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BRIEF COMMUNICATION

Invasive rainbow trout *Oncorhynchus mykiss* preying on the endangered naked characin *Gymnocharacinus bergii* at its thermal limits

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The expansion of the invasive rainbow trout *Oncorhynchus mykiss* into the thermal headwaters of Valcheta Stream (Patagonia, Argentina) and new predation records on the endangered endemic naked characin *Gymnocharacinus bergii* are presented here. These findings are discussed in relation to the contemporary evolution and thermal refuges hypothesis. This study has immediate implications for the conservation of *G. bergii*.

Key words: conservation; contemporary evolution; invasive species; predation; temperature tolerance; thermal refuges.

Salmonid species introductions are known to be related to the disappearance or decline of native fish in different parts of the world (McDowall, 1990; Fernando, 1991; McIntosh, 2000; Murillo & Ruiz, 2003). In Argentina, the introduction of exotic salmonids began in the early 20th century and, since then, the rainbow trout *Oncorhynchus mykiss* (Walbaum 1792) has become the most widely distributed species in Patagonia (Pascual *et al.,* 2002) where it has produced a dramatic change in the species composition of freshwater bodies (Macchi *et al.*, 2008).

The Valcheta Stream is an endorheic basin located in the north-east of Somuncura Plateau, Río Negro province, Argentina (Fig. 1). It originates in several thermal springs that give rise to two pairs of branches, locally called Hot Branch and Cold Branch, eastern and western pair respectively [Fig. 1(c)]. Water temperature ranges between

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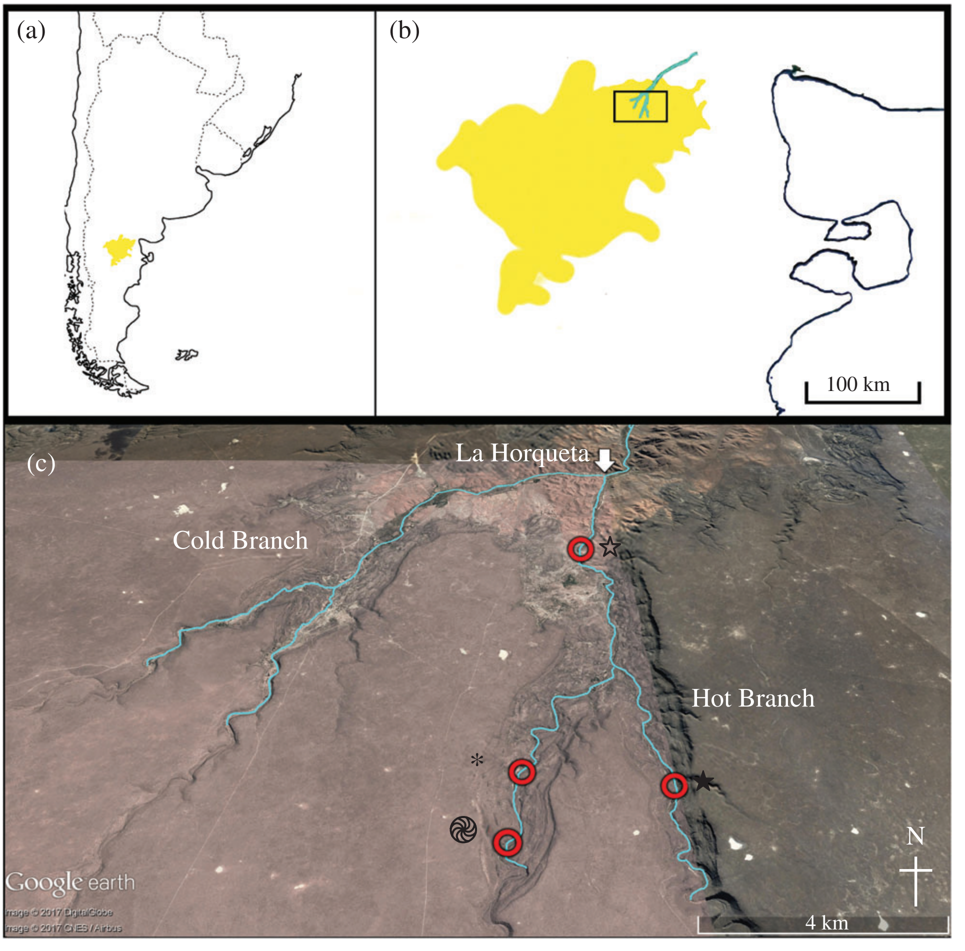

