

Description of a new killifish of the genus *Rivulus* (Teleostei: Cyprinodontiformes: Rivulidae) from south eastern Peru

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> Abstract

Rivulus parlettei spec. nov. from south eastern Peru (Departamento Cusco) is described. It is a member of the *R. limoncochae* group (as diagnosed by COSTA, 2010) and differs from all the other species of this assemblage by its unique colour pattern and different morphology. It is distinguished from its geographic neighbour *R. christinae* by irregular interrupted lines of dots wider than the interspaces on body sides (versus longitudinal rows of dots forming stripes narrower than the interspaces). The influence of the occupation of distinct microhabitats for the radiation of the clades and the possible process of speciation of the new species are briefly discussed.

> Resumen

Rivulus parlettei spec. nov. del sureste del Perú (Departamento Cusco) está descrito. Se trata de un afiliado del grupo de *R. limoncochae* (comprobado por COSTA, 2010) y se diferencia de todas las otras especies de este conjunto por su único patrón de coloración y la diferencias morfológicas. Esta diferenciado por su vecino geografico *R. christinae* por líneas interrumpidas de puntos mas largos que los espacios entre ellos sobre las laderas del cuerpo (versus líneas longitudinales de puntos formando líneas menos largas que los espacios entre ellos). La influencia de la ocupación de diferentes microhabitats para la radiación de los clados y el proceso posible de especiación es discutido en breve.

> Key words

Killifish, *Rivulus*, *Cynodonichthys*, new species, taxonomy, Peru, departamento Cusco, Rio Inambari drainage.

Introduction

The killifish genus *Rivulus* POEY, 1860 constitutes the most speciose (more than 125 species) and geographically widespread assemblage of American aplocheiloid fishes. Species of the genus occur from Middle America (Mexico and the Caribbean Islands) to northern Argentina in South America. In the current use the genus is possibly paraphyletic (HRBEK & LARSON, 1999; COSTA, 2006). The taxon *Rivulus* however comprises several monophyletic species assemblages, i.e. subgenera, (HUBER, 1992, 1999; COSTA, 2006, 2008), which are supported by phylogenetic analyses based on morphological and molecular

data (COSTA, 1998, 2006; HRBEK & LARSON, 1999; VERMEULEN & HRBEK, 2005). The most species rich subgenus is *Cynodonichthys* MEEK, 1904 (COSTA, 2006). The species subsumed under *Cynodonichthys* are divided into numerous putative monophyletic species groups or superspecies (HUBER, 1992, 1998, 1999; COSTA, 2010). Based on eidonomical features COSTA (2010) recently re-defined the *R. limoncochae* group and included the following species: *Rivulus christinae*, *R. erberi*, *R. intermittens*, *R. iridescens*, *R. rubrolineatus* and *R. taeniatus*.

During a killifish survey in October 2004 through the south-east of Peru C. PARLETTE and L. PECK collected *R. christinae* and another *Rivulus* species of the *R. limoncochae* group, which could not be attributed to either of the hitherto known species. This in the vicinity of Vitobamba (departemento Cusco) collected new species is described here.

Material and methods

Measurements and counts were taken as described in AMIET (1987), HUBER (1992) and VALDESALICI (2010). Measurements were made with a digital caliper, under a dissecting microscope, and rounded to the nearest 0.1 mm. All measurements are presented as percentages of standard length (SL), except for eye diameter and snout length, which are given as percentage of head length (HL). Terminology of the cephalic neuromast series follows COSTA (2001). Terminology of the frontal squamation as described in HOEDEMAN (1958) and HUBER (1992). Osteological preparations (cleared and stained, C&S) were made according to TAYLOR & VAN DYKE (1985), but not stained for cartilages.

Types and additional material are deposited in the following institutions: Museo de Historia Natural, Universidad San Marcos (MUSM), Lima, Peru; National Museum of Natural History, Smithsonian Institution (USNM), Washington, DC, USA; Museo Civico di Storia Naturale "G. Doria" (MSNG), Genova, Italy; Senckenberg Naturhistorische Sammlungen Dresden, Museum für Tierkunde (MTD), Germany.

