Limnologica 57 (2016) 23–26

Contents lists available at ScienceDirect

Limnologica

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

Short Communication

Ion deficit restricts the distribution of brown trout (*Salmo trutta*) in very dilute mountain lakes

Espen Enge[a,*], Trygve Hesthagen[b]

[a] University of Stavanger, NO-4036 Stavanger, Norway
[b] Norwegian Institute for Nature Research (NINA), P.O. Box 5685, Sluppen, NO-7485 Trondheim, Norway

ARTICLE INFO

Article history:
Received 8 July 2015
Received in revised form
12 November 2015
Accepted 23 December 2015
Available online 23 January 2016

Keywords:
Brown trout distribution
Dilute water
Mountain lakes
Climate change
EU Water Frame Directive

ABSTRACT

The current study is, according to our knowledge, the first study indicating that ion deficit is an important restrictor to the distribution of brown trout populations in very dilute mountain lakes. The brown trout populations in the study lakes may be able to survive solely due to traces of air borne sea salt spray.

Due to the distance to the sea and the subsequent limited marine ion contribution, mountain lakes, especially those located in areas with slowly weathering bedrock, typically have a water quality poor in dissolved salts (Gorham, 1961). Such lakes are found in parts of eastern Canada, northeastern USA, southern Sweden and southern Norway (Schofield, 1976).

In southern Norway, mountain lakes in the southwestern parts have particularly dilute water, possibly among the most dilute bodies of water in the world (Eilers et al., 1990). The bedrock in this area is close to inert and traces of sea salt "spray" is the major source of ions (Skartveit, 1981; Enge and Kroglund, 2011; Enge, 2013). In 2012, a comprehensive water chemistry survey carried out in southwestern Norway (Enge, 2013) showed a median conductivity and calcium concentration of 8.7 $\mu S\,cm^{-1}$ and 0.23 $mg\,L^{-1}$, respectively, for the lakes ($n = 128$) situated above an altitude of 500 m a.s.l. (m above sea level). Lowland lakes, however, had considerably higher ionic strength, having a median conductivity and calcium of 38.6 $\mu S\,cm^{-1}$ and 0.95 $mg\,L^{-1}$, respectively ($n = 279$).

Water bodies in this area have previously been seriously affected by acidification (Enge, 2013). Due to the recovery of the water chemistry in the past two decades (Garmo et al., 2014), the current water chemistry is close to the pre-acidification state (Enge, 2013). The median pH for the lakes above an altitude of 500 m a.s.l. was 5.71, which is not detrimental for brown trout (*Salmo trutta* L.), the only native fish species found in this mountain area. The independent H^+-effect is not associated with physiological stress for brown trout until pH <4.6 (Muniz and Leivestad, 1980).

Due to osmotic effects, fish living in freshwater experience a passive loss of ions to the water. This loss is compensated by actively uptaking ions from the water (Muniz and Leivestad, 1980; Heath, 1995). This uptake is, however, dependant on the existence of a certain concentration of ions in the surrounding water (Gonzalez et al., 2002). In the critically dilute water qualities in the mountain areas of southwestern Norway, the abundance of brown trout seems to be determined primarily by a combination of pH and conductivity (Muniz and Leivestad, 1980; Enge and Kroglund, 2011). This suggests that the availability of essential ions, such as sodium chloride (Heath, 1995), is the major limiting factor for sustaining healthy populations of brown trout. Other normally important parameters, as Ca and Al, did not appear to contribute (Enge and Kroglund, 2011).

In highly acidified waters the impact of low ionic strength is enhanced by the detrimental effects that high levels of H^+ and cationic Al have on gill permeability and ion uptake (Heath, 1995). Finally, the fish dies of ion regulation failure. The fact that low buffered lakes are particularly sensitive to acidification and fish death, is not only due to the low buffer capacity itself (i.e. low pH), but also due to the adverse physiological effects of the corresponding low ionic strength.

* Corresponding author.
E-mail address: espen.enge@lyse.net (E. Enge).

http://dx.doi.org/10.1016/j.limno.2015.12.004
0075-9511/

The natural state of the brown trout populations in the lakes in southwestern Norway is normally dense to overstocked (Sømme, 1941). An average gillnet catch for 209 brown trout lakes, test fished with a standard gillnet series (Jensen, 1977), was 31.1 specimens per 100 m^2 of gillnet area (CPUE), and only 5% of the lakes had a CPUE-value <5 specimens (Ugedal et al., 2005). Based on this evaluation, a CPUE of <2 specimens has been established as limit for "bad" ecological status in the Norwegian adaption of the EU Water Frame Directive classification (Iversen and Sandøy, 2013).

Adult fish are generally more water quality tolerant than younger life stages. Therefore, many lakes with a water quality that apparently restricts brown trout recruitment, may not be completely barren (will be discussed later). Subsequently, to define "unsuitable water quality" exclusively using lakes with no gillnet catch (CPUE = 0), may possibly underestimate the required water quality (conductivity), and further underestimate the true number of lakes having populations restricted by unsuitable water quality. As a practical approach to this, supported by the EU Water Frame Directive classification (Iversen and Sandøy, 2013), the current study has applied the CPUE-limit proposed by Enge and Kroglund (2011). Subsequently, the corresponding water quality to CPUE = 2.5 specimens, is considered as a threshold level for supporting persistent brown trout populations. Enge and Kroglund (2011) determined this limiting water quality by importing CPUE-values from test fishings performed within this mountain area, into a pH-conductivity diagram, and drawing an "iso-line" at CPUE = 2.5 specimens per 100 m^2.