FIG. 1. (a) Location of Somuncura Plateau in Argentina ( ); (b) Valcheta Stream in Somuncura Plateau ( ); (c) sites studied, Valcheta stream headwater, showing the Cold Branch and Hot Branch and the confluence zone in La Horqueta ( ). Records of *Oncorhynchus mykiss* along the Hot Branch ( ): ☆, 4 February 2014 (10 individuals); ★, 24 March 2016 (7); *, 5 February 2014 (2); , 14 January 2016 (12). Satellite images from Google Earth 2017.

20·5 and 22·5° C (Cold Branch) and 22 and 26° C (Hot Branch) throughout the year, while at the convergence zone [La Horqueta, located 13 km downstream, Fig. 1(c)] reaches only 17° C (Ortubay *et al.,* 1997). The isolation of this stream added to the thermal condition of its headwaters which led to the evolution of several species including two aquatic vertebrates, the valcheta frog *Pleurodema somuncurense* and the naked characin *Gymnocharacinus bergii* Steindachner 1903.

Gymnocharacinus bergii is the southernmost native characid in the world and the only species within this group occurring in Argentinean Patagonia. A remarkable feature of this fish is that the scales form during metamorphosis, but disappear during the juvenile and adult period (Miquelarena *et al.,* 2005). The conservation of *G. bergii* is of great concern among specialists and the species was listed as endangered in the IUCN Red List (World Conservation Monitoring Centre, 1996). Although several threats were identified for *G. bergii*, no study has been conducted to assess their effects on the population. Nowadays, threats include fragmentation of aquatic habitat (*e.g.* caused by trampling of livestock), water pollution, catches for illegal trade and interactions with introduced species, *i.e.* predation by *O. mykiss* (Ortubay & Cussac, 2000) and competition with the Uruguay tetra *Cheirodon interruptus* (Jenyns 1842) (Pérez *et al.,* 2015).

Oncorhynchus mykiss was introduced in the lower basin of Valcheta Stream in 1928 (Macchi & Vigliano, 2014). After it was established, the population thrived and extended its range along almost the entire stream. Some differences, however, have been observed between the Cold Branch, where *O. mykiss* were present all year round (with exception to the thermal springs) and the Hot Branch, where the species was present only occasionally during winter (Ortubay *et al.,* 1997). These differences were explained by a thermal barrier that prevented the access of *O. mykiss* to the warmer waters of Hot Branch (Ortubay & Cussac, 2000), in relation to the critical thermal maxima for *O. mykiss* (up to 26° C, Bidgood, 1980). Based on Ortubay *et al.* (1997) study, it was observed that the distribution range of *O. mykiss* contrasts with *G. bergii*, only being present in thermal springs at the Cold Branch, while it is widely distributed and at higher densities along the Hot Branch. Since occasional events of predation of *G. bergii* by *O. mykiss* were recorded at Cold Branch, but not at Hot Branch, the assumed thermal barrier would be also protecting *G. bergii* in these warm waters (Ortubay & Cussac, 2000).

