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Cottus poecilopus Heckel, 1836, in the river Javorinka, the Tatra mountains, Slovakia

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Abstract. This study focuses on the *Cottus poecilopus* from the river Javorinka in the north-east High Tatra mountains, Slovakia. The movement and residence of 75 Alpine bullhead in the river were monitored and carefully recorded using GPS coordinates. A map representing their location in the river was generated. This data was collected in the spring and summer of 2016 and in the autumn of 2017. Body length and body weight of 67 Alpine bullheads were measured. The largest bullheads were collected between 860-880 m a.s.l.. Bulheads found at the 1 000-1 100 m a.s.l. were significantly smaller. In favourable microhabitats of 850-900 m, mainly large light shade bullheads were collected. Fish monitoring in Javorinka was conducted aproximatelly 55 years following previous monitoring of this river performed by Václav and Sylvia Dyk.

Key words: Alpine bullhead, Javorinka river, Tatra Mountains, West Carpathians

Introduction

This work confims and monitors the presence of alpine bullhead (*Siberian sculpin*) in the Javorinka high-mountain stream in Belianske Tatras. The Javorinka stems from under the Javorový peak, 2 417.5 m a.s.l. and flows into the Biela voda (Bialka) river, which flows into the Baltic Sea north of Poland, east of Sweden and into the Atlantic Ocean. This work seeks to enhance current knowledge of bullheads, and the aim is to use this data to address ecological problems facing these fish today for the protection of their population and the preservation of the biodiversity of Europe and Slovakia.

Many authors have focused on the observation of fish in high altitude areas of the Tatra mountains. The German polyhistorian Johan Baptista Grossinger (1794) observed migrating salmon and eels in the influent streams of the river Dunajec in Slovakia. Reisinger (1830) and Kornhuber (1863) also noted fish populations in the Tatras. Fritsch (1859) and Mihályi (1954) summarized early information on fish from Bohemia and Hungary, respectively. In Tatranská Javorina under Muráň mountain, a small fish nursery was built by Christian Kraft von Hohenlohe around 1930. The most comprehensive studies on fish from the Tatra mountains were written by professor Václav Dyk (1957; 1961), Dyk and Dyková (1964a,b; 1965), who studied altitudinal distribution of fish, describing the highest points where fish were found. His studies on fish were likely the most complex studies of their kind during that period. Along with his wife Sylvia, who illustrated his studies, they published the first realistic studies on fish from the Tatra mountains including the river Javorinka (Dyk and Dyková 1964a). Ferianc (1948) published the first Slovakian nomenclature of fish in 1948. Eugen K. Balon (1964; 1966) was the next famous ichthyologist who became a recognised expert in the fish fauna of the streams of the Tatra mountains, the river Poprad, and various high mountain lakes. Data on fish species of the Dunajec and Poprad rivers was recorded by Kux and Weisz (1960). The next list of Tatra fish was published by Žitňan (1974), who found 26 species of fish and one species of lamprey in the Tatra mountains. The next studies of Tatra fish can be found in Holčík and Mihalík (1971) or Holčík and Nagy (1986). Salmon and bullhead are also mentioned in many general publications on fish from Slovakia – ex. Šimek (1954; 1959), Holčík *et al.* (1965), Oliva *et al.* (1968), and Sedlár *et al.* (1983).

Today, the ichthyofauna of alpine and mountain rivers and lakes is negatively influenced by fish farming at lower elevations, sport fishing and non-native invasive species such as Brook trout. From year to year, climate change seems to be a very influential factor on fish dispersion. New species shift to higher elevations where they may act as concurrence or at least as a stress factor on the original species. For example, in the past, *Cottus gobio* were considered to be a more threatened species than *C. poecilopus*, but today the opposite is true.