Data from HUBER (1992) and COSTA (2006) were used for comparisons.

Comparative material: *Rivulus christinae*: USNM 399460, 1 male and 1 female; MSNG 56049, 1 male (C&S); Peru, Departamento Madre de Dios, rio De Las Piedras drainage (12.417 S 69.251 W).

Rivulus parlettei spec. nov.

Figs. 1–2, Table 1

Holotype. MUSM 39906, male, 37.7 mm SL, Peru, Departamento Cusco, río Inambari system, río Araza drainage (13.313 S 70.803 W), at an altitude of approximately 820 m asl, 20th October 2004, leg. C. PARLETTE and L. PECK.

Paratypes. USNM 399459, 1 female, 33.2 mm SL, MSNG 56048A, 1 male, 29.7 mm SL; MSNG 56048B, 1 female, 30.3 mm

SL, MSNG 56048C, 1 male 30.0 mm SL (C&S), MTD 32437, 1 female, 32.6 mm SL; all collected with holotype.

Diagnosis. Males of *Rivulus parlettei* are distinguished from males of the remaining members of the *R. limoncochae* group by irregular interrupted lines of dots wider than the interspaces (versus longitudinal rows of dots, sometimes coalescing to form stripes narrower than the interspaces), by an inferior lip without distinctive colouration (versus red inferior lip), a dorsal and anal fin without a dark posterior tip (versus presence of dark tip), a light blue venter (versus yellow in *R. christinae* and white in the remaining species of *R. limoncochae* group) and a yellowish anal fin with a whitish basal region (versus yellow with light blue basal region). Females of *R. parlettei* can be distinguished from females of the other species of the *R. limoncochae* by the presence of variable shaped orange spots on body sides (mainly above anal fin) forming oblique bars (versus absence of spots or spots forming stripes), by a yellow-orange ventral parts of head, venter and caudal peduncle (versus light blue to light brown) and by having orange to yellow paired fins (versus yellowish hyaline or hyaline paired fins). An additional distinguishing feature of *R. parlettei* is the position of its dorsal-fin origin (dorsal fin origin above base of 7th or 8th of anal-fin ray versus 9th or 12th anal-fin ray in *R. christinae*, *R. erberi*, *R. iridescens*, *R. rubrolineatus*, and *R. taeniatus*).

Description. Measurements are summarised in Table 1. Largest examined male 37.7 mm SL; largest examined female 33.2 mm SL. Dorsal profile slightly convex from snout to end of dorsal fin base, about straight at caudal peduncle. Ventral profile slightly convex from lower jaw to anal fin origin; approximately straight from anal fin to posterior end of caudal peduncle. Body slender, subcylindrical anteriorly, compressed posteriorly, greatest body depth at midlength between pectoral fin base and anal fin origin. Snout short, rounded. Dorsal and anal fin rounded, without filaments in both sexes. Pectoral fins rounded. Pelvic fins small, reaching anus. Caudal fin rounded. Dorsal fin origin above base of the 7th or the 8th anal fin ray. Dorsal fin rays 8–9; anal fin rays 13–14; caudal-fin rays 24; pectoral-fin rays 13–14; pelvic-fin rays 6. Scales large, cycloid. Body and head entirely scaled. No scales on dorsal-fin and anal-fin base. Frontal squamation E-patterned. Longitudinal series of scales 37–40. Cephalic neuromasts: supraorbital 3+3. Lateral line interrupted. Basihyal subtriangular. Second pharyngobranchial with two teeth. Vomerine teeth 2. Lateral process of post-temporal short. Bifid antero-dorsal process of urohyal. Total vertebrae 30.



Fig. 1. *Rivulus parlettei*, MUSM 39906, male, holotype, 37.7 mm SL, Peru, río Araza drainage.



