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Fish and limnology of a thermal water environment in subtropical South America

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Synopsis

Two thermal sources with water temperatures from 51 to 59°C flow into a stream of 2 to 5 m width and about 0.5 m depth at Agua Caliente (23° 44′S, 64° 38′W) in Jujuy province, Argentina. Data from 3 years sampling show that the influence of the thermal sources maintains the water temperature of the stream section at a high and constant level (from 24 to 35°C), different from the thermal regime of other streams in the area. Composition of water (N = 13) has the following mean values: pH 8.36, conductivity 1591 $\mu S\ cm^{-1}$, dominant ions (in $mg\ l^{-1}$) CO_3^{--} 12.77, CO_3H^- 140.27, Cl^- 246.86, SO_4^{--} 460.14, Na^+ 400.45, K^+ 2.18, Ca^{++} 27.68 and Mg^{++} 2.14. Mean total dissolved solids: 1.3 $g\ l^{-1}$. Large amounts of SO_4^{--}, Na^+, and Cl^- are noticeable traits. Sixteen fish species (2460 specimens) were captured in the warmed reach. Dominant families were Characidae, Cichlidae and Loricariidae. New geographic distribution information is provided for eight species, some of them with restricted northwestern Argentina distributions. Most abundant species were the eurytopic characid *Astyanax bimaculatus*, followed by the cichlid *Bujurquina vittata*. These species have the highest critical thermal maximum according to field experiments. Temperature of acclimatization is closer to lethal than in fishes from 'normal' habitats. Agua Caliente differs from other thermal habitats in the lack of isolation, its placement in a rain forest area, a high number of species, and the lack of cyprinodontoids. The fish fauna here represents an opportunistic invasion of a habitat with water parameters strongly different from those in the area, particularly temperature and salinity. Both faunistic and limnological traits make of Agua Caliente a new type of environment within the subtropics.

Introduction

Northwestern Argentina is ichthyologically still a little known area. Within it, the fish fauna in the provinces of Salta and Jujuy, with about 15 to 20 species, is not especially rich (Ringuelet et al. 1967a, Ringuelet 1975, Arratia et al. 1983, Menni et al. 1992). Lower locations are considered part of the Paranensean province (Ringuelet 1975) although the exact western range of the province is still unsettled.

During the last ten years we have been studying the Argentinean ichthyofauna north of 36°S, establishing the faunistic composition of numerous basins. These include highlands in Cordoba in central Argentina (Menni et al. 1984), highlands in Sierra

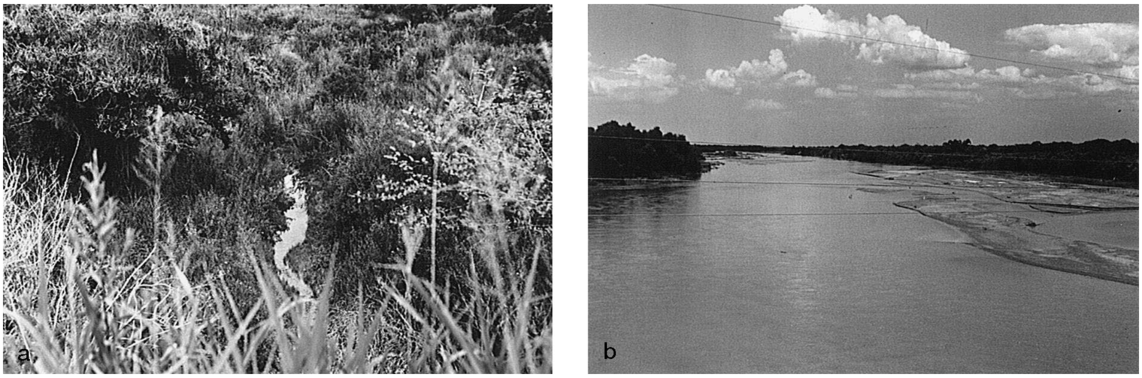

Figure 1. a – Agua Caliente, view of the creek. b – The San Francisco River near Agua Caliente, looking northeast (photograph by R.C. Menni).

de la Ventana in Buenos Aires (Menni et al. 1988), the Salado and Dulce rivers in Santiago del Estero (Casciotta et al. 1989), small tributaries of the Uruguay River and the Salto Grande Reservoir (López et al. 1984). Other locations in northeastern and western central Argentina (Miquelarena et al. 1990, Menni et al. 1996) and environments of the Pilcomayo–Paraguay basins in Formosa (Menni et al. 1992) were also studied. Two major patterns are evident in these areas (Ringuelet 1975, Arratia et al. 1983); the extension toward the NW of the so called Paranensean fauna, and the presence in nortwestern Argentina of several endemic species mainly related to endorrheic basins. Relative richness at the present appears related to climatic factors. This is suggested by the large number and abundance of species in the wet eastern sections of Formosa related to the Paraguay River. In contrast, the western dry section related to the more seasonal Pilcomayo River is poorer (Menni et al. 1992). In spite of this, specific composition is rather similar, so it is probably more influenced by historical than by climatic factors. Lack of phylogenetic data for any of the involved groups precludes other analyses. Moreover, the Brazilian-related Argentinean fauna is composed of a peripheral set of species, many of them traditionally assigned to more northerly forms, that often prove to be different, or new species, when closely examined. Among environments we sampled in northwestern Argentina, the Agua Caliente stream deserved study because its special ecological traits and fish composition.

The creek we studied here, Agua Caliente – literally 'Hot Water' – is an eastern tributary of the large San Francisco River (Figure 1a). This river and the Río Grande de Tarija are the main tributaries of the Bermejo River, which drains a basin that is a tributary to the Paraguay River (Figure 1b). No references are available about the fishes from the San Francisco River. Some species are reported from the Río de Las Piedras (Arratia et al. 1983), which enter the San Francisco River from the West about 13 km northward from Agua Caliente. These species are *Odontostilbe hastata, O. microcephala, Astyanax bimaculatus paraguayensis*, one species of *Bryconamericus* and one *Creagrutus. Parodon tortuosus* and *Cheirodon piaba* are apparently known from a nearby creek, but the locality is not clearly stated.

Thermal sources are common in northwestern Argentina because of the proximity of the Andes, and thermal waters are often used for human medicine and pleasure (Palanca 1991). Here we analyse a particular lotic habitat in a subtropical area (the tropic of Capricorn runs 18° northward of Agua Caliente), with environmental and faunistic characteristics strongly influenced by thermal sources. Its faunistic composition is described,the physical and chemical traits of the water are considered within the framework of local and general limnology, and the thermal resistance of several species is analyzed.

