

Unusual Findings of Softmouth Trout *Salmo Obtusirostris* (Actinopteri: Salmonidae) in the Marine Environment along the Middle Eastern Adriatic Coast as a Consequence of Extreme Weather Events

Neobični nalazi mekousne pastrve *Salmo obtusirostris* (Actynopterigii: Salmonidae) u morskom okolišu duž srednjoistočne obale Jadrana kao posljedica ekstremnih vremenskih nepogoda

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Abstract

The discovery of individuals of softmouth trout *Salmo obtusirostris* in the marine environment has been recorded several times in the period from 2015 to the present day in the wider area of the Neretva River delta and southern Adriatic coast. Although this phenomenon appears to be happening more frequently along the Adriatic coast, scientific reports regarding family Salmonidae species found in the marine environment are still very rare in the eastern Adriatic, especially for the softmouth trout. The findings reported here represent the first marine records of this endemic freshwater species. An increasing frequency of these findings may indicate that a higher number of individuals are ending up in the coastal environment during heavy storm events or other unusual hydrologic occurrence. Extreme weather conditions have become more frequent in recent years, mainly as a result of climate change and have led to unexpected phenomena and impacts on nature. The long-term effects on fish and community structure of rivers flowing into the sea require further research, as these weather-induced situations can be expected to become more common. Further investigation into the physiological costs and population consequences of these unusual ecological findings is warranted.

Sažetak

Nalaz jedinki mekousne pastrve *Salmo obtusirostris* u morskom okolišu zabilježen je više puta u razdoblju od 2015. godine do danas na širem području delte rijeke Neretve i priobalja južnog Jadrana. Iako se čini da se ovaj fenomen češće događa duž jadranske obale, znanstveni izvještaji o vrstama porodice Salmonidae koje se nalaze u morskom okolišu još uvijek su vrlo rijetki u istočnom Jadranu, posebno za mekousnu pastrvu. Ovdje opisani nalazi predstavljaju prve morske zapise o ovoj endemskoj slatkovodnoj vrsti. Sve veća učestalost ovih nalaza može značiti da veći broj jedinki završava u obalnom okruženju tijekom jakih oluja ili drugih neuobičajenih hidroloških pojava. Ekstremni vremenski uvjeti posljednjih su godina sve češći, uglavnom kao posljedica klimatskih promjena i doveli su do neočekivanih pojava i utjecaja na prirodu. Dugoročni učinci na ribu i strukturu zajednice rijeka koje utječu u more zahtijevaju daljnja istraživanja, budući da se može očekivati da će ove situacije izazvane vremenskim prilikama postati češće. Potrebna su daljnja istraživanja fizioloških promjena i utjecaja kao i populacijskih posljedica ovih neobičnih ekoloških pojava.

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KLJUČNE RIJEČI

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ekstremni vremenski uvjeti

1. INTRODUCTION

While most salmonid species have an anadromous life cycle that takes advantage of growth opportunities in marine or nearshore environments, some species or inland populations spend the entirety of their life cycle in freshwater, sometimes as river residents or river-lake migrants. In the formerly glaciated regions in Europe, many populations have abandoned the anadromy of their postglacial colonist ancestors and have adopted a freshwater migratory or resident life history [1], [2]. In the Adriatic Sea, it is not known whether individuals in the family Salmonidae will volitionally migrate to the sea or whether they can spawn in brackish water [1], [3], [4]. Such behaviors would be important to our understanding of their potential use of saline environments as tolerance to salinity gradients would otherwise restrict the movement of salmonids towards the transitional and marine waters of the eastern Adriatic. Therefore, any record of such resident salmonid species outside its natural freshwater habitat in marine habitat that cannot be attributed to migration or volitional movement is a unique discovery and certainly unusual.