Fig. 2. *Rivulus parlettei*, female Peru, río Araza drainage.

Colouration. Body sides of males (Fig. 1) metallic green-yellow, dorsolateral portion of body between postorbital region and anterior portion of flank pale brownish with dark brown mottling; broad interrupted lines comprised of red dots on entire flank. Dorsum brownish. Venter light blue. Opercular region green-yellow. Ventral part of head light blue. Upper jaw light brown, lower jaw dark brown. Iris yellow. Dorsal fin pale yellowish with a transverse red stripe and short oblique red bars on posterior portion. Anal fin pale yellowish, base whitish with red spots on posterior portion. Caudal fin pale yellowish to hyaline on posterior margin and with red spots on proximal portion. Pelvic fins yellowish. Pectoral fins yellowish to hyaline. Body sides of females (Fig. 2) light yellow, with irregular dark brown mottling and orange spots and oblique marks of variable shape, forming three irregular lines on caudal peduncle. Dorsum brownish. Venter orange yellow. Opercular region with large dark brown blotch. Ventral part of head yellow. Upper jaw light brown; lower jaw yellow. Iris yellow. Dorsal fin hyaline to pale yellow-

ish with three transverse dark brown to black stripes. Anal fin yellow, base whitish with red spots. Caudal fin hyaline, with 5 narrow brown to black bars, yellow on ventral portion; close to its dorsal margin with small, vertically elongate black spot, proximal margin with a small light yellow zone. Pelvic fins and pectoral fins yellow.

Distribution. Currently known only from the type locality, a small stream belonging to the río Araza in the vicinity of Vitobamba, at an altitude of about 820 m asl, Departamento Cusco, south eastern Peru (Fig. 3).

Habitat notes. Type specimens were collected in a small forest stream (Fig. 4) and in an adjacent shallow pool with mud and leaf litter on its ground. The water was clear and transparent; temperature about 25 °C, pH approx. 7 and electric conductivity about 15 µS/cm. No other fish species was found there.

Etymology. Named after Casey PARLETTE, who collected the type specimens.

Table 1. Morphometric data of *Rivulus parlettei*. All measurements are presented as percentages of standard length, except eye diameter and snout length as percentages of head length, standard length in mm.

	holotype	males (n = 3)	females (n = 3)
Standard length	37.7	29.7–37.7	30.3–33.2
Depth at pelvic fins	21.2	20.8–21.2	17.1–21.1
Predorsal length	77.7	77.4–77.7	76.2–76.6
Preanal length	61.0	61.0–62.6	61.0–62.7
Prepelvic length	50.3	50.3–53.1	50.0–50.4
Caudal peduncle length	21.7	19.8–21.7	19.8–20.8
Caudal peduncle depth	12.9	12.9–13.8	10.8–11.9
Head length	25.4	25.4–28.9	25.4–27.7
Snout length	29.1	24.4–29.1	22.6–25.5
Eye diameter	29.1	25.4–29.1	25.5–30.1

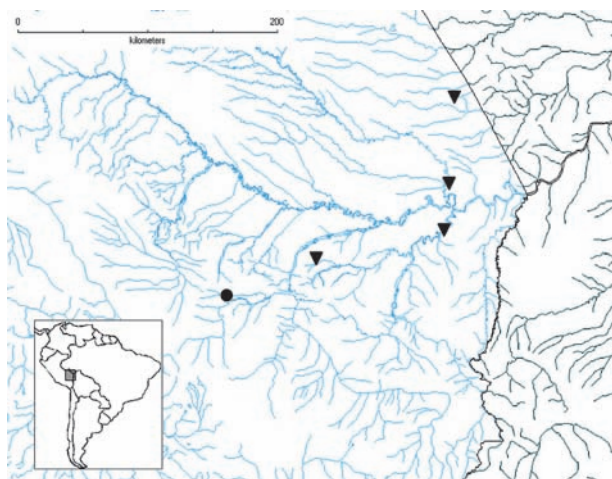


Fig. 3. Distribution map of *Rivulus parlettei* (circle) and *Rivulus christinae* (inverted triangle).