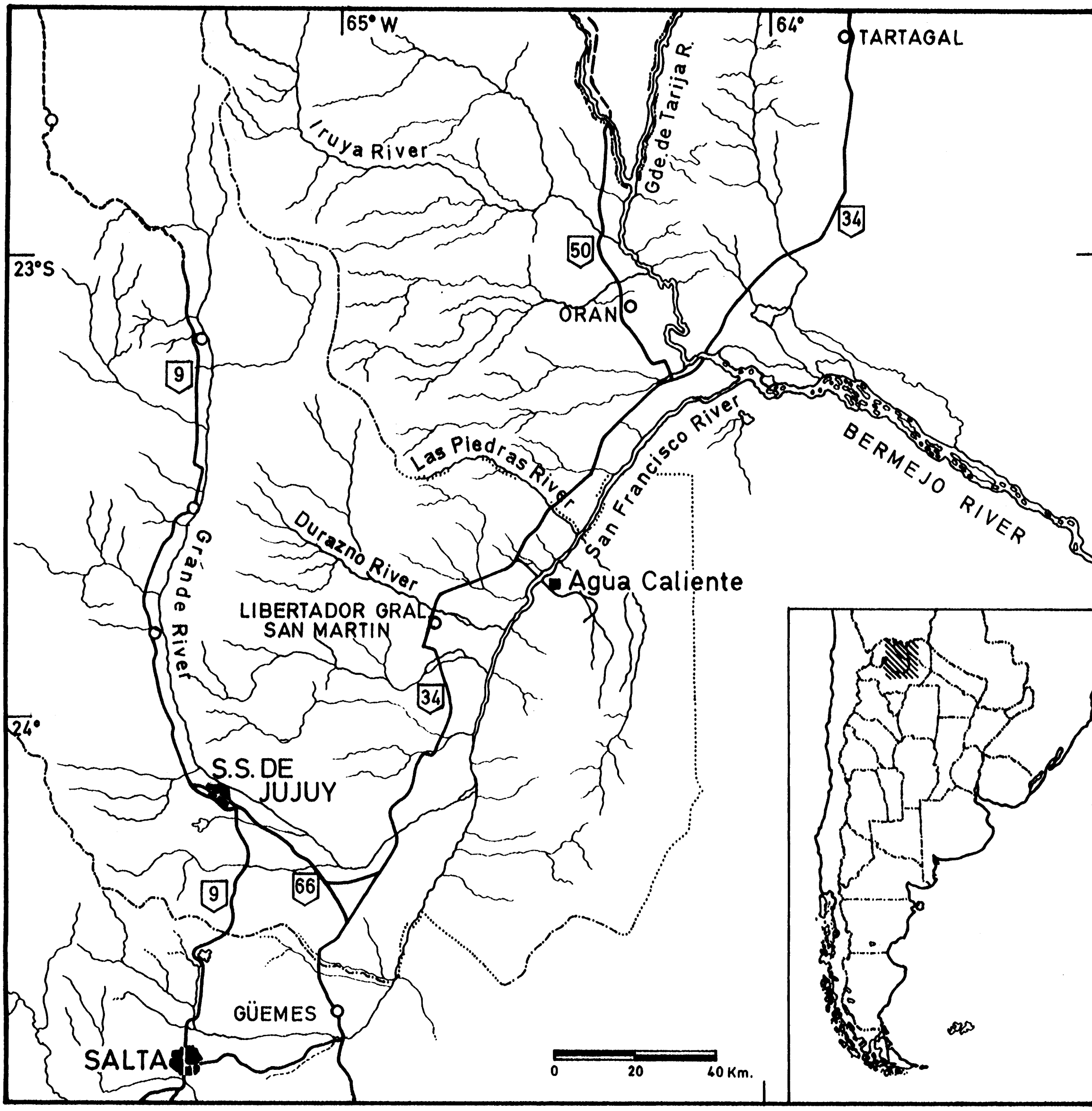

Figure 2. Agua Caliente. Position in NW Argentina. For Orán and Güemes see climatograms in Figure 3.

The site

Agua Caliente is a complex of thermal sources (23° 44′S, 64° 38′W; 500 m a.s.l.) in the province of Jujuy (Figure 2). It is placed in the Yungas phytogeographic province, with a warm tropical highland climate according to the Köppen system of classification (Instituto Geográfico Militar)[1]. The predominant botanical formation is a cloud forest very rich in Lauracea and Mirtacea, reaching 1800 to 2500 m a.s.l. (Cabrera 1971, 1976). Both temperature and

[1] Instituto Geográfico Militar. 1989. Atlas de la República Argentina (6th ed.). 81 pp.

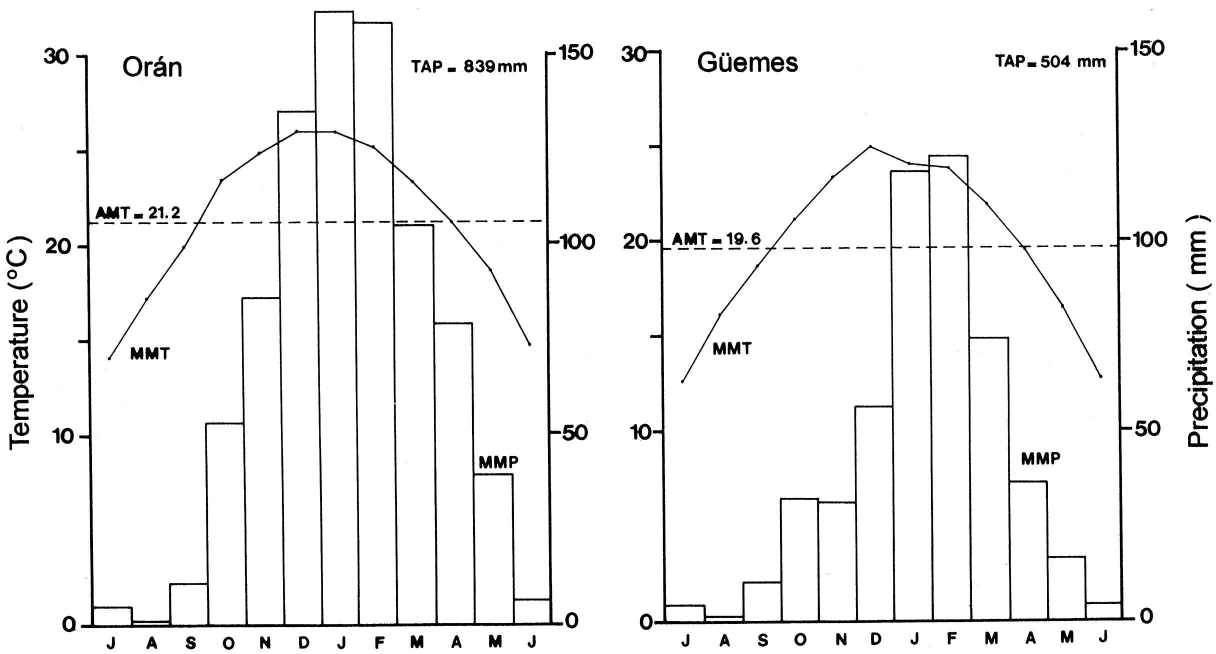

Figure 3. Climatograms in the vicinity of Agua Caliente: a – Orán, 22° 09′S, 64° 19′W, 357 m a.s.l. b – Güemes, 24° 46′S, 65° 02′W, 718 m a.s.l. (TAP = total annual precipitation, AMT = annual mean temperature, MMT = monthly mean temperature, MMP = monthly mean precipitation). For locations see Figure 2.

rainfall quickly decrease with increase in altitude between low-level Orán and high-level Güemes (Figure 3).

At Agua Caliente, an unnamed creek runs in a small channel bounded by soil banks from about 1–2 m to over 10 m high. Pools, riffles and sandbars 4–6 m length are common features (Figure 4a, b, c and d). At the center of a broad bend in the channel, about 2 meters above the creek level, there is a small thermal source about a meter in diameter (Figure 4e). There, thermal water emerges at 51 to 59°C into a small pool, which drains about 50 m into the creek. Between this source and the creek, a system of rudimentary concrete channels (obviously replacing in part a narrow natural course) brings the water through a group of baths used by people from the neighbourhood. Where the channel enters the creek, water is at 43.5–46°C. About two hundred meters upstream, at the left side of the creek, the bank is a wall over 3 m high, through which a second source of thermal water flows at 46–53°C (Figure 4f). Through this reach of the creek, water is hotter in the left bank, where the wall source and the channel of the main spring enters the creek. There may be other thermal sources in still unexplored sections of the creek. Variability in flow and strong seasonality resulted in changes of vegetated littoral habitats.

Material and methods

Three study trips were made to Agua Caliente on March 1987, October 1988, and August 1991, and temperature data were also obtained in January 1994. Twenty one sites were sampled including the two thermal sources, bath channel and the creek (Figure 5). Specimens were captured with moderate amounts of Pronoxfish^R rotenone emulsion, beach nets and hand nets. Fish specimens were identified and samples were deposited at the Instituto de Limnología de La Plata for reference (Table 1). Diversity was calculated according to Shannon & Weaver and similarity according Jaccard (Sneath & Sokal 1973, Margalef 1983).