This study is a step toward understanding the history of a group of Javorinka alpine bullhead over the last 50 – 100 years, as well as the history of these freshwater cottids and salmons; their ecological relatives in the river. The family Cottidae belongs to the suborder Cottoidei. In its entirety, Cottoidei is comprised of eleven families, and its distribution encompasses all the world's oceans. The diversity of the family Cottidae (sculpins) is the highest in the marine environments of the northern Pacific (Froese and Pauly 2003). Freshwater cottids outside Lake Baikal are confined to four genera: Mesocottus, Trachidermus, Myoxocephalus, and Cottus, which includes 40 species found within North America and Eurasia. Through these adaptive radiations, a tremendous diversity of morphological, ecological, physiological and life historical traits now exist in freshwater sculpins. A common anatomical feature for cottids, and also for Baikalian cottoids, is the lack of a swimming bladder, which determines their typically benthic life-style. Only three species of *Cottus* are widespread in Eurasia. The Alpine bullhead *C. poecilopus* is a cold-adapted fish, which inhabits rivers and lakes from the Russian Far East to restricted areas of Northern and Eastern Europe. The European common bullhead *C. gobio* is also a cold-adapted species, but in mountain areas it normally lives downstream of the *C. poecilopus* range (Witkowski 1979). Both *C. poecilopus* and *C. gobio* also thrive in the brackish coastal waters of the Baltic Sea (in salinities up to 6 and 7 p.p.t, Andreasson 1972). Alpine bullhead is a very polymorphic species, and alpine bullheads of Slovakian origin are members of the Sudeten - Carpathian group.

The majority of freshwater sculpins belong to the genus *Cottus*. This genus is suitable for studies of the evolutionary biology, fresh water and local habitual adaptations, as well as speciation in fishes derived from marine environments. Origins of the biodiversity in the *Cottus* species are very suitable for a general understanding of the phylogeny of coldwater adapted freshwater fishes in the Northern Hemisphere (Sideleva and Goto 2009). Like salmonids, bullheads are an important component of fish communities in rivers and lakes distributed in the middle to high latitudinal regions (Dyk 1961; Balon 1964; 1966). The species richness (64 species) of *Cottus* is similar to those of the salmonids, *Salvelinus* (56 species), and *Coregonus* (72 species) and exceeds those of *Phoxinus* (25 species) and *Thymallus* (13 species), all of which share Northern Hemisphere ranges similar to that of the *Cottus* species (Eschmeyer and Fricke 2010). Cottus species show regional specificity in their geographic distribution, with 16 species living in Europe, and they are generally sedentary (Oliva *et al.* 1968, Natsumeda 2007), tending to be isolated to specific areas within each habitat (Kozlowski *et al.* 2017). Because their local populations may adapt locally, a species may diverge both ecologically and morphologically. Such diverse features of individuals have contributed to the high species richness in this local region (Nolte *et al.* 2006). *Cottus* species inhabit a variety of freshwater environments that include lakes and the upper, middle and lower courses of rivers (Balon 1966; Holčík and Mihálik 1971). In addition, there are several species that inhabit marine coastal areas for a short period of their life, but are still categorized as freshwater amphidromous fishes. Amphidromous bullheads produce many small eggs in the lower reaches of streams and rivers. Hatched larvae rise to the surface of the river due to their phototactic response, and drift downstream. This strategy may contribute to the high survival of larvae (Goto 1993; McDowall 2007). The pelagic larvae spend some time in marine coastal areas before migrating to rivers. Such pelagic larvae occur in all lineages except the lineage of *Cottus poecilopus* from Eurasia. Fluvial species, which live in rivers for their entire lives, utilize the latter for both growth and reproduction, and usually produce a small number of large eggs (Dyk 1957). Larvae undergo direct development and are benthic after hatching (Jurajda 1992; Przybylski and Borowska 1998). Larval ecological characteristics of these species have not been reported on and pelagic larvae for this lineage are unknown (Pasko and Mašlak 2003). The lineage of the *Cottus poecilopus* group is distributed throughout northern Eurasia from Primorskii to the Siberian region of Russia, and in central Asia and Europe (Sideleva and Goto 2009). The aim of this study was to monitor the presence of mountain fish in the river Javorinka, to describe their local microhabitats and to understand the potential migration process. Another important goal of this study was to map favourable sites of high mountain Alpine bullheads and specimens of native wild brown trout.