Fig. 4. Habitat (type locality) of *Rivulus parlettei*.

Discussion

The taxon *Rivulus* is a diversified and in a cladistic sense probably a non-monophyletic unit (HRBEK & LARSON, 1999; VERMEULEN & HRBEK, 2005; COSTA, 2010, COSTA & DE LUCA, 2011). The type species of the genus *R. cylindraceus* POEY 1860 belongs to a basal clade and is phylogenetically not closely related to the species treated herein (HRBEK & LARSON, 1999; COSTA, 2006). Nevertheless, we include the new species in *Rivulus* because it is in congruence with the re-descriptions and the current use of the genus (e.g. COSTA, 1998, 2006, 2008, 2010; HUBER, 1992, 1999).

The subgenus *Cynodonichthys* (recently re-described by COSTA, 2006) includes more than 60 species from Middle and South America. The species from the coastal river basins of eastern Brazil listed as *Cynodonichthys* were later transferred to the recently erected subgenus *Atlantirivulus* COSTA (2008).

The taxa *Vomerivulus* FOWLER and *Oditichthys* HUBER were treated as synonyms of *Cynodonichthys* in COSTA (2006). COSTA & DE LUCA (2011) however re-used *Oditichthys* as a conceivably subgenus. *Cynodonichthys*, as defined by COSTA (2006), is characterised by the presence of yellow stripes on the dorsal and ventral caudal-fin margin in males. This character state is often inconspicuous or even absent in some members (COSTA, 2006). In a cladistic sense this character state is consequently ambiguous and taxonomically doubtful to constitute *Cynodonichthys*. Nevertheless, we recognise and endorse *Cynodonichthys* in the sense of COSTA (2006, 2008, 2010) as a convenient assemblage because no contrary phylogenetical analysis is available. *Rivulus parlettei* is considered to be a member of the subgenus *Cynodonichthys*.

COSTA (2010) re-defined the *R. limoncochae* species group to include six species, viz. *R. christinae*, *R. erberi*, *R. intermittens*, *R. iridescens*, *R. rubrolineatus* and *R. taeniatus*. These are distributed in the western



Fig. 5. *Rivulus christinae*, male, Peru, río De Las Piedras drainage.



Fig. 6. *Rivulus christinae*, female, Peru, río De Las Piedras drainage.



Fig. 7. *Rivulus christinae*, male, Peru, río Manuripi drainage.

parts of the Amazonian drainage. He discriminated this group from the *urophthalmus* group by the possession of contact organs on the flanks of males (versus contact organs absent) and by the presence (versus absence) of an oblique transverse stripe on the

middle of dorsal fin (COSTA, 2006). Whereas, HUBER (1998, 1999) found no diagnostic characters to separate species of the *R. limoncochae* group and the *R. urophthalmus* group. He mentioned that it is difficult to provide clear cut key characters to discriminate be-



Fig. 8. *Rivulus christinae*, female, Peru, río Manuripi drainage.



Fig. 9. *Rivulus christinae*, male, Peru, río Tambopata drainage.

tween these rivulids because of their phenotypically similarity and their variation even at population level. In this study we recognise the *R. limoncochae* group as a taxonomic unit only because it allows a better handling of the subsets of the subgenus and we do not consider it as a phylogenetically robust clade.