Water temperature was measured with a digital

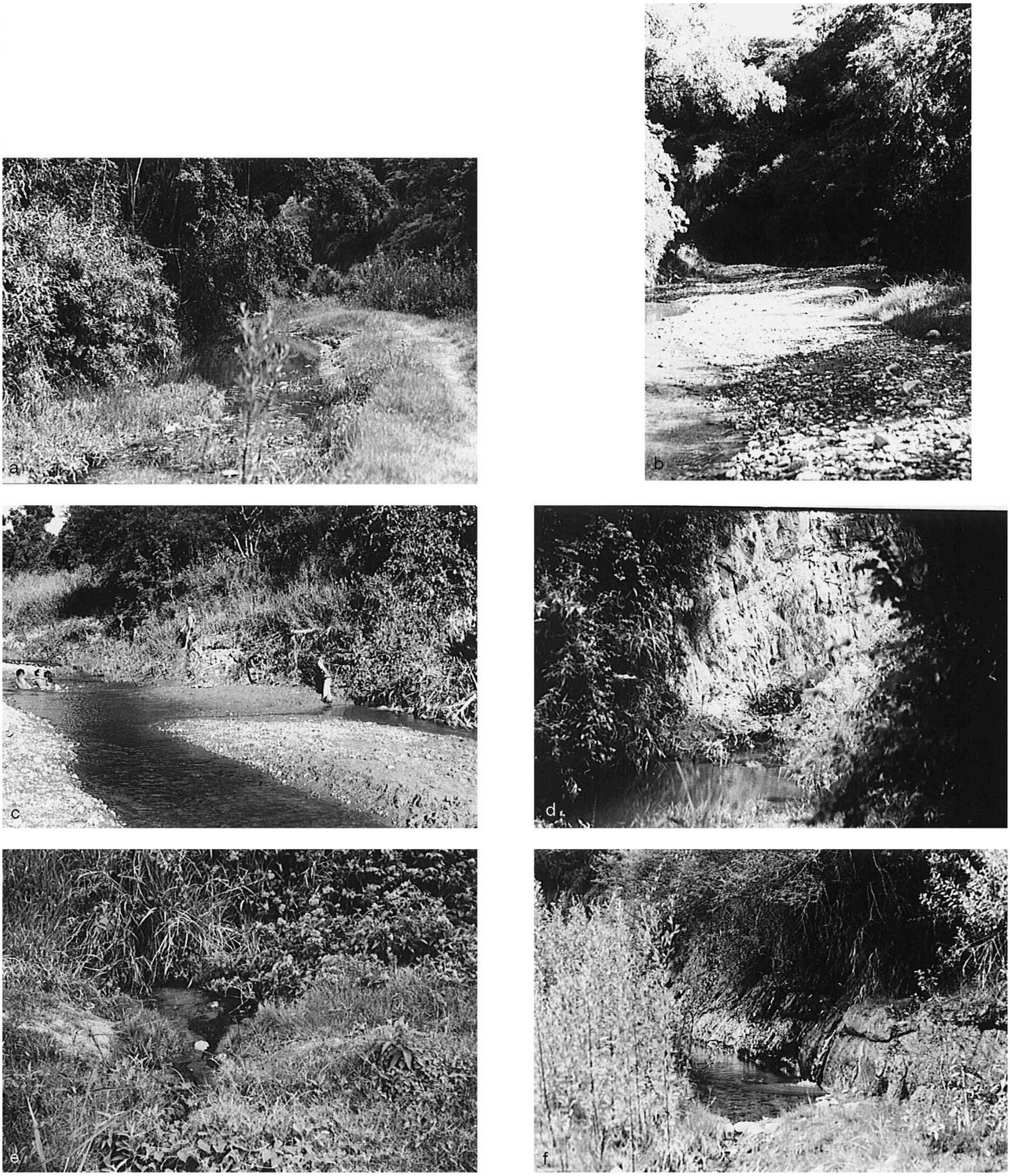

Figure 4. Agua Caliente: a – Riffles downstream the thermal wall near station 10, b – Rocky bottom upstream the thermal wall, c – Sand bank near station 16 (photographs by A.M. Miquelarena), d – High wall in NE bank, over station 9, e – The thermal source (St.1), f – The thermal source flowing from the high wall bank (St.12)(photographs by R.C. Menni).

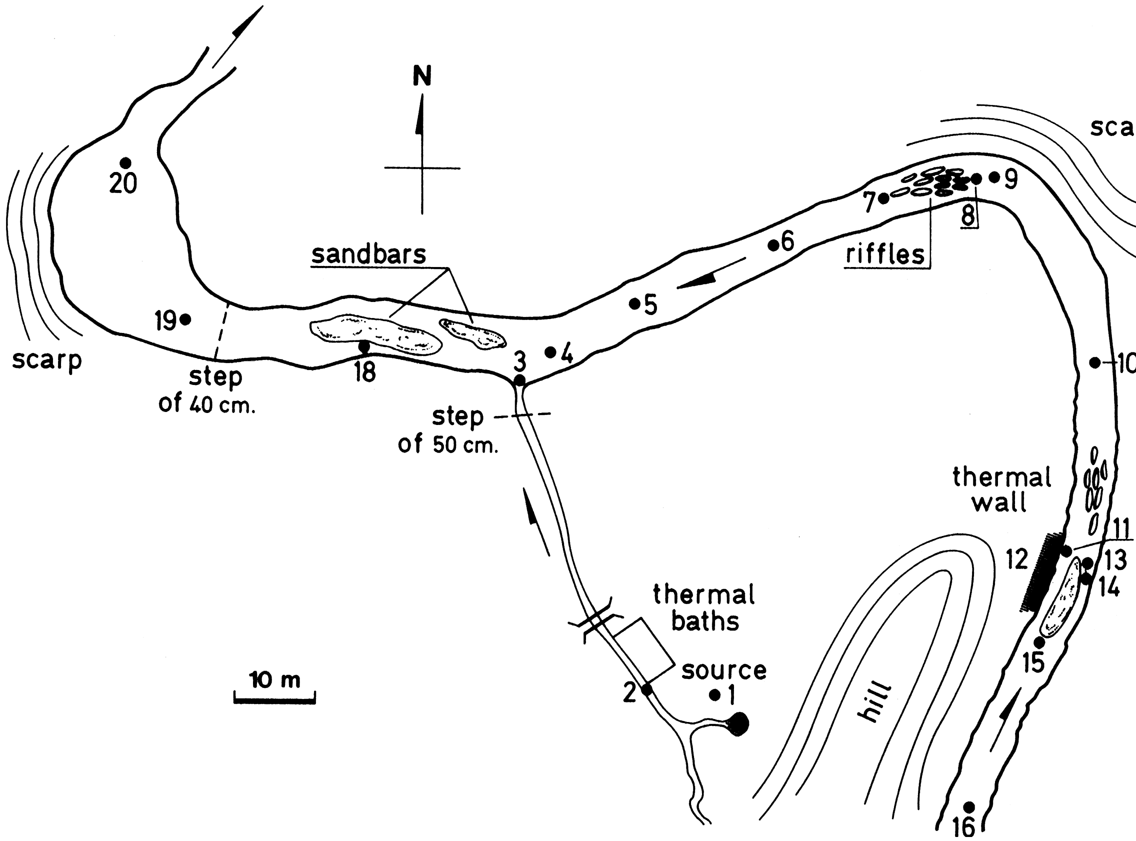

Figure 5. Position of stations in the stream of Agua Caliente (diagrammatic). The thermal source (1) and the thermal wall (12) are stippled. (* indicates absence of fish): St. 1. – * thermal source on soil; St. 2 – * thermal water entrance at baths; St. 3 – * entrance of thermal water to the creek, about 40 cm width; St. 4 – creek course 5 m upstream Station 3, depth 10 – 20 cm; St. 5 – creek course 17 m upstream Station 3, depth 10–20 cm; St. 6 – creek course 30 m upstream Station 3, depth 10–20 cm; St. 7 – creek course 70 m upstream Station 3, depth 10–20 cm; St. 8 – slow flowing pool just downstream of Station 9, diameter 2 m, depth 0.80 m; St. 9 – small riffles with rocks till 30 cm diameter below a vertical wall 100 m upstream Station 3; St. 10 – creek course 150 m upstream Station 3; St. 11 – * small pond under the thermal wall; St. 12 – * thermal wall 3 to 10 m hight, with multiple thermal exits in the vertical bank about 1.5 m high, 270 m upstream Station 3; St. 13 – creek course in front of thermal wall (Station 12); St. 14 – riffles on the right bank in front of thermal wall (Station 12); St. 15 – creek course 290 m upstream Station 3; St. 16 – creek course 360 m upstream Station 3; St. 17 – creek course 410 m upstream Station 3; St. 18 – creek course 20 m downstream Station 3, depth 15 cm; St. 19 – creek course 40 m downstream Station 3 at a sandbank end, course width 6 m, depth 20 cm; St. 20 – pool 7 m diameter and 80 cm depth, about 100 m downstream Station 3; St. 21 – creek course (modified in 1994), running under a bridge downstream former Station 20 about 115 m downstream Station 3. (St. 17 and 21 not marked).

thermometer from Aquatic Ecosystems DT2 (USA) with an accuracy ± 0.1°C and a mercury thermometer with an accuracy ± 0.5°C. Values of pH were recorded with a pH meter from Aquatic Ecosystems (USA) with an accuracy ± 0.1 units. Dissolved oxygen values were recorded with a digital meter Digidox (Luftman, Argentina) with an accuracy ± 0.1 mg l^{-1}. Chemical analyses were conducted at the former Water Chemistry Laboratory of the Instituto de Limnología de La Plata, according to APHA[2] methods.