In the framework of a study to design management actions for protecting *G. bergii*, fieldwork was carried out between 2014 and 2016 in the headwaters of Valcheta Stream, from the origins of the watercourse to the site called La Horqueta [Fig. 1(c)]. The presence of *O. mykiss* was recorded during summer and early autumn at four pools ranging from 1·5 to 3 m depth in the Hot Branch [Fig. 1(c)]. *Oncorhynchus mykiss* was sharing habitat with *G. bergii* at the three sites closest to the origin of the stream. In January 2016 four *O. mykiss* were captured by gillnet fishing and their stomachs contents were analysed searching for *G. bergii*. Two *O. mykiss* regurgitated one individual of *G. bergii* immediately after being pulled from the water and the other two had one *G. bergii* each in their stomachs. The expansion of the *O. mykiss* to the thermal headwater suggests two possible explanations that are not mutually exclusive, contemporary evolution of warm water tolerance (Stockwell *et al.*, 2003; Primmer, 2011) or the use of thermal refuges. If this finding is added to the record of predation on *G. bergii* at Hot Branch it has relevance to the conservation of this endangered fish.

In North America the streams inhabited by *O. mykiss* may have summer water temperatures that approach or exceed lethal levels (25° C) (Baird & Krueger, 2003). Salmonids have been reported to thermoregulate behaviourally by detecting and staying within localized areas of cool water (Berman & Quinn, 1991; Baird & Krueger, 2003). In the same way, the pools along the Valcheta Stream, where depth and flow conditions may lead to thermal stratification, could serve as thermal refuges (Matthews *et al.,* 1994; Nielsen *et al.,* 1994) allowing *O. mykiss* to stay in the Hot Branch during the summer. Furthermore, the population of *O. mykiss* in Valcheta Stream, by being exposed for almost 100 years to high temperatures, may have acquired greater tolerance to this environment. In the south of Western Australia, Chen *et al.* (2015) examined the thermal tolerance of a population of *O. mykiss* subjected to high temperatures for 19 generations, concluding that this population has undergone selection and shows the ability to tolerate higher water temperatures. This being so, the thermal barrier that prevented *O. mykiss* from accessing the Hot Branch could be gradually overcome by the species.

The results of this study are of main concern for the conservation of endemic and endangered species inhabiting the headwaters of the Valcheta Stream. As the last refuge for the biggest populations of *G. bergii* and *P. somuncurense*, the Hot Branch is now at risk. A strict monitoring programme should be conducted at the site to detect if *O. mykiss* is really adapting to warmer waters and to define relevant management actions. Laboratory physiological experiments on *O. mykiss* could also help to test this hypothesis in future studies.

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References

Baird, O. E. & Krueger, C. C. (2003). Behavioral thermoregulation of brook and rainbow trout: comparison of summer habitat use in an Adirondack River, New York. *Transactions of the American Fisheries Society* **132,** 1194–1206. https://doi.org/10.1577/T02-127

Berman, C. H. & Quinn, T. P. (1991). Behavioral thermal regulation and homing by spring Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), in the Yakima River. *Journal of Fish Biology* **39,** 301–312. https://doi.org/10.1111/j.1095-8649.1991.tb04364.x

Bidgood, B. F. (1980). Tolerance of rainbow trout to direct changes in water temperature. *Fisheries Research Report of the Fish and Wildlife Division of Alberta*, **15,** p. 11.

Chen, Z., Snow, M., Lawrence, C. S., Church, A. R., Narum, S. R., Devlin, R. H. & Farrell, A. P. (2015). Selection for upper thermal tolerance in rainbow trout (*Oncorhynchus mykiss* Walbaum). *Journal of Experimental Biology* **218,** 803–812. https://doi.org/10.1242/jeb.113993

Fernando, C. H. (1991). Impacts of fish introductions in tropical Asia and America. *Canadian Journal of Fisheries and Aquatic Sciences* **48,** 24–32. https://doi.org/10.1139/f91-301

Macchi, P. J. & Vigliano, P. H. (2014). Salmonid introduction in Patagonia: the ghost of past, present and future management. *Ecología Austral* **24,** 162–172.

Macchi, P. J., Vigliano, P. H., Pascual, M., Alonso, M. F., Denegri, M. A., Milano, D., García Asorey, M. & Lippolt, G. E. (2008). Historical policy goals for fish management in northern continental Patagonia Argentina: A structuring force of actual fish assemblages? *American Fisheries Society* **49,** 331–348.