The Adriatic Sea and its contributing watersheds have been recognized as one of the ichthyological “hot spots” in Europe, having both high diversity and many endemic species [5]. The contributing watersheds, especially the Neretva River, provide abundant salmonid habitat and harbour numerous salmonid species, two of which are endemic: Neretva softmouth trout *Salmo obtusirostris* (Heckel, 1851) and dentex trout, *Salmo dentex* (Heckel, 1852), as well as the Adriatic trout *Salmo farioides* Karaman, 1938 and marble trout *Salmo marmoratus* Cuvier, 1829 endemic for the Adriatic Sea watershed [3]. Additionally, the widespread brown trout *Salmo trutta* Linnaeus, 1758 is broadly distributed in these waters. Collectively, the diversity of salmonid populations from the Adriatic basin contributes to such considerable morphological, ecological and behavioural variation that the current status and distributional limits of specific species remains a subject of scientific debate [6], [7].

Softmouth trout, also recognized as both Adriatic trout and soft-muzzled trout, is a salmonid species endemic to the Adriatic river system of the western Balkans which inhabits rivers of the southeastern Adriatic Sea coast [3]. It is distributed in the Krka, Jadro, Žrnovnica and Vrljika rivers in Croatia, the Neretva River Neretva River River in Bosnia and Herzegovina and the Zeta and Morača rivers in Montenegro [8]. Its most obvious morphological characteristics are an elongated snout, a small and fleshy subinferior mouth with small jaws and teeth, relatively large scales and high body depth. The species’ use of brackish environments is not well studied and its tolerance for spatial or temporal gradients in salinity is not well understood [9]. It is endangered (EN) according to the IUCN [10], however in Croatia [10] and Bosnia and Herzegovina its status is Critically Endangered (CR) [11]. The Neretva River softmouth trout population is under heavy pressure including anthropogenic habitat changes and illegal fishery, leading to disappearance in a number of formerly inhabited areas [8].

Due to the effects of climate change on regional weather patterns, many watersheds in the Adriatic region are experiencing increasingly warmer and dryer periods,

followed by heavy rain, especially during summers. Extreme precipitation events, whose maxima can be associated with devastating floods and minima with droughts are, together with wind storms, the most recurrent hazardous weather phenomena along the Croatian coast [12], [13]. Such events can be dramatic and significantly influenced by local orographic factors, especially the Dinaric Mountains, which are located on the coast or very close to it [14]. When considered together, these climatic and landscape processes can have significant impacts on the river fish community structure [15].

The aims of the present study are 1) to provide a preliminary, but robust, assessment of softmouth trout individuals found in the marine environment 2) to seek understanding of underlying causes and mechanisms for this unconventional distributional phenomenon. We attempt to correlate findings of the species’ marine occurrence with patterns of weather records and propose hypotheses about the damage that increasingly severe climatic-related events can have on the population status of this endemic species.

2. MATERIALS AND METHODS

In the present study, we analyzed information provided by professional and recreational fishermen about their catches and the local marine environment. This data approach, referred to as ‘Local Ecological Knowledge’ (LEK), is an outstanding alternative source of local information on natural phenomena [16] that can complement regional scientific information, especially where no comprehensive and targeted monitoring system has been deployed. In February and March 2021, in a period of several days, four individuals of *S. obtusirostris* were captured by a recreational fishermen using gillnets and by spearfishing in Mala Duba near Makarska and Ploče (Table 1; No. 13 – 16). After interviews with the fishermen who provided this information, we perceived that there are actually more such unusual observations, and that fishers occasionally come across more such findings. This cognition encouraged us to seek additional information from other fishers of similar occurrence with the common goal of a scientific discovery. Photos, descriptions and catch information were gathered through interviews with the professional and recreational fishermen who collected the specimens. The identification of the individuals was based on the photos presented in Table 1.