To determine thermal resistance of fish, upper loss of equilibrium and death temperatures were determined in field tests using the critical thermal

[2] American Public Health Association. 1985. Standard methods for the examination of water and wastes. 16th ed. Washington. 1268 pp.

Table 1. Reference material from the Agua Caliente stream, basin of the San Francisco River, Jujuy, Argentina. (ILPLA = Instituto de Limnología de La Plata, MLP = Museo de La Plata).

Astyanax bimaculatus asuncionensis: ILPLA 313, 1241 spec. from 18 to 70 mm SL (mean: 34 mm, SD 9 mm), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 314, 87 spec. from 19 to 87 mm SL (mean: 46, SD 16 mm), October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón. ILPLA 315, 28 spec., 36 to 70 mm SL (mean: 47 mm, SD 9), August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Astyanax eigenmanniorum: ILPLA 344, 3 spec. 33, 35 y 35.7 mm SL, August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez, 1991.

Astyanax lineatus: ILPLA 316, 129 spec., 18 to 82 mm SL (mean: 36, SD 10), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 317, 11 spec. 50 to 89 mm SL (mean 65 mm, SD 11), October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón. ILPLA 318, 21 spec. 45 to 89 mm SL (mean: 40, SD 5), August 1991, R.C. Menni, H.L. López and S.E. Gómez, 1991.

Bryconamericus stramineus: ILPLA 339, 18 spec. 30 to 39 mm SL (mean: 34, SD: 3), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta.

Bryconamericus thomasi: ILPLA 282, 128 spec. (1 stained), 23 to 46 mm SL (mean: 33, SD: 4), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 283, 9 spec. 22 to 44 mm SL (mean: 32, SD: 8), October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón.

Acrobrycon sp.: ILPLA 340, 3 spec. 30, 32.3 and 34.5 mm SL, March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 341, 1 spec. (stained) 46 mm SL, August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Odontostilbe piaba: ILPLA 357, 1 spec. 25 mm SL, August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Characidium sp.: ILPLA 336, 9 spec. 31 to 55 mm SL (mean: 36, SD: 7), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta.

Parodon carrikeri: ILPLA 342, 3 spec. 28.6, 38.5, 40.5 mm SL, March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 343, 1 spec. 68 mm SL, August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Hoplias malabaricus: ILPLA 337, 11 spec. 29 to 149 mm SL (mean: 63, SD: 35), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 338, 2 spec. 95 and 98 mm SL, October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón.

Loricaria tucumanensis: MLP 9057, 11 spec., October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón. MLP 9058, 12 spec., August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez. ILPLA 347, 37 spec. 41 to 130 mm SL (mean: 69, SD 21), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta.

Loricarichthys maculatus: ILPLA 345, 2 spec. 62 and 73 SL, March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 346, 1 spec. 138 mm SL, October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón.

Hypostomus borelli: ILPLA 351, 49 spec. 22 to 94 mm SL (mean: 43, SD: 19), March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 352, 14 spec. 27 to 84 mm SL (mean: 41, SD: 17), October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón.

ILPLA 353, 67 spec. 19 to 131 mm SL (mean: 54, SD 24), August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Hypostomus sp.: ILPLA 348, 18 spec. 30 to 70 mm SL, March 1987, coll. R.C. Menni, A.M. Miquelarena and J.R. Casciotta. ILPLA 349, 8 spec. 23 to 130 mm SL, October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón. ILPLA 350, 1 spec. 167 mmSL, August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Bujurquina vittata: ILPA 354, 97 spec. 18 to 69 mm SL (mean: 34, SD: 12), October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón. ILPLA 355, 175 spec. 18 to 49 mm SL (mean: 37, SD: 5), August 1991, coll. R.C. Menni, H.L. López and S.E. Gómez.

Cichlasoma dimerus: ILPLA 356, 3 spec. 61, 65 and 68 mm SL, October 1988, coll. R.C. Menni, A.M. Miquelarena, J.R. Casciotta and A.E. Almirón.

maximum (CTM) method. Specimens were tested immediately after capture. Tests started from acclimation temperature, assuming that specimens were acclimated to water temperature at the time and site of capture. Water was heated at a constant rate of 18°C h^{-1} in a 5 l plexiglass experimental chamber. A portable generator was used to provide electricity for heating the water. Field conditions precluded the use of an extensive number of specimens. Loss of equilibrium temperature and death temperatures for individual fish were recorded according to Becker & Genoway (1979). Mean arithmetic values for loss of equilibrium (LET) and death temperature (DT) were calculated for each species. Exponential equations were used to describe the relationships between acclimatization temperature (AT) and death temperature (DT).

Results

Taxonomic composition

The fish fauna from Agua Caliente comprises 3 orders, 6 families and 16 species (Tables 1, 2). The Characiformes include the families Characidae with 7 species (69.43% in number of specimens), Crenuchidae with 1 species (0.37%), Parodontidae with 1 species (0.16%) and Erythrinidae with 1 species (0.53%). The Siluriformes include 1 family, Loricariidae with 4 species (9.55%), and the Perciformes family Cichlidae with 2 species (19.96%). Distribution of species occurring at Agua Caliente, which includes new reports from the area, is briefly discussed below.

Table 2. Agua Caliente. Species abundance by year.

Species	Number of fish				
	1987	1988	1991	Total	%
Astyanax b. asuncionensis	1241	87	37	1365	55.49
Bujurquina vittata	205	97	186	488	19.84
Astyanax lineatus	129	11	26	166	6.75
Bryconamericus thomasi	129	9	10	148	6.02
Hypostomus borelli	47	15	79	141	5.73
Loricaria tucumanensis	37	11	16	64	2.60
Hypostomus sp.	18	8	1	27	1.10
Bryconamericus stramineus	18	0	0	18	0.73
Hoplias malabaricus	11	2	0	13	0.53
Characidium sp.	9	0	0	9	0.37
Astyanax eigenmanniorum	0	0	5	5	0.20
Acrobrycon sp.	4	0	1	5	0.20
Parodon carrikeri	3	0	1	4	0.16
Cichlasoma dimerus	0	3	0	3	0.12
Loricarichthys maculatus	2	1	0	3	0.12
Odontostilbe piaba	0	0	1	1	0.04
Number of species	13	10	11	16	
Number of specimens	1853	244	363	2460	
Diversity index	1.23	1.53	1.46	1.45	

Family Characidae

Astyanax bimaculatus asuncionensis Géry, 1972.– This species is widely distributed in the Río de La Plata basin (Ringuelet et al. 1967a). Southward it is known from Berisso (Buenos Aires province) (Miquelarena 1982). It is abundant in northern Argentina (Menni et al. 1992, Butti & Miquelarena 1995) and very common in the 'esteros' (tropical swamps) of the Santa Lucía River, in the Northeast (Baldo et al. 1994). In the use of the subspecies we followed Géry (1972a).

Astyanax eigenmanniorum (Cope, 1894).– The distribution of this species is summarized in López et al. (1980) and Menni et al. (1984, including the most western locality). The species is also reported from Magdalena on the Río de La Plata (Miquelarena 1982), from the El Palmar National Park in Entre Rios (Fernández Santos et al. 1982), several places in Santiago del Estero (Casciotta et al. 1989), and northern Tucumán (Buti & Miquelarena 1995). Almirón et al. (1992) gathered all references from the Buenos Aires province. After this Miquelarena & López (1995) reported it from the 'lagunas' Encadenadas del Oeste in western Buenos Aires province.

Astyanax lineatus (Perugia, 1891).– Not often mentioned from Argentina (Ringuelet et al. 1967a), *A. lineatus* is known from the upper and middle Paraná southward to Santa Fé, eastern Formosa (Pignalberi de Hassan & Cordiviola de Yuan 1988), from the Bermejo River and also from the Matto Grosso

(Brazil) and Bolivia. The present record is the most westernmost locality of the species.

Bryconamericus stramineus Eigenmann, 1908.– Originally reported from Piracicaba and the Uruguay River, this species is known from several localities on the Uruguay River (Eigenmann 1927, Devincenzi & Teague 1942) and the San Francisco River of Paraguay (Eigenmann 1927). It was also reported from the Río de La Plata at Punta Lara and Ensenada (Azpelicueta & Braga 1980), El Palmar National Park on the Uruguay River (Fernández Santos et al. 1982) and from the Paraná River delta in San Nicolás (Liotta et al. 1994). The present report represents a considerable westward extension of its recorded distribution.