Material and Methods

Study area

Sampling was carried out in the Javorinka river, which is part a of the Javorová mountain valley. Formation of the watershed of the Javorinka river in the Belianske Tatras in Slovakia and the assumed start of introduction of trout into mountain streams is assumed to be when the Poprad and Javorinka rivers began to form in the last interglacial period, 6 000-2 000 years ago. Many mountain albedoes exist as remnants of melted mountain glaciers, which were the last of the ice Wurme. The arrival of trout in mountain streams is anticipated to have occurred 3 000-300 years ago, when the Tatra forest stands developed into their current composition of fir beams, maples and others species. Relief of Javorinka is from the glacial valley to the north through Tatranská Javorina. Huge boulders in the channel are evidence of regular avalanches and rockfalls. The Belianske Tatry and the Javorinka river are situated on flysh subsoil (alternating layers of saplings and clay, slate). The best living conditions for fish fauna are in mountain stream stretches such as the Javorinka river where the shores are strengthened by old forest (Fig. 1) stands. Mature trees with deep roots are important as a support for the whole ecosystem.

Fig. 1. Profile photo of Javorinka river surrounded at many sites by 200 year old trees of *Abies alba*. At the left side, there is a deeper bank suitable for trouts, right sight may serve as microhabitat for alpine bullheads (Photo: Martin Janiga, 2017).

Field collections and laboratory measurements

The fish were observed or found in the river Javorinka in the spring and summer of 2016 and in the autumn of 2017. 75 Alpine bullheads in the river were monitored and carefully GPS coordinated. In the field, we recorded the elevation, relative slope and the geographic coordinates with GPS navigation, using Google Earth and Arcgis Arcmap 10.4 software for computer processing of samples. Photo documentation was performed at many of the sites. When deceased fish were found in the river, they were weighed with a spring balance and measured with callipers.

Statistical analysis

The allometric relationships between morphometric characters of fish were modelled by non – linear regression analysis. The body weights and body lengths among different groups of bullheads were compared by one-way analysis of variance (ANOVA) with significance level at P = 0.05. For all calculations, the STATISTICA 8. software was used. In the first analysis a simple exponential line and points graph was used to compare the relationship between body weight and length of fish. In the second analysis a polynomial points and line graph (regression) was used to show the relationship between elevation and body weight. A polynomial scatterplot graph was used to show the relationship between length, weight and elevation. The third analysis included a least square means ANOVA – one way analysis of variance, where I showed the relationship between two colours of bullheads and the elevation. In this last analyses the relationship between body characteristics was shown against the slope.

Results

The most important fish habitats are described in Fig. 2. The species utilizes a particular habitat, preferring a gravel substrate with many flat rocks on the riverbed, although some individuals were found on sandy substrate in areas of the river deeper than one meter. In general, brown trout were seen at higher elevations than alpine bullhead. Optimal habitats for bullhead are located in near Podspády, and stretch to approximately one hundred metres beyond the state border between the Slovak Republic and Poland.

An increase in body weight versus body length begins in sculpins approximately in the first third of their life cycle in the Javorinka (Fig.3). The largest bullhead were found between 860 – 880 m a.s.l. (Fig. 4), while bulhead found at 1 000 - 1 100 m a.s.l. were significantly smaller. In alpine bullheads, body length and body weight significantly decreased in habitats at a higher altitude.

The microhabitat between 870 and 900 metres was favourable for lighter coloured bullhead. In this altitudinal range, the heaviest (Fig. 5) and