3. RESULTS AND DISCUSSION

At least 17 specimens of softmouth trout were caught in the period from 2015 to 2021 (Table 1; Figure 1) in the area from Ploče to Makarska (Figure 2). Most of the specimens were caught near the coast using gillnets or by spearfishing. The timing of capture is of potential interest since all individuals were caught between mid February and mid March. Also, according to the fishers, all individuals were caught in a short period after instances of particularly bad weather and high precipitation rates across the wider area that encompasses the Neretva River area. To our knowledge, the present study represents the first records of *S. obtusirostris* in the marine environment and, as such, the first recordings of what appears to be an increase in the frequency of this distributional observations.

The *S. obtusirostris* specimens were positively identified by strikingly obvious morphological characteristics: colouration, a

Table 1. Details on the softmouth trout *Salmo obtusirostris* records observed in the marine environment of Adriatic Sea, all from fisherman report

No.	Locations of catch	Date of record	Remarks	Markings from Picture 1
1.	Ploče	28.02.2015.	specimen (1.5 kg) caught by spearfishing, dazed and easy to catch	A
2.	Ploče	04.03.2015.	specimen caught by spearfishing	
3.	Ploče	Winter 2015	1 specimen on photo. Fisher claims catch of 4 more specimens before, biggest 3,5 kg. All had wounds on the skin	B
4.	Ploče	28.03.2015.	specimen caught by spearfishing	
5.	Živogošće	17.03.2017.	caught in gillnet	C
6.	Ploče	12.03.2016.	caught in gillnet	D
7.	Ploče	14.03.2018.	2.41 kg on scale	E
8.	Ploče	15.03.2018.	caught in gillnet	
9.	Ploče	17.03.2017.	caught in gillnet	
10.	Ploče	12.03.2018.	caught by spearfishing	F
11.	Pelješac	18.03.2018.	caught by spearfishing	G
12.	Uvala Soline	19.03.2020.	caught by spearfishing	H
13.	Mala Duba near Makarska	14.02.2021.	caught using gillnets	
14.	Lake Jezerina, Neretva River mouth	20.02.2021.	caught using gillnets	
15.	Ploče	22.02.2021.	caught by spearfishing, fisher caught more previously	I
16.	Ploče	13.03.2021.	caught by spearfishing	J
17.	Makarska	06.04.2022.	Gillnet, 2 m depth, 2,5 kg	

small and fleshy subinferior mouth, and high body depth which easily distinguishes this species from other conspecifics [9]. The digestive system of all caught individuals was investigated and all intestines were found empty of any recent prey forage. One individual had developed gonads (Figure 1 J). Unfortunately, none of the specimens were able to be preserved for further tissue or morphological examination, but typical morphological features allowed accurate identification from a single photo when the specimen was not preserved [17].

The phenomenon of anadromous migration (from rivers to saltwater and return) is a widely recognized behavior for salmonids. Even within populations of Atlantic salmon or brown trout that are predominantly resident for their entire freshwater lives, migratory individuals can co-exist alongside resident individuals where an unobstructed passage to saltwater is available. Contrary to some populations showing facultative anadromy, many others spend their entire life cycle in freshwater. Recording the findings of salmonid species in marine habitat is taxonomically important evidence, but it certainly does not indicate their possibility of longer stay or even inhabiting marine habitats.

The softmouth trout is found predominantly in the mid order reaches of river sections that include wide riverbeds and productive but clear running habitats. As with most freshwater salmonids, softmouth trout is a rheophilic species that prefers clean, oxygen-rich waters [8], [9] but has never been previously reported within marine environments. The Neretva softmouth trout lives only in schools in deeper pool habitats of the upper and middle parts of the river [8] that tend to have lower velocity flows during summer seasons. Therefore, these records of individuals found in typical marine waters with no nearby estuary, are highly unusual. The most probable explanation for this uncommon phenomenon is that these individuals have