Bryconamericus thomasi Fowler, 1940.– Recently resurrected (Miquelarena & Aquino 1995) from the synonymy of *B. iheringi*, *B. thomasi* occurs in the upper Bermejo River in Salta and Jujuy, the Pasaje-Juramento River basin, and Agua Caliente.

Acrobrycon sp.– The distribution of *A. tarijae*, the only species of the genus known from Argentina, was detailed in Ringuelet et al. (1967a). It is also known from Salta (El Rey National Park) (Miquelarena 1982), from the Cuarto and Tercero rivers in Cordoba (Haro et al. 1991, 1994), from the Salí basin in Tucumán (Chuscha River at La Higuera, occurring during Autumn at 1040 m a.s.l., Buti & Miquelarena 1995) and from Río Calera (Miquelarena et al. 1990). The specimens from Agua Caliente are rather small, and more material is needed to confirm its specific identification.

Odontostilbe piaba (Lütken, 1874).– Ringuelet et al. (1967a) reported *O. piaba* from the Pilcomayo River in Formosa and the San Lorenzo River in Jujuy. It is reported from the 'madrejón' Don Felipe (a secondary branch of the Paraná River), the Santa Lucía River and Bella Vista in Corrientes (Miquelarena 1982, Casciotta et al. 1992). It is abundant in Formosa environments (Menni et al. 1992).

Family Crenuchidae

Characidium sp.– This species, historically referred to as *C. fasciatum* in Argentina, is widely distributed in the Bermejo and Salí river basins, the middle Paraná and Uruguay, a tributary of the Paraguay River and other localities near Asunción, Misiones and the Iberá swamp (see references in Menni et al. 1992). It was reported from the Salto Grande reservoir (López et al. 1984), El Palmar National Park (Fernandez Santos et al. 1982) and the Paraná River delta (Liotta et al. 1994). According to Buckup (1992) *C. fasciatum* lacks scales in the isthmus; our specimens are scaled and must represent another species, which will be treated elsewhere. The familial position of this genus is unsettled. Géry (1972b) placed it in the family Characidiidae, while Buckup[3] allocated it to the Crenuchidae. Traditionally it has been referred to the subfamily Characidiinae within the Characidae (Nelson 1994).

Family Parodontidae

Parodon carrikeri Fowler, 1940.– This species was known previously only from the type locality, the Lipeo River in the North of the Salta province, Argentina. This is the second report of the species.

Family Erythrinidae

Hoplias malabaricus (Bloch, 1794).– *H. malabaricus* is widely distributed in the Río de La Plata basin. Its southern limit is the 'laguna' (lake of 3th order) Alsina in southern Buenos Aires province (Miquelarena & López 1995). The record represents a new locality in extreme nortwestern Argentina.

Familiy Loricariidae

Loricaria tucumanensis Isbrücker, 1979.– Previous-

[3] Buckup, P.A. 1992. The Characidiinae: a phylogenetic study of the South American darters and their relationships with other characiform fishes. Diss. Abstr. Int. 52 (7).

ly known only from its type locality in the Salí River basin; this is the second report of the species.

Loricarichthys maculatus (Bloch, 1794).– *L. maculatus* was previously recorded from the Pilcomayo River basin in Formosa, the middle Paraná River, the Río de La Plata and the lower Uruguay River (Ringuelet et al. 1967a). This is the first record of the species in northwestern Argentina.

Hypostomus sp.– Only two of the twelve species of *Hypostomus* have been reported from northwestern Argentina (López & Miquelarena 1991): *H. borelli* (see below) and *H. cordovae*. This is probably a new species belonging to the *H. microstomus* group which posseses a low number of teeth.

Hypostomus borelli (Boulenger, 1897).– This species was reported from western Argentina at elevations of 1500 and 2000 m by Arratia et al. (1983), apparently based on Fowler's (1940) description. It has been reported from the Riachuelo and Itacuá basins in Corrientes and the Uruguay River (but these references are doubtful), and from the Pilcomayo and Bermejo rivers (López & Miquelarena 1991).

Family Cichlidae

Bujurquina vittata (Heckel, 1840).– This species is widely distributed in the upper and middle Paraná River and its tributaries in Misiones, Corrientes, Chaco and northern Santa Fé; in Formosa it occurs in tributaries of the Paraguay, Pilcomayo and Bermejo rivers (Miquelarena et al. 1990). In northern Argentina it is known from the Salí River basin, Tucumán and Catamarca. This is a new report for northwestern Argentina.

Cichlasoma dimerus (Heckel, 1840).– Formerly reported as *A. portalegrensis*, which does not occur in Argentina, *C. dimerus* is mainly distributed in the Paraná basin, with a report from Orán in Salta (Ringuelet et al. 1967a, Kullander 1993).

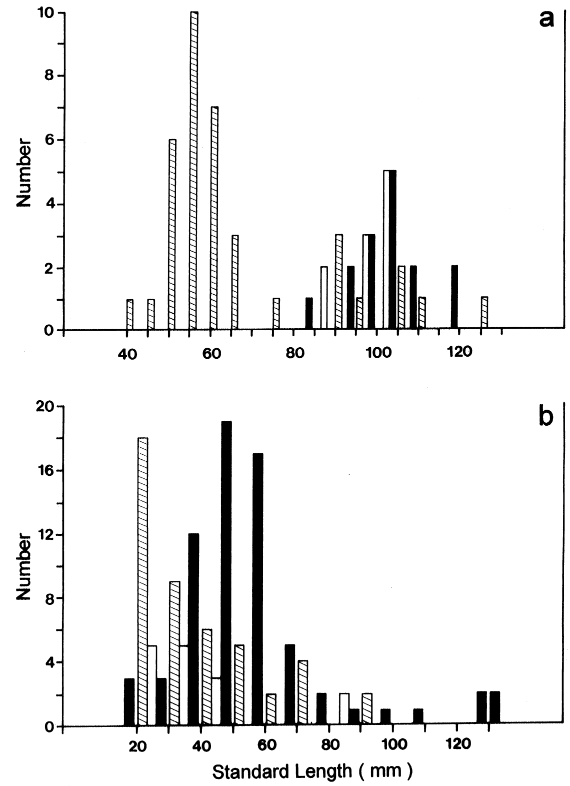

Figure 6. Size distribution of a – *Loricaria tucumanensis* and b – *Hypostomus borelli* in Agua Caliente (stippled bars = March 1987, open bars = October 1988, closed bars = August 1991).

Biology

Seven of the 16 species (representing 2399 specimens, 97.5%) occurred in all three sampled years (Table 2). Three species (*A. bimaculatus, B. vittata* and *A. lineatus*), comprised over 80% of the total catch. *C. dimerus, O. piaba,* and *A. eigenmanniorum* each appeared in only single samples and in low numbers. Low Jaccard similarity indeces among years demonstrate temporal changes in faunistic composition (1987/1988: 0.64, 1987/1991: 0.47, 1988/1991: 0.36).

Based on all samples, the fish community appears dominated by *A. bimaculatus* with 55.49% of abundance in number of specimens (Table 2). The second most abundant species, *B. vittata,* comprises 19.84%. During 1987, dominance of *A. bimaculatus* was evident (1241 specimens vs. 205), but during 1991 *B. vittata* was most abundant, though the difference was smaller (186 vs. 37). During 1988, difference in abundance between the two species was not significant. Courtship behaviour was observed in *B. vittata* in Agua Caliente between 29 to 35.5°C.

Size distributions of *A. bimaculatus* and *A. lineatus* show smaller mean sizes during the end of summer (1987), with specimens reaching larger sizes in the other two seasons (end of winter 1991, spring 1988) (Table 3).

In the late summer of 1987 numerous small individuals of *Loricaria tucumanensis* were captured together with a few adults; in the spring of 1988 and winter of 1991 only large specimens were present (Figure 6a).

Small individuals of *Hypostomus borelli* occurred in all three years, with larger numbers found during late summer of 1987. Large individuals and all size classes were present at the end of the winter of 1991 (Figure 6b).

Resistances to high temperatures for 8 species based on lethal temperatures in CTM experiments are shown in Table 4, under three acclimatization temperatures corresponding to precise location within the creek. A susceptibility order can be established among the 8 species, with *Bujurquina vittata* the most resistant and *Bryconamericus thomasi* the least resistant (Figure 7). The relationhsip between AT and DT are:

for *B. vittata* $DT = 20.9847\ AT^{0.2027}$

with r = 0.999,

and for *B. thomasi* $DT = 25.3236\ AT^{0.1253}$

The second most thermally resistant species was *Astyanax bimaculatus*, which together with *B. vittata*, are the numerically most abundant species (Table 2).