Matthews, K. R., Berg, N. H., Azuma, D. L. & Lambert, T. R. (1994). Cool water formation and trout habitat use in a deep pool in the Sierra Nevadas, California. *Transactions of the American Fisheries Society* **123,** 549–564. https://doi.org/10.1577/1548-8659(1994)123<0549:CWFATH>2.3.CO;2

McDowall, R. M. (1990). When galaxiid and salmonid fishes meet, a family reunion in New Zealand. *Journal of Fish Biology* **37,** 35–43. https://doi.org/10.1111/j.1095-8649.1990.tb05018.x

McIntosh, A. R. (2000). Habitat and size-related variations in exotic trout impacts on native galaxiid fishes in New Zealand streams. *Canadian Journal of Fisheries and Aquatic Sciences* **57,** 2140–2151. https://doi.org/10.1139/f00-1888

Miquelarena, A., Ortubay, S. & Cussac, V. (2005). Morphology, osteology and reductions in the ontogeny of the scaleless characid *Gymnocharacinus bergi*. *Journal of Applied Ichthyology* **21,** 511–519. https://doi.org/10.1111/j.1439-0426.2005.00656.x

Murillo, V. H. & Ruiz, V. H. (2003). The puye *Galaxias globiceps* Eigenmann 1927 (Osteichthys Galaxiidae): a species threatened with extinction? *Guyana Zoológica* **43,** 10–20. https://doi.org/10.4067/S0717-65382002000200013

Nielsen, J. L., Lisle, T. E. & Ozaki, V. (1994). Thermally stratified pools and their use by steelhead in northern California streams. *Transaction of the American Fisheries Society* **123,** 613–626. https://doi.org/10.1577/1548-8659(1994)1232.3.CO;2

Ortubay, S. & Cussac, V. (2000). Threatened fishes of the world: *Gymnocharacinus bergi* Steindachner, 1903 (Characidae). *Environmental Biology of Fishes* **58,** 144–144. https://doi.org/10.1023/A:1007694308513

Ortubay, S. G., Gómez, S. E. & Cussac, V. E. (1997). Lethal temperatures of a Neotropical fish relic in Patagonia, the scale-less characinid *Gymnocharacinus bergi*. *Environmental Biology of Fishes* **49,** 341–350. https://doi.org/10.1023/A:1007317602738

Pascual, M., Macchi, P., Urbanski, J., Marcos, F., Rossi, C. R., Novara, M. & Dell'Arciprete, P. (2002). Evaluating potential effects of exotic freshwater fish from incomplete species presence–absence data. *Biological Invasions* **4,** 101–113. https://doi.org/10.1023/A:1020513525528

Pérez, C. H. F., Kacoliris, F. P., López, H., Povedano, H. E., Petracci, P. F. & Gosztonyi, A. (2015). La mojarrita *Cheirodon interruptus* en el arroyo Valcheta, Río Negro, Argentina. ¿Otra posible amenaza para la mojarra desnuda (*Gymnocharacinus bergii*)? *Nótulas Faunísticas* **177,** 1–5. https://doi.org/http://hdl.handle.net/10915/49576

Primmer, C. R. (2011). Genetics of local adaptation in salmonid fishes. *Heredity* **106,** 401–403. https://doi.org/10.1038/hdy.2010.158

Stockwell, C. A., Hendry, A. P. & Kinnison, M. T. (2003). Contemporary evolution meets conservation biology. *Trends in Ecology & Evolution* **18,** 94–101. https://doi.org/10.1016/S0169-5347(02)00044-7

Electronic Reference

World Conservation Monitoring Centre (1996). *Gymnocharacinus bergii*. The IUCN Red List of Threatened Species 1996: e.T40695A10337994. Available at http://www.iucnredlist.org/details/40695/0/ (last accessed 27 February 2017).