originated from one of the rivers where this species lives and reached the sea during exceptional hydrological conditions. Evidence regarding extreme hydrological events potentially implicate it as a source [14]. Although the study [13] generally showed a significant increase in the mean annual and seasonal temperature and a weak decreasing trend in annual and seasonal precipitation, the same study showed that highest values for annual precipitation generally occur in winter, and more precisely in March, which corresponds with the timing of the reported observations and obtained data. More extreme temperatures and precipitation in warmer climates may therefore reduce the ecological stability of habitats in some unanticipated ways. Similar recent examples of unusual cross-system estuarine movements exist. The combined effects of drought prevalence and reduced freshwater discharge due to climate change have periodically increased the salinity in river deltas, and consequently, the movements of marine organisms into these historically more freshwater environments [18].

The Neretva River system is the most significant and largest habitat by watershed area of this species and in months preceding specimen capture, the area has been subject to heavy rain conditions that have raised the river level (Glamuzina, *pers. obs.*). Consequently, there exists a possibility that such high-flow conditions contribute to individuals reaching the sea. Table 1 shows that all findings were recorded during periods from late February to early April with the most frequent findings from March which corresponds to the time of high winter flows that corresponds to heavier rains in the Neretva area [19].

Upon arrival at sea, the studied individuals w likely followed a strong flow of low salinity, conditions that are the result of increased Neretva discharges caused by high rains and outflows that follow the coastline [19]. A similar record was reported for specimens of marble trout, which is also thought to have



Figure 1 Specimens of softmouth trout *Salmo obtusirostris* (Heckel, 1851) caught along the middle Eastern Adriatic coast

reached this location in the same manner [20]. Individual findings of related salmonid species: dentex trout and marble trout were recorded in the wider area of the Neretva River delta after similar hydrological events [21]. It is not known how much time these individuals spent in the sea prior to capture, but, except the individual A from Figure 1, based upon their physical appearance with no signs of physical damage, morphological

alteration or stress, they would appear to have maintained healthy conditions during their presumed short residency in the marine environment. According to the fishers, after such heavy rains and strong southern wind, the transport of individuals from potential source habitats in the basin to the mouth of the Neretva River can be quite rapid, e.g. within a day(s). Furthermore, this does not seem to be a completely unusual