Limnology

A series of water temperature measurements (N = 98) was made at 21 stations within the creek (Figure 5). Minimum and maximum values were 23.8 and 59°C. Considering all temperature data (Table 5), the mean temperature for stations with fish was 29.5°C (range 23.8–38°C, SD = 3.54, N = 77). For stations without fish the mean was 47.7°C (range 26.8–59°C, SD = 6.90, N = 21). In nine stations (Table 6) temperature data were taken at the same time with chemistry samples. The mean was 46.7°C for samples where fish did not occur and 32°C for samples with them ($t = 5.09$, $p < 0.05$). Water temperature values are higher than in all other localities studied by us (Menni et al. 1996).

In spite of small sinusoidal fluctuations throughout the 24 h period, comparison between air temperatures and water temperatures from nearby environments (range 17.6–21.7°C, mean 20.29°C, N = 14), clearly supports the influence of the geothermal sources on the thermal character of Agua Caliente (Figure 8). Three stations upstream the thermal wall (St. 15, 16 and 17) have a water temperature mean of 24.5°C (Table 5), suggesting the presence of other thermal sources along the stream.

At both thermal sources studied, high values of water temperature were recorded in the four sampling periods. Values were 46 to 53° C at the wall (St. 12) and 51 to 59°C at the source (St. 1). During the last trip in summer (January 1994) the flow appears greatly reduced, with a great development of

Table 3. Mean standard length (mm) of abundant species in each sampling period (subsamples).

	March 1987 Summer			August 1991 Winter			October 1988 Spring		
	Mean	Range	N	Mean	Range	N	Mean	Range	N
A. bimaculatus	34	18–70	1241	47	36–70	28	46	19–87	87
B. vittata	19	15–24	5	37	18–49	175	34	18–69	97
A. lineatus	36	18–82	129	52	45–62	21	65	50–89	11
H. borelli	43	22–94	49	54	19–131	67	41	27–84	14
L. tucumanensis	69	41–130	37	102	84–118	15	98	87–105	11

vegetation, but this appears to be a seasonal state. Temperature in the thermal source, the thermal wall and some of the sampling points were slightly higher in summer than in other seasons.

Forty-one dissolved oxygen measurements were made at 12 stations. The following values (in percentage of saturation of O_2) were obtained. At the place where thermal water flows into the creek (St. 3) values of O_2 are low, with a range between 7.1–55.4%. Upstream station 3, at stations 5, 6, 7, 8, 9, 11, 13 and 14, O_2 values ranged from 21.9 to 139.9%. High variation in this sector corresponds to diverse topographic features of the creek and the presence of the thermal wall. Highest values were from riffles opposite the thermal wall (St. 14).

Immediately downstream of station 3 (St.18), O_2 content is again very variable, between 15.4 and 134.2%, resulting from the incomplete mixing of the thermal flow and the main creek current. This is reflected in the high SD of temperature values (Table 5). In downstream stations 19 and 20, O_2 values ranged from 49.2 to 130.1% suggesting more complete mixing.

Values of pH ($\bar{x}$ = 8.40) (Table 6) are high compared with other areas in Argentina, including basins in Formosa, Tucumán, Córdoba, and the Paraguay and Paraná rivers. Acid values in natural waters in Argentina are relatively rare (Menni et al. 1996), and known from some cold lakes in western Patagonia and tropical lagoons at the Iberá swamps.

Total dissolved solid (TDS) values are within the oligohaline interval (0.5 to 5 mg l^{-1}, sensu Ringuelet 1962). They are more saline than in most areas that have been examined in the country. Accordingly, conductivity values ranged from 1335 to 1795 µS cm^{-1}. Waters with 500 to 1000 µS cm^{-1} are considered strongly mineralized (Margalef 1983). Values over this range are known in water bodies in desert areas in western Córdoba (Menni et al. 1984), the Salado River of Santiago del Estero (1244–2077 µS cm^{-1}, Casciotta et al. 1989), and some pampas 'lagunas' with large salinity variations (Ringuelet et al. 1967b). Waters in center and northeastern Argentina are normally hypohaline.

Ionic content is characterized by a large amount of SO_4^{--}, Na^+, and Cl^- in decreasing order of abundance, as well as by a high level of CO_3H^- (Table 6). These values are rather different from both the world and South America means, and also from values from 54 localities in Argentina referred to by Menni et al. (1996). The index Na/Na+Ca (Gibbs

Table 4. Critical thermal maximum (°C) of 8 fish species from Agua Caliente (LET= mean loss equilibrium temperature, DT= mean death temperature, Range= range of death temperatures, N= number of specimens, LST= mean standard length mm).

Species	LET	DT	Range	N	LST
Mean acclimation temperature = 25.0 °C (Station 5)					
B. thomasi	36.95	37.90	37.65–38.25	4	30.4
A. eigenmanniorum	38.60	39.40	39.00–39.80	2	39.6
A. bimaculatus	38.60	39.80	–	1	43.0
B. vittata	38.60	40.30	–	1	35.4
Mean acclimation temperature = 29.25 °C (Station 20)					
P. carrikeri	40.30	41.40	–	1	68.0
L. tucumanensis	40.30	41.40	–	1	109.0
H. borelli	> 39.30	41.42	40.80–41.70	10	82.4
A. lineatus	40.90	41.58	41.50–41.65	4	60.9
B. vittata	40.55	41.59	41.20–41.80	4	36.5
Mean acclimation temperature = 34.15 °C (Station 18)					
B. thomasi	39.05	39.41	38.20–39.90	6	36.6
A. lineatus	40.95	41.95	–	1	48.0
A. bimaculatus	41.38	42.20	42.10–42.40	8	54.1
B. vittata	42.52	42.93	42.50–43.20	6	39.6

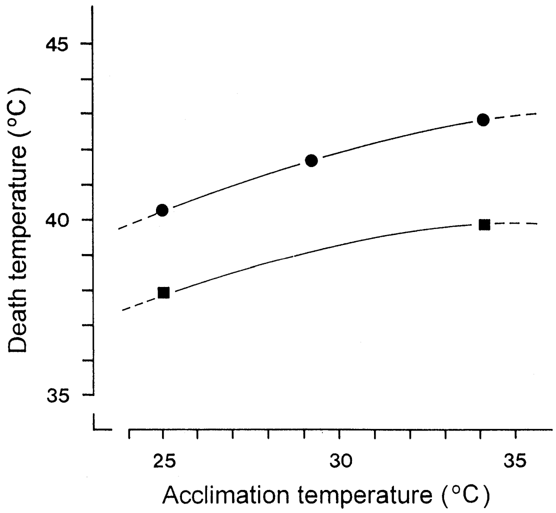

Figure 7. Death temperatures as function of acclimation temperature for *B. vittata* (circles) and *B. thomasi* (squares) collected from Agua Caliente. See also Table 4.

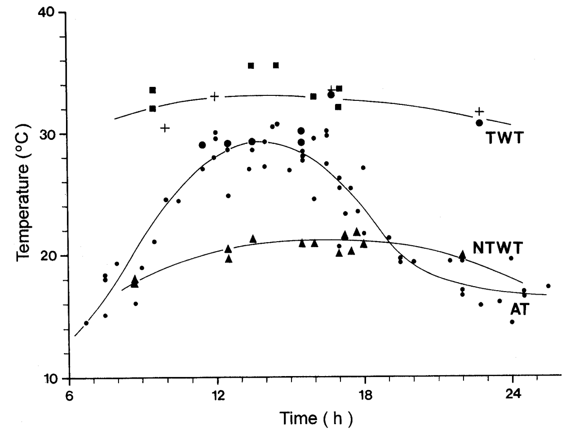

Figure 8. Thermal characteristics of Agua Caliente and environs (August 1991): hourly variation of temperature (AT = air temperature, small dots, NTWT = non thermal water temperature from several localities near Agua Caliente, open triangles, TWT = Agua Caliente thermal water temperature at stations 18, closed squares, 19 crosses and 20 closed circles).

1970) provides a mean value (0.93) which places Agua Caliente water nearer to the Baltic Sea and the Jordan River than to most world rivers and lakes.