Here, the water chemistry data from the survey in 2012 (Enge, 2013) is used to predict possible brown trout abundance within this mountain area. The study area was restricted to Rogaland county (Fig. 1), which has a total area of 9400 km^2, where 3800 km^2 is located above an altitude of 500 m a.s.l. The sampling sites (n = 407) were primarily lake outlets, and they were evenly distributed throughout the study area, possessing important geographic properties such as location and altitude.

The water samples were analysed for a number of chemical parameters, including pH, conductivity and chloride (Enge, 2013). Conductivity was adjusted for the H^+ contribution, by subtracting 0.35 $\mu S\,cm^{-1}$ per $\mu eq\,H^+\,L^{-1}$ (Eaton et al., 1995). Thus, the applied conductivity values in the current study, represent the concentrations of dissolved salts in the water. Estimations of the conductivity due to marine components in the samples were performed by first estimating the concentrations of the major seawater components based on the ratio to chloride (Skartveit, 1981). The corresponding conductivity was calculated using standard values for specific conductivity (Eaton et al., 1995). Subsequently, 1 $mg\,L^{-1}$ Cl represents a "sea salt conductivity" of 4 $\mu S\,cm^{-1}$.

The current brown trout abundance was assessed by importing this water chemistry data set directly into the pH-conductivity diagram. Other scenarios were simulated by modifying the water chemistry prior to being imported into the diagram. This includes a scenario excluding the marine ion contribution, and a scenario representing a doubling of the conductivity.

These predictions demonstrated that 50 (12%) of the 407 study sites apparently had a water quality limiting the distribution of brown trout (Table 1). Separating the sites by altitude demonstrated that the water quality in lowland lakes apparently did not restrict brown trout, while 46 (36%) of the 128 lakes located >500 m a.s.l. had an insufficient water quality to support brown trout (Fig. 2). To check this water chemistry-based prediction, fish status was gathered from 116 of the 128 lakes >500 m a.s.l., based on information from local environmental administrations, landowners and anglers. These registrations revealed that brown trout were currently absent in 45% of these lakes, being relatively close to the predicted abundances based on water chemistry.

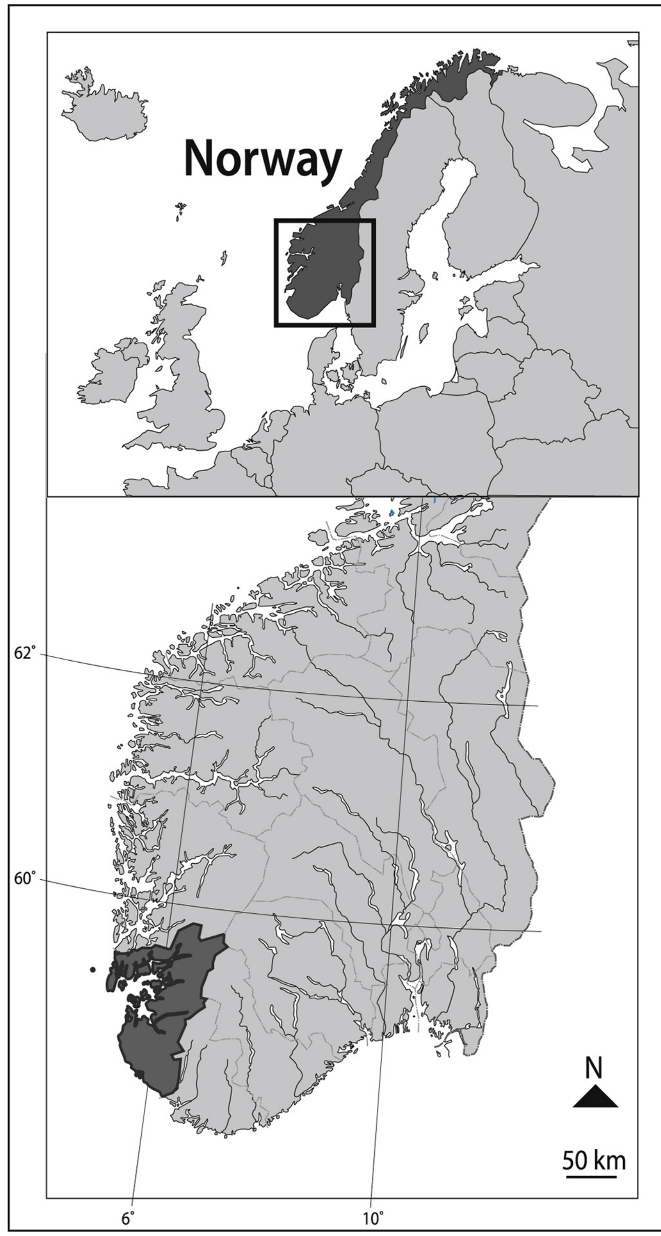

Fig. 1. The study area is located in southwestern Norway.

The lack of brown trout in mountain lakes has been attributed to a number of factors, including acidification, lack of suitable

Table 1
Number of lakes having insufficient water quality, predicded by water chemistry.

Altitude m a.s.l.	n	Number of lakes with insufficient water quality to support trout		
		Sea salts excluded	Present situation	Doubling of cond.
<500	279	101 (36%)	4 (1%)	0 (0%)
>500	128	114 (89%)	46 (36%)	6 (5%)
Σ	407	215 (53%)	50 (12%)	6 (1%)