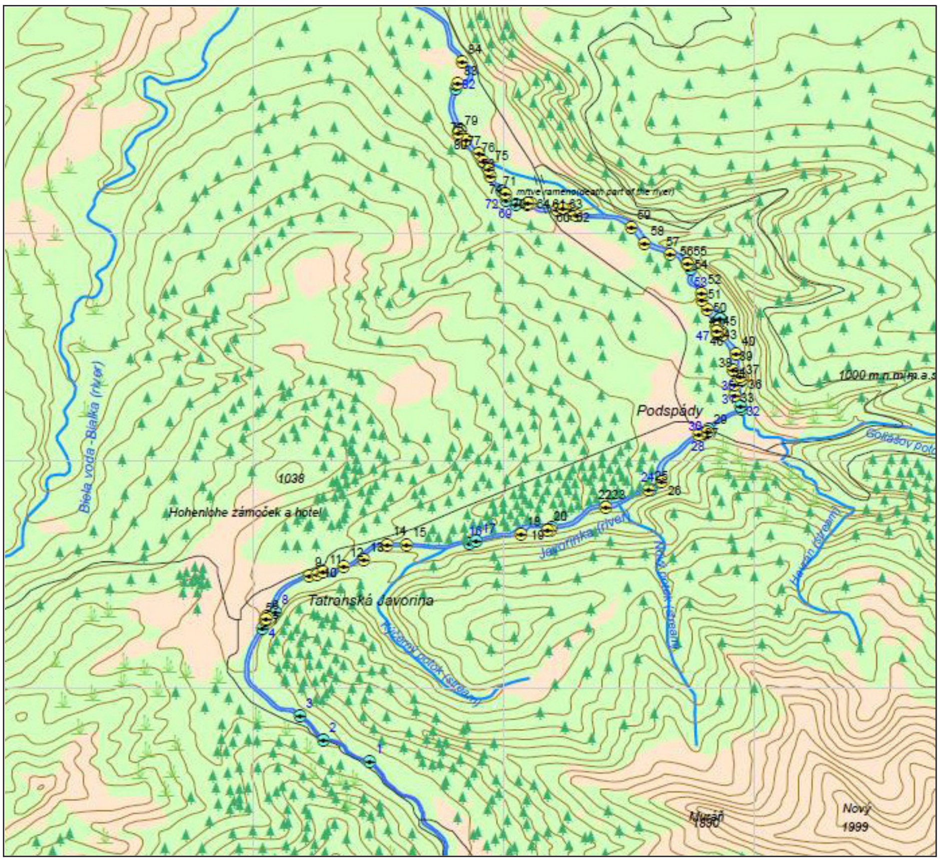

Fig. 2. The most important localities of fish occurence in the stream Javorinka – 2017 . Yellow – *Cottus poecilopus*, green *Salmo trutta* (Author: Martin Janiga).

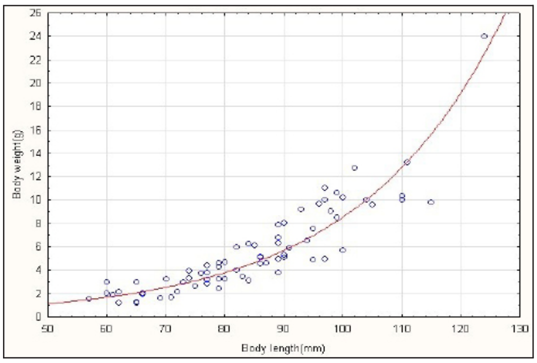

Fig. 3. Allometric (exponential) relationship between body length and body weight in Alpine bullheads in the river Javorinka. The body weight increases more rapidly when the animals reach the length of approximately 85 milimeters.

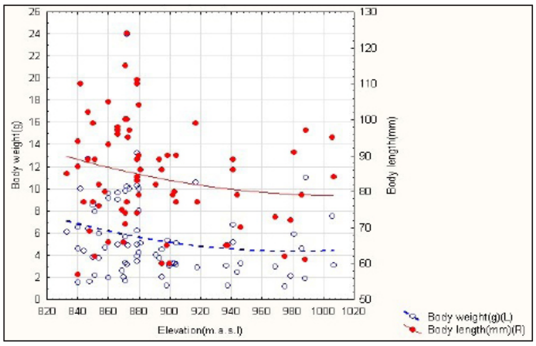

Fig. 4. Scatterplot of body weight and body length of *Cottus poecilopus* against the elevation The longest and biggest fish were found at the level from 860 to 880 m a.s.l. Both body characteristics decreased continually with increasing elevation.

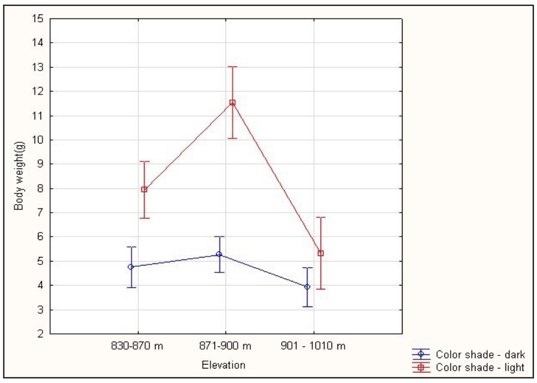

Fig. 5. Least square means with standard errors of body weight of *Cottus poecilopus*. Fish were the lightest in body weight at the higher elevations (F(2,65)=5.1, P=0.009) and the lighter bullheads (color shade) were significantly heavier than dark animals (F(1,65)=15.3, P=0.0002). At all elevations the light fish in color shade werer statistically significantly heavier than dark individuals. There was not interaction between the factor color shade and elevation (F(2,65)=2.1, P=0.12, NS).