Although the Agua Caliente creek runs throughout a well forested area and has well developed littoral vegetation, values of chemical oxygen demand (COD) were very low ($\bar{x}$ = 4.61 mg O_2 l^{-1}) compared with environments in downstream Pilcomayo–Paraguay basins, with values from 24.5 to 39.5 mg O_2 l^{-1} (Menni et al. 1992). They are also slightly lower than in Sierra de la Ventana highlands (38° 08′S, 61° 47′W, 260 m a.s.l.; Menni et al. 1988), close to the northern border of Patagonia. Considering that environments in Sierra de la Ventana are mountain creeks in an area with scarce vegetation, while the

Table 6. Water chemistry. Ions and total phosphorus in mg l^{-1} (TDS = total dissolved solids, in g l^{-1}, SC = specific conductivity, in µs cm^{-1}, Temperature in °C, COD = chemical oxygen demand, in mg O_2 l^{-1}, * = absence of fish at that station, SD = standard deviation). Samples from 1987 (creek course) do not correspond to stations defined after.

	1987		1988		1991					1991				Mean	SD	Range
Stations	6/87	6/87b	6	1*	2*	2*	3*	12*	12*	6	17	19	20			
CO_3^-	0.0	0.0	19.6	7.3	0.0	4.8	4.8	4.8	4.8	38.4	28.8	24.0	28.8	12.78	13.281	0.0–38.40
CO_3H-	227.3	230.1	114.5	117.0	104.9	119.6	117.1	117.1	117.1	122.0	187.9	126.9	122.0	140.27	44.019	104.9–227.30
Cl-	248.5	248.5	209.4	267.0	240.0	240.0	233.1	274.8	281.8	250.5	226.1	247.0	243.5	246.94	19.482	209.4–281.88
SO_4^-	362.4	372.9	464.1	557.0	482.8	476.0	469.4	469.4	462.8	419.9	503.7	503.7	437.8	460.15	52.771	362.4–557.00
Na+	365.5	369.3	369.9	469.7	373.8	373.8	397.8	419.3	425.3	396.6	425.3	425.3	394.2	400.45	31.104	365.5–469.70
K+	4.2	3.8	2.3	2.2	1.6	1.4	1.3	1.4	1.3	2.2	2.6	1.9	2.2	2.18	0.916	1.3–4.20
Ca++	38.0	40.4	25.8	17.0	26.5	21.8	18.7	17.9	17.2	31.2	40.6	32.0	32.8	27.68	8.813	17.0–40.60
Mg++	3.9	5.8	7.5	1.5	0.1	0.1	2.0	2.0	1.0	3.0	0.2	0.6	0.2	2.15	2.334	0.1–7.50
TDS	1.25	1.27	1.22	1.46	1.25	1.25	1.27	1.37	1.33	1.30	1.43	1.37	1.27	1.31	0.075	1.22–1.46
pH	7.14	6.98	8.86	8.46	8.30	8.38	8.35	8.52	8.39	9.04	8.90	8.94	9.01	8.40	0.656	6.98–9.04
SC	1,689	1,795	1,492	1,763	1,428	1,428	1,335	1,695	1,746	1,592	1,592	1,592	1,541	1,591.38	143.358	1,335–1,795
COD	4.9	5.5	7.6	4.4	2.2	0.2	2.8	2.2	2.6	6.6	7.8	6.6	6.6	4.61	2.420	0.2–7.80
P	no data				0.03	0.03	0.06	0.06	0.05	0.07	0.08	0.10	0.09	0.06	0.025	0.03–0.10
Temp.	35.0	35.0	no data		43.5	43.5	44.5	51.0	51.0	29.7	24.5	34.2	34.0	–	–	–

creek in Agua Caliente is inside a cloud forest, this is somewhat surprising, but the creek is 500 m a.s.l. and the residence time of water is probably short. Though the species number is higher than in Sierra de la Ventana (16 vs. 8), it is well under the numbers obtained in environments related to the Paraná River. We have suggested that COD is correlated with species number in several environments in Argentina (Menni et al. 1992) and the relationships obtained in this study support that trend.

Values of total P(mg l^{-1})are also low (N = 9; $\bar{x}$ = 0.06, SD = 0.024). Water at Agua Caliente has TDS values higher than Sierra de la Ventana creeks, being close to the more southern Napostá creek values and similar to a few localities in Córdoba.

Discussion

The first reference to fishes inhabiting thermal waters in Argentina was for manmade habitats in Barreto, Córdoba province (33° 30′S 63° 20′W)(Mac Donagh 1938). Two thermal springs were reported there, with water emerging at 28°C in one and 32°C in the other. The water was sulfate–alkaline, with TDS values of 1.2360 and 0.5852 g l^{-1}.

Table 5. Water temperature values (°C) at each station (St = stations, $\bar{x}$ = arithmetic mean, SD = standard deviation, N= number of data, * indicates absence of fish).

St	$\bar{x}$	SD	N	Range
1*	56.0	4.36	3	51.0–59.0
2*	50.7	10.25	2	43.5–58.0
3*	44.8	0.78	8	43.5–46.0
4	25.9	1.18	3	24.5–26.6
5	27.4	3.60	7	24.0–34.7
6	27.6	2.64	6	24.0–31.5
7	27.7	1.95	6	24.3–29.7
8	27.5	1.77	5	24.7–29.6
9	27.9	1.90	5	24.6–29.2
10	31.7	5.43	3	28.5–38.0
11*	36.4	13.58	2	26.8–46.0
12*	50.1	2.71	6	46.0–53.0
13	24.5	0.99	2	23.8–25.2
14	28.8	0.35	2	28.5–29.0
15	24.5	–	1	–
16	24.5	–	1	–
17	24.5	0.00	2	–
18	32.9	2.15	13	28.3–35.5
19	32.0	1.64	10	29.2–34.2
20	30.7	2.02	10	29.0–34.0
21	38.0	–	1	–

The cyprinodontoid *Jenynsia lineata* was found near the first spring, but no information is given about how close the fish was to it. In the second spring, the cichlid *Cichlasoma facetum*, the characids *Astyanax fasciatus* and an *Oligosarcus* identified as *O. hepsetus* were living near the source, at approximately 31°C, together with *J. lineata*, juvenile *Hoplias malabaricus* (Erythrinidae) and a *Corydoras* species (Callichthyidae). Since these thermal habitats were manmade, Mac Donagh (1938) stated that they were colonized from the nearby Río Cuarto after fish crossed swamps and ponds, a mechanism attributed to Cuenot. The most abundant fish species at Barreto were *Astyanax fasciatus* and *Cichlasoma facetum*, both very common species in temperate Argentina.

A second thermal locality studied in Argentina is the Valcheta Creek in the Somuncurá Plateau, in northern Patagonia, inhabited only by the naked characin *Gymnocharacinus bergi*. Here the thermal character of water allows the species to survive within climatic environs otherwise inappropriate for a paranensean fish (Menni & Gómez 1995).

The Agua Caliente fish fauna is composed of a relatively high number of species (sixteen species in 3 orders in 6 families), in spite of high water temperature and salinity. The Valcheta Creek in southern Argentina and most thermal spots in the southwestern United States are inhabited by single species (Deacon & Minckley 1974, Menni & Gómez 1995).

The fish fauna from Agua Caliente has traits of its own. Several of the species are new for this area of Argentina, most of them usually having restricted distributions. *Astyanax bimaculatus* (Characidae) and *Bujurquina vittata* (Cichlidae) constitute the bulk (75.33%) of fish abundance at Agua Caliente. This is consistent with the fact that several *Astyanax* species are ranked among the most eurytopic species in Argentina (Menni et al. 1996).

Faunistic composition at the ordinal level shows a relative scarcity of siluriforms compared with the fish fauna from many habitats of the Paraná Basin. There are groups (e.g. *Trichomycterus* and *Heptap-*

terus) that could be expected to be in Agua Caliente based on zoogeography, but they apparently are absent because of the high temperature. Stream size is probably not large enough to support populations of relatively larger catfishes like *Pimelodus albicans*, a common species in many harsh environments, or smaller forms like *Pimelodella* and *Corydoras*. Loricariids of relatively large size were found, but not in large numbers, these being the only siluriforms obtained in the stream.

As in Agua Caliente, siluriforms were scarce in Barreto. By contrast, southward of Agua Caliente, in central Argentina in the highlands of Córdoba province, siluriforms are the most abundant order representing 44% of 25 species. Environments here are mainly highly seasonal small streams, which occur in the western edge of the Paranensean ichthyological province under a severe highland climate (Menni et al. 1984, 1996).

