Bussing 1998), the specimens appear to be a male and a female (Figure 1B). At the time of collection, mean water depth was approximately 61.3 cm, velocity was 0.73 m/s, water temperature was 23.2°C, salinity was 0 ppt, specific conductivity was 45.7 µS, oxygen was at saturation (9.56 mg/L), pH was 8.1, and the bottom consisted primarily of boulder and sand, with some silt, cobble, leaves, algae, and wood debris. Two other specimens were collected at 434 m in elevation as part of a quick survey of a tributary to the Jubones River and a male was photographed fresh in the field (Figure 1C). The sex of the other specimen was not recorded. The site was located at 03°17.9160′S, 079°36.7524′W. At the time of collection, mean water depth was 44.7 cm, velocity was 0.55 m/s, water temperature was 20.5°C, salinity was 0 ppt, specific conductivity was 55.1 µS, oxygen was at saturation (9.75 mg/L), pH was 8.3, and the bottom consisted primarily of sand and boulders/large rocks, with silt and cobble.

To identify the species to which these specimens belonged to and provide information on the morphology of the specimens, we measured several common morphological traits and counted fin rays and scales for the Santa Rosa specimen and the two Jubones specimens collected at 136 m (Table 2). The other two Jubones specimens collected at 434 m were not available for measurement. To examine whether there are other unpublished records of the genus from south of the Esmeraldas River in Ecuador, we searched the Vertnet (http://vertnet.org/index.php) and Fishnet2 (http://fishnet2.net/) online databases, as well as several of the most relevant museum databases, using the search terms "*Sicydium*" and "Ecuador" (Table 1). We repeated the search using the terms "*Sicydium*" and "Peru" given the proximity of the rivers surveyed to Peru.

Unfortunately, the limited number of specimens collected and the size differences among specimens make interpretation of the morphological data collected difficult, so we focus only on the most noteworthy aspects of the phenotypic variation documented. The Santa Rosa female was the largest specimen collected, although the Jubones male was similar length, being just 3.7 mm shorter in standard length (Table 2). The Jubones female was substantially smaller than the other two specimens. The Jubones male had greatly extended rays in the first dorsal fin as characterizes males of the genus, however, other fin measures were also larger in the male relative to both females, including the base of the second dorsal fin (with the rays reaching the caudal fin, which did not occur in either female), the length of the base of the anal fin, the length of the pectoral fin and the length of the caudal fin. The distance between the two dorsal fins was also much shorter in the male and the caudal peduncle was longer than in the females. The male was clearly very distinctive phenotypically and sexual dimorphism is very strong.

There was also notable divergence for a few traits between the Santa Rosa and the Jubones specimens. Although fairly similar in length to the Jubones male, the Santa Rosa female was a much more robust fish. The difference in body width in the anterior part of body between the Santa Rosa and Jubones specimens is very obvious, both from the dorsal (Figure 4A) and ventral perspectives (Figure 4B). In addition, the distance between the first and second dorsal fin seems noticeably larger in

the Santa Rosa female than in the Jubones female (Figure 4A). The Jubones male has a very short distance between the dorsal fins, but this is likely due to sexual dimorphism. There were also differences in pigment patterns in the anal fin among the preserved specimens. The Santa Rosa female has some black pigment that is faint and unevenly distributed throughout the anal fin (Figure 4C). The Jubones male has a relatively thick band of dark pigment at distal edge of the anal fin that is different from the two female specimens (Figure 4D). The Jubones female specimen has a very pronounced, thin and sharp line of dark pigment close to, but not touching, the distal edge of anal fin (Figure 4E). The difference in pigment pattern between the Jubones male and female is likely attributable to sexual dimorphism, but the difference between the Santa Rosa and Jubones females is noteworthy. The teeth in the upper jaw of all specimens were numerous and similar in shape, being bicuspid to truncate depending on wear (Figure 4F–I). However, there was a very curious difference in the pattern of tooth placement between the Santa Rosa and Jubones specimens. The Santa Rosa specimen had teeth alternating between a slightly longer and a slightly shorter tooth (Figure 4F, G), while both the Jubones specimens had a much more pronounced pattern of a long tooth alternating with a much shorter tooth (Figure 4H, I). Finally, the Santa Rosa female seemed to have smaller and more numerous scales, with the number of scales in a traverse series being larger than that for the Jubones specimens. Given the small sample sizes, it is unclear whether these differences are significant.

Table 2. Morphometric and meristic variables measured for the three specimens of *Sicydium* collected in southwestern Ecuador. Total length and standard length given in mm. The other measures given as percentages of standard length.

