Aquaculture Reports xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

Rainbow trout adaptation to a warmer Patagonia and its potential to increase temperature tolerance in cultured stocks

Sonia Alejandra Crichigno[a,*], Leandro Aníbal Becker[a], Mabel Orellana[b], Rodrigo Larraza[b], Guillermo Mirenna[b], Miguel Angel Battini[a], Víctor Enrique Cussac[a]

[a] Instituto Patagónico de Tecnologías Biológicas y Geoambientales (IPATEC), Universidad Nacional del Comahue (UNCO) – Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Quintral 1250, Bariloche, 8400 Río Negro, Argentina
[b] Centro de Salmonicultura Bariloche (CENSALBA), Universidad Nacional del Comahue (UNCO), Argentina

ARTICLE INFO

Keywords:
Climate change
Growth
Oncorhynchus mykiss
Preferred temperature
Thermal tolerance

ABSTRACT

The viability of rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) culture is being challenged progressively by global warming. Previous trials with Australian and Japanese rainbow trout lines suggested that improvements in thermal performance may be possible. Here, we hypothesized that strain-related differences in physiological response to temperature exist between a north Patagonian hatchery stock (CENSALBA), a Neotropical one (Criadero Boca de Río), and a thermal stream (Valcheta) population of wild introduced rainbow trout. This was tested by comparing, at 20 °C, the thermal preference, specific metabolic rate, thermal tolerance, growth, and condition on juveniles of the three strains, and on a Valcheta stream male x CENSALBA female F1 cross. Preferred temperature (PT) and loss of equilibrium temperature (LET, a measure of thermal tolerance) of Valcheta stream and F1 were significantly higher than those of CENSALBA, and the average PTs of Valcheta stream and F1 were higher than the 95% confidence interval of available reference data for rainbow trout. These results suggest that the F1, reared under standard hatchery conditions and selected by growth and thermal preference, presents higher thermal preference and higher thermal tolerance than the current CENSALBA hatchery stock. Introduction of this naturally adapted strain to hatchery stocks would likely result in the improvement of their temperature resistance to warmer waters. Current studies on adults of this F1 generation are underway.

1. Introduction

The viability of rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) culture is being progressively challenged from temperate to tropical waters, and from high to low altitudes, which is accentuated by global warming (Ellender et al., 2016). The thermal range that lies between preferred temperature (PT) and tolerance temperature encompasses an ensemble of stressful conditions (Elliot, 1981). These may be conspicuous, such as slower growth rates and higher occurrences of diseases, or subtle, such as decreases in reproductive performance and gamete quality, e. g. partial or complete retention of oocytes in the ovary, low survival rate in ovulated oocytes (Power, 1980; Estay et al., 1995; Jobling et al., 1998), gonadal development disorders, atresia, and degeneration of oocytes (Jobling et al., 1998; Pankhurst et al., 1996).

PT is a useful indicator of temperature-related performance, as it is usually similar to, or lies within, the optimum temperature range, i.e. the range within which feeding occurs and there are no external signs of abnormal behavior (Elliot, 1981). Different populations and stocks of rainbow trout show a wide variation of PTs. In only a few cases evidence was found of adaptation to high temperature in Australia (Molony, 2001; Molony et al., 2004; Oku et al., 2014; Chen et al., 2015) and artificial selection improving heat tolerance in Japan (Ineno et al., 2005, 2008; Crozier and Hutchings, 2014). In particular, these trials with Australian and Japanese lines indicate the possibility of improving thermal performance in rainbow trout.

Summer corresponds to the gametogenesis period of rainbow trout, and Northern Patagonia, the main area of rainbow trout culture in Argentina, has been affected by a considerable increase in mean summer air temperature (MSAT, 1.0–2.5 °C from 1961 to 2015, http://www.smn.gov.ar/serviciosclimaticos/?mod=cambioclim&id=7, Báez et al., 2011). Rainbow trout eggs were first sent from the United States in 1904, probably from the McCloud River, California (Marini, 1936; Pascual et al., 2001; Riva Rossi et al., 2004), to the Centro de Salmonicultura Bariloche (CENSALBA), in order to generate a sport fishery

* Corresponding author.
E-mail address: soacri@yahoo.com.ar (S.A. Crichigno).

https://doi.org/10.1016/j.aqrep.2017.11.001
Received 17 April 2017; Received in revised form 29 October 2017; Accepted 4 November 2017

(Tulian, 1908). In 1931 more eggs were sent from Chile (Marini, 1936), from fish which had originally been imported in 1905 from Hamburg, Germany (de Buen, 1959). In 1969 rainbow trout from Denmark were brought to CENSALBA (mean annual water temperature 10–12 °C, with maximum = 18 °C and minimum = 4 °C, based on daily records along 2014), from where they were extensively distributed to commercial aquaculture facilities throughout Argentina (Baiz, 1973; Macchi et al., 2008); including Criadero Boca de Río, Cordoba (mean annual water temperature 14 °C, with maximum = 20 °C and minimum = 10 °C).

The Valcheta stream belongs to the endorheic basin of Curicó pond in Northeastern Patagonia, with thermal (20–26 °C) headwaters (Menni and Gómez, 1995; Ortubay et al., 1997) and lower reaches with temperatures ranging from 8 to 10 °C. The founding stock of *O. mykiss*, a lot of 600 individuals stocked in 1941 for sport fishery purposes (Ortubay, 1998), were provided by the CENSALBA hatchery (Macchi et al., 2008). Rainbow trout prey on *G. bergii* when they swim upstream during the winter to the thermal headwaters (Ortubay and Cussac, 2000). Kacoliris et al. (2015) have reported a progressive upstream expansion of *O. mykiss* distribution.