Cyprinodontoids, typical of high-temperature and other harsh environments, are absent from Agua Caliente. It is not easy to evaluate if the few cyprinodontoids living nearby do not occur there because of environmental conditions or because of historical or geographic reasons for lack of colonization. We have proposed that the central Paraná Basin is at present the 'normal' habitat for paranensean species (Menni et al. 1996). This implies that for those paranensean species with strong tolerance to harsh conditions, low temperatures are more limiting than high ones. In fact, they rarely will found higher temperatures than in its normal habitat. Therefore, when species of this group appear in environments at the border, or far, from their normal habitats, it is in sites with lower temperatures than in the paranensean area. According to this, *J. lineata, C. decemmaculatus* and, to a less extent, *B. iheringi*, are pionering species (Menni et al.1996) in Sierra de la Ventana (Menni et al. 1988), some Patagonian habitats, and in highland areas in western central Argentina, all places where cold is an important limiting factor (Menni et al. 1984).

Although encountered less commonly than cyprinodontoids, cichlids also occur in 'austere' conditions (Deacon & Minckley 1974, Beadle 1974, Rantin & Petersen 1985). *Oreochromis grahami* lives permanently at a maximum temperature of 39°C in the Magadi Hot Springs and tolerates up to 41°C for short periods of time, and a subspecies of *O. niloticus* has been found in alkaline hot springs in northern Kenya, with a 2.5‰ salinity and a temperature up to 41° C (Beadle 1974). This occurrences are similar to the abundance of *Bujurquina vittata* in Agua Caliente.

With the possible exception of a loricariid species, the fish fauna from Agua Caliente includes 'rare' species but no endemics, probably due to the lack of isolation of the creek. Hubbs (1941) reported a more rapid speciation occurring among isolated fish populations of warm springs than among fish of pools at normal (lower) temperatures.

A pronounced dominance in abundance by a single species is a usual tendency in fish populations in narrow streams (Winger 1981). *A. bimaculatus* is the dominant species in Agua Caliente, though *B. vittata* may outrank it in some years. As a result, values of the diversity index are relatively low, ranging from 1.23 to 1.53 (Table 2). Eastward from Agua Caliente, in Formosa environments in the Paraguay River plain, values of that index ranged from 0.71 to 3.92 (Menni et al. 1992). Among thermal environments studied worldwide, Agua Caliente appears to have the higher diversity in fishes, which is explained by its lack of isolation from other waters.

The size distribution of characids and loricariids suggest a reproductive period every year (reproductive seasonality), and/or some periodical migration out of the sampled area. As water temperature in Agua Caliente is constant through the annual cycle, this is an evidence of recent colonization by species maintaining seasonal reproductive cycles established in non-spring environments. It has been suggested that increasing day–length combined with increasing food availability may provide the stimulus for gonad development and spawning in thermal springs (Minckley & Deacon 1973); *B. vittata* display courtship behaviour in Agua Caliente.

Locations within the creek show only slight differences in species composition (Table 4). At station 20, a pool deeper than other sections, with lower current speed and stronger turbidity, only two species of armored catfish, *Hypostomus borelli* and *Loricaria tucumanensis*, were obtained.

Ambient water temperature differences are so great that selection has occurred for species and individuals that differ in lethal temperature, as we demonstrated in our physiological testing. Individuals obtained at different locations with different temperatures within the creek, show that higher acclimatization temperatures and higher lethal temperatures have a positive correlation. This means that fish remain in precise locations long enough to become acclimatized to the site's temperature. In Agua Caliente, fish species in some stations are acclimated to a temperature closer to the lethal one than in other habitats in temperate Argentina (Gómez 1996).

It has been observed that fishes placed in a temperature gradient move along it, but after 2 hours spent most of the time within a relatively narrow temperature range (Wootton 1990). Fishes at Agua Caliente have wide opportunity of avoiding the thermal area of the creek both upstream and downstream; to the extent that they do not, we presume that they are acclimatized or adapted to the high temperature of that sector. Conditions of constant high temperature in springs may introduce stresses to which only a few fish species have succesfully adapted (Deacon & Minckley 1974).

Temperatures where fishes occur in Agua Caliente are rather different from those observed in lotic habitats without thermal sources in tropical and subtropical areas. In the subtropical zone of northeastern Argentina, at the same latitude of Agua Caliente, in creeks with important forest cover, mean water temperatures for February (summer) and August (winter), are 28.2 and 15.3°C, respectively (Gómez et al. 1990). Menni et al. (1992) recorded a maximum of 28°C among 30 localities (day data) in Formosa environments at a latitude similar to Agua Caliente, and a maximum of 31°C from 54 localities in several areas in Argentina (both lenitic and lotic environments, day data) (Menni et al. 1996). In lentic habitats the situation may be different; e.g. Ringuelet (1975) reported temperatures as high as 40°C near surface in the 'madrejón Don Felipe' a well studied lentic environment influenced by the Paraná River (Bonetto et al. 1970), but these high values were related to the presence of dense vegetation or peculiar stratification conditions.

Though Agua Caliente is at the core of a subtropical vegetated zone, it has some ecological features similar to desert habitats in southwestern United States, especially regarding temperature. For example (among many), in Seruggs Springs (Nevada), *Cyprinodon nevadensis pectoralis* lives at depths from about 4.5 to less than 30 cm with a water temperature from 32.8 to 33.3°C (Miller & Deacon 1973), and *C. macularius eremus* lives in a stream with a water temperature from 39.6 to 41.0°C (Miller & Fuiman 1987). Though the comparison with desert environments is appealing as we refer in both cases to 'thermal fishes', it must be clear that Agua Caliente is very far from being a desert habitat. Faunistically there is an important difference from the desert fishes from North America, that are endemic species in small habitats. Fishes from Agua Caliente live in a thermal section of a habitat related to normal streams and rivers. Though some desert fishes tolerate up to 43°C, a temperature near the desnaturalization of proteins, most of them live at about 30–35°C. In this case it appears more probable that fishes have developed a physiological acclimatization, more than selected adaptations involving genetic changes as the Yellowstone algae and other organisms in similar situations (Wiegert & Fraleigh 1972, Margalef 1983).

Water chemistry at Agua Caliente may be considered 'idiotrophic' (from the Greek 'idios' = one's own; water with extraordinary traits), in the sense used by Ringuelet (1962). Total dissolved solid content and ions values, particularly SO_4^{--}, Na^+, and Cl^-, are higher here than in most other localities in Salta and Jujuy. These values are within the oligohaline range according to Ringuelet et al. (1967b) system. Several components levels in the water are significantly higher than those of water in near and distant environments in Argentina (Bonetto & Lancelle[4], Menni et al. 1984, 1988, 1996). An exception is the Salado River in Santiago del Estero (Casciotta et al. 1989), where SO_4^{--} values (835.4 mg l^{-1}) are the highest observed with fish presence in Argentina (Menni et al. 1996).

Nevertheless, comparison of water composition

[4] Bonetto, A.A. & H.G. Lancelle. 1981. Calidad de las aguas del río Paraná medio. Principales características físicas y químicas. Com. Cient. CECOAL 11: 1–22.

from Agua Caliente with data from many thermal locations in USA, Mexico, Australia and Africa, conspicuous by their endemic fish fauna (Deacon & Minckley 1974), show that Agua Caliente is far less haline. Cyprinodontoids in the Death Valley (USA) tolerate salinities that are fivefold that of marine water (Soltz & Naiman 1978).

Agua Caliente is not an isolated spring, but an open section of a creek, influenced by thermal sources. Its importance is not only the high values of Cl^{-}, SO_4^{--} and Na^{+} content in the water, but that a full set of conditions including temperature, salinity, chemical composition and topography, provides a particular habitat for the species involved. Moreover, it represents a natural experiment (Odum & Caldwell 1955) for contrasting diversity of ranges and other biological subjects.

The three thermal environments with a fish fauna known from Argentina share the following traits: they are lotic environments, they are limited sites in ecotonal areas, their waters range from oligo- to mesohaline and are inhabited by few species in peculiar combinations. The number of species decreases southward.

As a fish environment, Agua Caliente (as Barreto), largely differs from other thermal or thermal related habitats in the literature in the lack of isolation. This creek is part of a rich hydrographic basin in a seasonal rainy area, with dense subtropical forest. The resident fish fauna represents an opportunistic invasion of a habitat with the highest water temperature and salinity for the area. Though differences in immigration rate due to distance/time are possible, the influence of temperature is probably far more important.

As Agua Caliente is used in an ‘artisanal’ fashion for human bathing, the habitat is in an obvious danger of ecological alteration.

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