	Santa Rosa F	Jubones M	Jubones F
Total length (mm)	149.7	148.41	119.54
Standard length (mm)	120.63	116.9	100.48
Expressed as percentage of standard length			
Maximum body depth	16.5	16.2	17.7
Body depth from 2nd dorsal to anal	15.0	14.8	16.7
Head length	20.3	21.4	21.7
Head width	16.7	15.6	17.0
Upper jaw length	10.1	10.7	11.1
Length of eye	3.5	3.2	3.8
Interorbital width	7.0	8.0	8.7
Snout length	8.9	8.9	9.7
Postorbital length	8.9	10.2	9.4
Body width	13.4	11.6	12.8
Predorsal length	33.4	32.5	33.7
Snout to 2nd dorsal	57.3	54.2	57.0
Snout to pectoral	22.2	23.4	23.7
Snout to pelvic	18.5	19.6	20.1
Preanal length	57.1	54.3	59.2
Length of first dorsal base	18.8	20.4	19.8
Length of second dorsal base	26.9	30.0	26.5
Length of longest dorsal ray	15.5	49.1	16.3
Length between 1st and 2nd dorsal	6.8	2.0	5.2
Length of anal base	22.9	26.6	22.7
Length of pectoral fin	19.1	22.9	18.0
Length of caudal fin	25.0	26.6	20.0
Depth of caudal peduncle	11.1	11.0	11.2
Length of caudal peduncle	19.1	21.4	19.2
Meristics			
Dorsal fin	vi, i–10	vi, i–10	vi, i–10
Anal fin	i–10	i–10	i–10
Pectoral fin	19	19	19
Scales in lateral series*	80	77	75
Scales between 2nd dorsal and anal*	25	20	21

*Scale counts are approximate.

The methods of measurement followed HUBBS & LAGLER (2004) except for traits measured not described there: Body depth from 2nd dorsal to anal measured from the origin of the 2nd dorsal fin to the origin of the anal fin, Body width measured between the insertions of the pectoral fins, Snout to 2nd dorsal measured from the tip of the snout to the origin of the 2nd dorsal fin, Snout to pectoral measured from the tip of the snout to the insertion of the left pectoral fin, Snout to pelvic measured from the tip of the snout to the insertion of the left pelvic fin, Preanal length measured from the tip of the snout to the origin of the anal fin, Length between the 1st and 2nd dorsal measured from the posterior end of the membrane of the last ray of the first dorsal fin to the origin of the first ray of the second dorsal fin, and the length of caudal fin measured from the posterior end of the hypural plate to the posterior-most tip of the caudal fin. We note that the caudal peduncle length was measured from the posterior base of the last ray of the anal fin to the posterior end of the hypural plate as indicated by HUBBS & LAGLER (2004) and not from the base of the last ray of the dorsal fin as done by WATSON (1995).

Despite the morphological differences described above, the Jubones and Santa Rosa specimens were similar for the major characteristics used to distinguish species of *Sicydium* along the Pacific coast of the Americas. Of the three species previously reported for Ecuador, *S. salvini* can be ruled out based on the form of its teeth. *Sicydium salvini* has very pronounced tricuspid teeth (BUSSING 1998) while all specimens examined here clearly have bicuspid to truncate teeth. Of the two remaining species, the specimens seem to fit the description of *S. rosenbergii* better than that of *S. hildebrandi* (BOULENGER 1899; EIGENMANN 1918), although there are significant discrepancies with both species. The scales in a lateral series are higher in *S. rosenbergii* (70–76) than *S. hildebrandi* (70), and the scale counts of our specimens were high and closer to *S. rosenbergii* (Table 2). Body depth for *S. rosenbergii* is listed as fitting 6 times in body length, while it fits 5.5 times in *S. hildebrandi*. The Santa Rosa female and Jubones male fit 6.1 and 6.2 in SL, while this value was 5.7 in the Jubones female. Head length is listed as fitting 5–5.5 times in body length in *S. rosenbergii* while it is 5.25 for *S. hildebrandi*. All our specimens were just below 5 for this ratio (4.6–4.9) and thus closer to the lower limit listed for *S. rosenbergii*. *Sicydium rosenbergii* is also the only species of the genus originally described from Ecuador. However, some features do not fit the description for *S. rosenbergii*. Besides the small deviations listed above, the scales in a traverse series are listed as 16–17 for *S. rosenbergii* while we count 20 or more in our specimens. Eye diameter is listed as fitting 5 times in the length of the head while our specimens have measures for this ratio close to or above 6, making them more similar to *S. hildebrandi*. However, eye diameter is known to decline with size as fish increase in body size so this difference may be due to allometry given the size of the type for *S. rosenbergii* (113 mm total length).