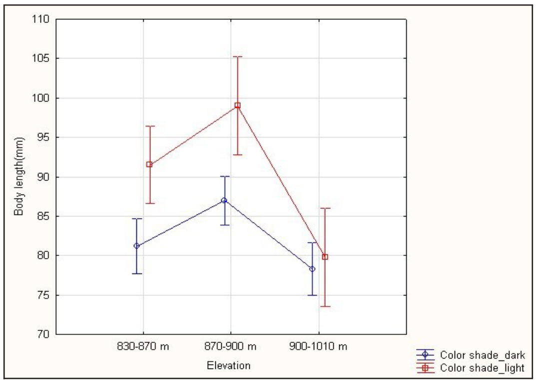

Fig. 6. Least square means with standard errors of body length of *Cottus poecilopus*. Fish were the shortest at higher elevations (F(2,65)=3.9, P=0.02) and the lighter bullheads were significantly longer than darker animals (F(1,65)=4.2, P=0.04). At lower elevations the light fish in color shade were statistically significantly longer than dark individuals. There was not interaction between the factor color shade and elevation (F(2,65)=0.7, P=0.52, NS).

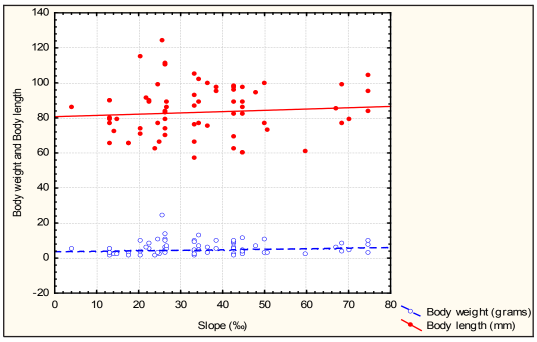

Fig. 7. Multiple exponential scatterplot graph showing relation between slope and both body weight and body length of Alpine bullheads *Cottus poecilopus*, bullheads were found mostly on 2,5 % steep site, the heaviest and the longest individuals were also found mostly in 2,5% steep slope.

the longest (Fig. 6) bullheads were found, and they were mainly fish of a lighter colour pattern (color shade).

Although there was a tendency for sculpins to increase in body length at steeper sites, the regressions were not statistically significant (Fig. 7).

Discussion

Elevation and morphomety of Cottus poecilopus

For *Cottus poecilopus,* the most suitable slope was 25% but bullhead were also found at a slope of 74% and an approximate elevation of 1 007 m a.s.l. Kozlowski *et al.* (2017) found bullhead at steeper slopes than reported by Balon (1966), such as in the Suchá voda stream at 101% slope. The highest point where the fish were present was Roztoka stream at 1 150 m a.s.l. Balon (1966) found the first Cottus poecilopus in the River Poprad close to the Štôla (elevation ca. 900 - 1 000 m a.s.l – ca. 26,7‰ relative slope). *Cottus poecilopus* usually prefer wider and lower channels of rivers with an average slope of 25%. Strong floods can really affect the lifecycle of this species, because they tent to remain in deeper waters without a sufficient amount of oxygen.

Allometry

Fish morphometrics have been a hot topic in ichthyological studies for many years, but the initial steps date back to the time of Galileo Galilei. The allometric model seems to be the most appropriate for describing morphometrics in fishe (Lleonart *et al.* 2002) and applies to the vast majority of relationships of morphological characteristics with body length. In the case of bulhead, growth is allometric. In the first third of their growth period, the species grows faster in length than in weight, but when the fish are older they gain weight faster than they increase in body length. The significance of allometry is related to the effect of the increasing body length to the relative efficiency of the intestine to absorb nutrients from digested food. Since growing organisms require more energy and nutrients, changes to the structural capacity, i.e. lengthier intestines, must occur in order for those needs to be met. Structural adaptation of the intestines will ensure that food can be retained longer in the tract, an thus, more nutrients will be absorbed, so additional receptors for the absorption of energy and nutrients will be available (Kramer and Bryant 1995). Typical allometric relationships between body weight and body length were noted in the bullhead found in Javorinka.