In the *R. limoncochae* group, *R. parlettei* is hypothesised to be closely related to its geographic neighbour *R. christinae* (Figs. 5–9). Both are differentiated by divergent character states mentioned in the diagnosis. Additionally the distribution of *R. christinae* is (so far known) limited to the plains at the western border of the Departamento Madre de Dios (HUBER, 1992; STAECK, 1994; this study). It occurs in the río Madre de Dios drainage including río de las Piedras, río Marcapata, río Manuripi and río Tambopata. In contrast, *R. parlettei* occurs more to the west on the most eastern foothills of the Andes at a comparatively high altitude of about 820 m asl in the upper río Inambari system in the Departamento Cusco. The Inambari area is associated with the refuge hypothesis as a model of vertebrate speciation in Amazonia and is characterised by a high diversity of endemic species (HAFFER, 2008). Furthermore, analy-

ses of freshwater fish beta diversity have shown that neighbouring areas differing in altitude often harbour dissimilar sets of species (LEPRIEUR *et al.*, 2011). Such differences in species composition may reflect an adaptation to abiotic conditions by range shifts or by vicariance (LEPRIEUR *et al.*, 2011). A similar pattern of vicarious distribution as found for *R. parlettei* and *R. christinae* is known from *Hemibrycon inambari*, occurring only in the upper parts of the río Alto Madre de Dios and the río Inambari drainages, and *H. jelskii*, which inhabits the lower parts of these river systems (BERTACO & MALABARBA, 2010). There are also vicarious species pairs in Cyprinodontiformes. For instance the evolutionary process of speciation and separation of species along an elevational gradient is well documented in some species pairs of the poeciliid genus *Xiphophorus* (e.g. *X. malinche* and *X. birchmanni*; *X. clemenciae* and *X. helleri*) from the Atlantic slopes of the Sierra Madre in Mexico (KALLMAN & KAZIANIS, 2006; CULUMBER *et al.*, 2010). Thus, it is not unlikely that *R. parlettei* evolved from a peripherally isolated allopatric population of its putative sister species *R. christinae*. Speciation based on peripheral isolation is well known in evolutionary biology and

is thought to be a major factor in the evolution of new species (MAYR, 1967). HUBER (1998) discussed the relevance of a separation along elevational gradients, the significance of refuge areas and the importance of isolated population at the periphery of distribution areas as factors in the speciation within the Killifish. He argued that such peripheral species (called ‘frontier species’ by HUBER, 1998) are usually characterised by a restricted distribution (in comparison to their sister taxon), by a distinctive colour pattern (particularly on the body sides of males) and a divergent position of the dorsal-fin origin in comparison to that of the anal fin. With all these three requirements being met in *R. parlettei* (cf. figures 1–2, 5–9 for differences in colour pattern; dorsal fin origin above base of the 7th or the 8th anal fin ray in *R. parlettei* versus the 9th or 10th anal fin ray in *R. christinae*), it is likely that it represents an independent lineage in the sense of the evolutionary species concept sensu WILEY (1978).

Field observation in the habitats of the Amazonian species of *Rivulus* revealed that different lineages occupy distinct kinds of biotops, suggesting a divergent specialisations during the evolution of the species clades (COSTA, 2006). Subsequent studies (e.g. SCHINDLER & ETZEL, 2008; SCHINDLER & VALDESALICI, 2011) confirm this observation for the subgenera *Melanorivulus* and *Owiye*. The tendency of species or groups of monophyletic clades to maintain the ancestral ecological traits of their lineages over time is discussed and known as ‘phylogenetic niche conservatism’ (LOSOS, 2008; WIENS *et al.*, 2010). In the case of the cis-Andean *Rivulus* the retained ecological trait (as discussed in COSTA, 2006) is the occupation of a similar habitat or microhabitat (resource utilisation) in related species. For example all the members of the *Rivulus limoncochae* group, including *R. parlettei*, prefer shallow creeks at sunny glades in forest areas. This may be regarded as phylogenetic niche conservatism. It seems to be a well-founded hypothesis that the ancestral ecology played a role both during the evolution of the different groups and speciation (cf. COSTA, 2006). However, habitat data of as many species of *Rivulus* as possible have to be compared in a phylogenetic framework (cf. LOSOS, 2008; WIENS *et al.*, 2010) in order to confirm the hypothesis that there is a tendency of species or monophyletic groups to maintain the ancestral ecological traits of their clade.

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