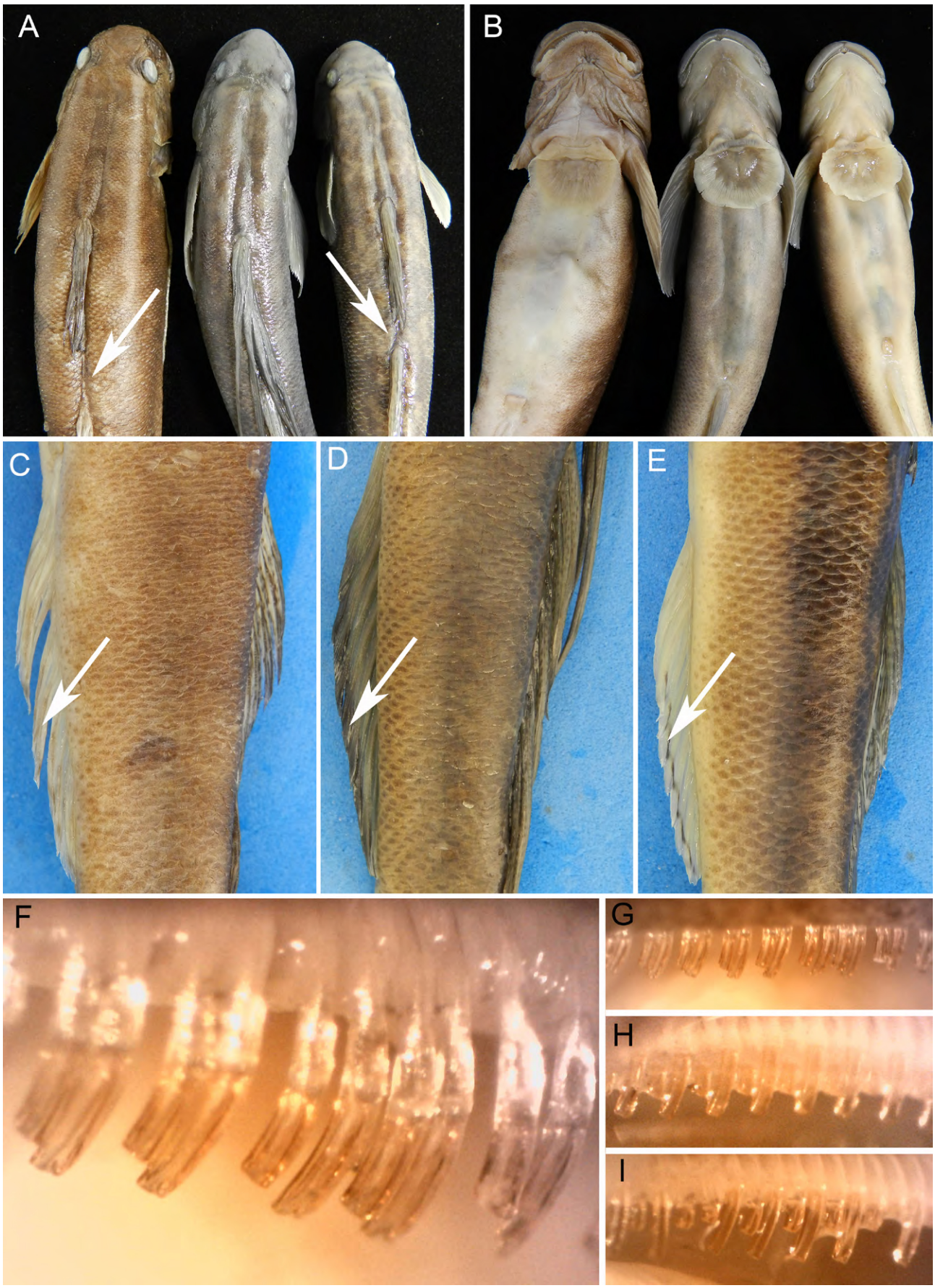

Figure 4. Morphological variation among specimens collected in southwestern Ecuador. **A:** Differences in dorsal form between Santa Rosa, Jubones male, and Jubones female specimens. Arrows point to an apparent difference in the distance between the first and second dorsal fins in the Santa Rosa and Jubones females. **B:** Differences in ventral form among specimens. Order the same as in A. **C–E:** Differences in pigment pattern on the edge of the anal fin between Santa Rosa (C), Jubones male (D), and Jubones female (E) specimens. **F:** Closeup of upper jaw teeth of Santa Rosa specimen. **G-I:** Tooth placement pattern in Santa Rosa (G), Jubones male (H), and Jubones female (I) specimens.

Additionally, examination of photographs of the syntypes of *S. rosenbergii* and the type of *Sicydium hildebrandi* clearly show that they have scales on the belly, while all three of the specimens examined here have a descaled region on the belly.