Species characteristics of the genus Cottus

Differences in characteristics between *Cottus poecilopus* and *Cottus gobio* are listed below. With regard to the European bullhead, abdomen fins are white, and they may have irregularly appearing grey spots, that do not join in contiguous strips as in the Alpine bullhead. European bullhead have two paired abdominal fins, which consist of four rays. Abdominal fins are short, do not reach the anal orifice and the inside fourth ray of abdominal fins is about half as long as the longest ray of the abdominal fin. The differences between European bullhead and Alpine bullhead are mainly in these abdominal fins. While both species have four rays of abdominal fins, there is a difference in their particular length. In case of European bullhead, the outside rays are about half as long as the two longest middle rays of abdominal fins and the aforementioned inner ray slightly exceeds half the length of the middle rays. The longest rays of *Cottus gobio* are the symmetrical middle rays.

Cottus poecilopus, the Alpine bullhead has abdominal fins that are proportionately longer than those of the European bullhead and they reach or exceed the anal orifice. The anal fin of the Alpine bullhead has 13 to 15 rays. In the front dorsal fin there are 9 rays, and in the back dorsal fin there are 17 rays. However, the most interesting-looking are the bizarre cheek spines above the branchiae, as well as the two outer perculae, which are better developed and larger than in the case of European bullhead. Comparatively, European bullhead have only one such spine or perculum placed above the branchiae, and it is more even. In males, the head is generally wider and larger, and the abdominal fins are longer compared to females.

Cottus poecilopus has four rays of abdominal fins that vary in length compared to the European bullhead, as each ray is of a different length. The longest ray is the middle outer ray. The middle inner is about 5/6 the length of the middle outer ray. The outer ray is about 2/5 the length of the inner rays. The internal ray is less than half as long as the middle rays, coming to a maximum of 1/6 to 2/5 of the longest middle ray when compared to the European bullhead.

Habitat of the Alpine bullhead

Alpine bullhead can be found from Scandinavia to the Kolymu River in Siberia, in the basin of the Amur, the Danube, and Dniester rivers as well as rivers flowing into the Sea of Japan. In Slovakia, its habitat includes the tributaries of the Danube, Visla, Poprad, Dunajec, and Javorinka rivers and the basins of the Black and Baltic Seas. In the Czech Republic, Alpine bullhead exist in the river basins of the Morava and Odra rivers. Alpine bullhead thrive at higher altitudes than European bullhead. According to Zelinka (1952), Alpine bullheads live only in water with an oxygen ratio of at least 8 mg of oxygen per 1 litre of water. They mainly live on *Hydropsyche* species. Bullheads hide under large flat stones that cannot be easily displaced by currents (Dyk 1957; Kozlowski *et al.* 2017).

The resting positions of bulheads and habitats are closely related to their reproduction sites, which runs from March to May. Balon (1966) described the entire ethological ritual of reproduction, sexual behaviour and methods of the solicitation of females by males before mating. Holčík *et al.* (1965), in the basin of the White Orava River, found where bullheads were abundant and where they were mating. They state, "... When a female stops in front of the hole with the waiting male, the male starts luring the female to get in by fluttering movements. The male comes out of the nest cavity several times and gets back... these preparatory ceremonies take sometimes more days until the female enters the hole and copulates with the male. After the copulation and laying eggs, the female remains lying for 20 minutes, then goes away and for the coming 15 days, the eggs are being taken care of by the male only. It fans them by the means of pectoral fins and cleans them from debris.'' It can be inferred from this, that in March, April, and May we can find mating bullheads in the stony side tributaries as well as in the main flow where males take care of the eggs in their resting positions. This is confirmed by an earlier claim of Dyk (1957) from research in the Bela River in 1937: "Alpine bullheads ... reproduce most abundantly in "teplice", i.e., powerful springs, which make up little creeks near the basin and after a few tens of meters flow into the main flow. Also in the side, mildly flowing basins, there are rich numbers of bullheads, but not in the bays and river arms with still water, and the bottom covered by detritus through which, under normal conditions, water does not flow." Male Alpine bullhead, however, is a territorial fish, and it defends its territory whether it protects eggs or not. European and Alpine bullheads lay around 100-1 400 eggs.

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