We hypothesized that strain-related heritable differences in physiological response to temperature exist between CENSALBA, Criadero Boca de Río and Valcheta stream rainbow trout. As a first step this was tested by comparing, at a high acclimation temperature (20 °C), thermal preference, specific metabolic rate, thermal tolerance, growth, and condition on the three strains, and on a Valcheta stream male x CENSALBA female F1 cross.

2. Materials and methods

2.1. Fish stock data collection

Oncorhynchus mykiss juveniles were obtained from two hatcheries: Centro de Salmonicultura Bariloche (CENSALBA, 41°07′37″S, 71°25′14″W, 800 m a.s.l.; mean annual air temperature (MAAT) 1981–2010 = 8 to 10 °C; mean summer air temperature (MSAT) = 14 to 16 °C) and Criadero Boca de Río (Córdoba, 31°54′47″S, 65°06′48″W; 560 m asl; MAAT 1981–2010 = 16 to 18 °C; MSAT = 22 to 24 °C), and from the Valcheta stream (MAAT 1981–2010 = 14 to 16 °C; MSAT = 20 to 22 °C) (http://www.smn.gov.ar/serviciosclimaticos/?mod=elclima&id=74&clave=Temperatura-Media). Water temperature data were not equally available for comparison, so MAAT and MSAT were used (Becker et al., 2017). Individuals from Valcheta stream were captured in December 2013 by electro-fishing at three sites (Route 60 bridge, 40°43′17″S, 66°17′16″W, 237 m a.s.l.; Chipauquil, 40°54′13″S, 66°33′09″W, 401 m a.s.l.; La Horqueta, 40°56′05″S, 66°34′11″W, 421 m a.s.l.). Preferred temperature (PT), Specific metabolic rate (SMR) and a proxy of thermal tolerance, the loss of equilibrium temperature (LET), were assessed on individuals from each of the three stocks (Table 1).

2.2. Thermally selected F1 generation

In June 2014 new individuals from Valcheta stream were captured (water temperature at capture = 13.1 °C). Only mature males were obtained and sperm samples were brought to the laboratory while maintained at 3 °C.

The F1 cross was performed with 6 females from CENSALBA and 8 males from Valcheta stream to produce 48 families. Each female's brood was divided in eight 500 mL glasses (approximately 383 oocytes in each) and fertilized with 100 µL of milt from each male. Eggs were hydrated for 30 min and then distributed randomly in 6 vertical incubation trays, with 8 spacers each. At eclosion, 23 families were successful.

Selection of F1 individuals with good growth performances was carried out 85 days after first feeding. Thirty-eight individuals with a weight > 0.4 g (Fig. 1) were selected from a total of 116 surviving individuals from 16 families (founded by 6 females and 5 males). Subsequently, to select individuals with preference towards high temperature among those F1 individuals showing good growth, these 38 individuals were subjected to a shuttle-box challenge, consisting in two connected compartments (each box 17 cm in diameter × 18 cm in height, with a canal 14 cm in length × 18 cm in height, Neill et al., 1972), one at the initial water temperature (13 °C) and the other two degrees higher (15 °C), increasing or diminishing water temperature of compartments in relation to the election of the fish, always keeping a difference of 2 °C between compartments. As a result, we obtained a thermally selected F1 generation of 21 juvenile individuals belonging to 11 families (founded by the same 6 females and 5 males) that presented good growth and preferred warm water. They were reared apart in a circular fiber tank (500 L) under natural temperature and photoperiod conditions for 5 months.

Table 1
Number of juvenile individuals (*N*), weight (mean and range, g) and standard length (*SL*, mean and range, cm) in each determination of preferred temperature *(PT),* specific metabolic rate *(SMR), and* loss of equilibrium temperature (*LET*).

Experiment Stocks	*PT*	*SMR*	*LET*
CENSALBA			
N	11	11	11
Weight	12.59 (7.83–19.24)	12.59 (7.83–19.24)	12.32 (5.61–22.93)
SL	9.45 (8.03–11.03)	9.45 (8.03–11.03)	9.04 (6.83–11.45)
Criadero Boca de Río			
N	11	10	8
Weight	14.59 (9.32–20.1)	14.63 (9.32–20.1)	25.86 (17.38–36.83)
SL	9.72 (7.94–11.07)	9.69 (7.94–11.07)	11.8 (10.08–13.12)
Valcheta stream			
N	12	11	8
Weight	10.14 (4.47–18.93)	9.34 (4.47–18.1)	12.14 (4.93–26.95)
SL	9.12 (6.96–11.65)	8.88 (6.96–11.09)	9.4 (7.21–12.36)
Selected F1			
N	18	18	16
Weight	23.02 (5.11–43.24)	23.02 (5.11–43.24)	29.24 (9.8–49.78)
SL	11.88 (7.8–13.84)	11.88 (7.8–13.84)	12.49 (8.61–14.31)

2.3. Feeding

Fish from Criadero Boca de RÍo, CENSALBA and the thermally selected F1 were fed *ad libitum* on standard commercial formulations. Valcheta individuals were fed *ad libitum* with a mix of *Daphnia* sp., *Tubifex* sp. and standard commercial formulations in an attempt to provide adequate feeding.

2.4. Acclimation

Physiological processes of fishes could depend on acclimation temperature (McNab, 2002). A high acclimation temperature (20 °C) in relation to the final temperature preferendum of rainbow trout (13.5 °C, Aigo et al., 2014) was selected in order to measure performance under a thermal condition where non adapted fish can be expected to show poor results. Juveniles from Criadero Boca de Río and Valcheta stream were taken to CENSALBA facilities in December 2013 (summer). Individuals of each stock (Criadero Boca de Río N = 79, Valcheta N = 80, and CENSALBA N = 102) were put in a circular fiber tank (250 L), with UV