Of other species occurring along the Pacific Coast of the Americas, *S. adelum* and *S. altum* can be ruled out on the basis of tooth shape since they have tricuspid teeth like *S. salvini* (Bussing 1996). *Sicydium condotense* from Colombia and *S. cocoensis* can be ruled out on the basis of differences in scale counts, with both having 60 or less scales along a longitudinal series (Regan 1914; Bussing 1996). *Sicydium fayae* can be ruled out on the basis of its distinctive color pattern and higher number of scales, approximately 106 in males and 89 in females (Brock 1942). Thus, we tentatively identify the specimens described here as *Sicydium* cf. *rosenbergii* noting the morphological differences observed between the Santa Rosa and Jubones rivers and deviations from the description of the type of the species. Whether the differences we note represent intraspecific variation or constitute an undescribed species will require a more comprehensive analysis of material from throughout the Pacific coast of South America.

Our field collections substantially expanded the known range of the genus to coastal mountain streams in southwestern Ecuador, close to the border with Peru. To examine whether there might be additional unpublished records of *Sicydium* south of Esmeraldas drainage, we conducted a search of online Museum databases, which turned up two records (Table 1). One is a specimen identified as *S. hildebrandi* collected in 2012 in the Cutuguay River in Cañar province by D.C. Taphorn and collaborators (ROM 93779). The Cutuguay River is a tributary of the Taura River, which runs very close to the Guayas River and drains independently into the Gulf of Guayaquil. This collection site is east of the city of Guayaquil along the western slope of the Andes and significantly north of the Jubones and Santa Rosa Rivers. The other record is a specimen identified as *S. rosenbergii* from the vicinity of Carhuaquero in northwestern Peru collected in 2007 by J.C. Tetreault (ROM 91180). Based on the location of the GPS coordinates, the specimen appears to have been collected at approximately 350 m of elevation, making it unlikely to be another goby genus. If correctly identified, this would constitute the southernmost record for the genus *Sicydium* along the Pacific coast of South America. Given that much of the fish fauna is shared between southwestern Ecuador and northwestern Peru, and that *Sicydium* is an excellent colonizer of coastal mountain streams, this record is certainly plausible.

Curiously, we found no records of the genus *Sicydium* from the Guayas River drainage, which is the largest and most species rich drainage in western Ecuador (Jiménez et al. 2015), and is located between the previously listed southern limit and the new records reported here. The Guayas River has been sampled relatively well because of its size and importance (e.g., Barnhill-Les et al. 1974; Barriga 2012; Revelo & Laaz 2012; Jiménez et al. 2015). We suspect that its apparent absence or rarity in the drainage may be due to its life history requirements. Lyons (2005) analyzed the distribution of *Sicydium* along the Pacific and Atlantic coasts of Central America and found the presence of *Sicydium* was strongly associated with the distance between ocean and suitable adult habitat. He hypothesized that the larvae or juveniles may starve during migration between the ocean and the adult mountain stream habitat if the distance is too long (approximately greater than 60–75 km). This scenario seems consistent with our data from western Ecuador. The Santa Rosa and Jubones rivers are mountain streams lacking large flood plains and the distance between the ocean and the adult habitat is relatively short. The Guayas River, on the other hand, has the largest large flood plain in the region and the distance between ocean and suitable adult habitat is typically greater than in other rivers.

In conclusion, we report verified collections of *Sicydium* from two different costal mountain streams in southwestern Ecuador, significantly extending the known range of the genus southward. The specimens are tentatively identified as *Sicydium* cf. *rosenbergii* based on their morphological characteristics, but there seem to be quite a few discrepancies between the specimens we examined and the possible described species. A revision of the genus in northwestern South America is needed and our identification should be verified once knowledge of the genus in the region increases. We also report the existence of specimen-based records from the Royal Ontario Museum of the genus from the Taura River in southwestern Ecuador and the Chancay River in northwestern Peru. The latter would extend the range even farther south. The collection of specimens over multiple years in four different rivers from the region, and the relatively large size of the specimens from southwestern Ecuador reported here, suggests *Sicydium* is established at least to southwestern Ecuador and possibly northwestern Peru. However, it does not seem to be very abundant in the region based on the low number of specimens collected. Unfortunately, Western Ecuador is heavily impacted by numerous anthropogenic factors (e.g., Aguirre et al. 2013; Jiménez et al. 2015) and much remains to be learned about the fish fauna (e.g., Tan & Armbruster 2012; Román-Valencia et al. 2013; Lujan et al. 2015), making appraisal of the current status of *Sicydium* in the area all the more urgent.

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