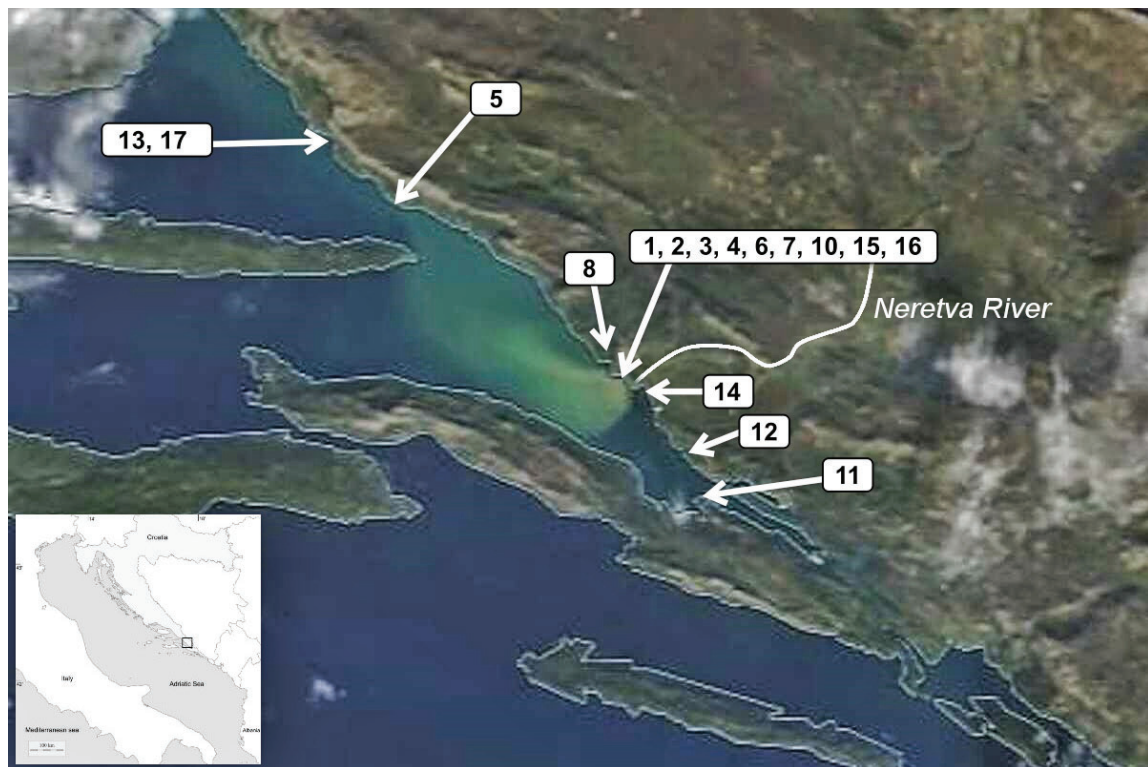


Figure 2 Map showing Neretva River flow impact on wider marine area during high rainy season with the present records of softmouth trout. Photo taken from Google Earth on 25. February 2022

phenomenon with records existing for past catches. Two years ago, the same fisher reported catch of three individuals of the same species estimated to be 1 kg, 2 kg and 5 kg, but without any complementary data or photos. It is therefore indicative that there are still numerous aspects of its ecology that are still unknown. Such occasional seasonal strong inland storms, accompanied by freshwater bursts and rising Neretva river levels, seem to cause some loss in the population of this already endangered fish species. However, at the moment the extent of loss is unknown, as is whether the events have any sub-lethal consequences to the population. Therefore, more effort to understand these phenomena would contribute to our management and conservation efforts.

With the exception of marble trout record [20] for the eastern Adriatic Sea coastal waters, only brown trout *Salmo trutta* L. 1758 has been mentioned in the literature [22], [4] for other species from Salmonidae family. The first mention was made by [23] on the basis of one specimen weighing 3 kg, which was caught in 1879 near Vranjic (Kaštela Bay). When another specimen was caught in the same place in 1889, Kolombatović described the species as new, under the scientific name „*Trutta adriatica*“. After that, a few specimens were caught several times in the Adriatic Sea along the coast. However, discussions about its status are still ongoing [4]. Furthermore, record of individual rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) from 1931 close to the mouth of the Jadro River, presumably originating from an upstream fish farm near Solin was reported [24]. This species is the product of regional aquaculture along the coast in watercourses at few locations along the Adriatic Sea and is most likely that caught individuals caught were aquaculture escapes. Unfortunately, apart from anecdotal reports on web portals [25], there are no scientific information related. Therefore, the presented findings can certainly be characterized as

exceptionally rare finding of salmonids members in the eastern Adriatic Sea.

It is currently unknown how many individuals reach marine waters in this way and what their further fate is in the marine environment. Fishers described their behavior at sea as “confused” and less active and is not known exactly how staying in the new habitat affects them. Although individual salmonids show the ability to osmoregulate depending on size [26], such rare records indicate that this species were physiologically not capable of direct transfer to full strength seawater. The evolutionary pattern of euryhaline of these species is therefore not yet at such a level that the limit in the sea osmoregulation gradient can be successfully overcome.

4. CONCLUSIONS

The regular updating of our understanding fish diversity and species distributions is essential for national management diversity agencies. The unexpected and rare records of the softmouth trout in marine waters reported here represent a new addition to the fish species list in the Eastern Adriatic Sea, updating the current state of information and further supporting high biodiversity for the region. This work underscores the importance of reporting such scientific findings and updating distributional data regularly to address key local and global conservation imperatives. Key priorities in the future will be to build stronger communication networks with fishers that can increase the data acquisition on these potentially rare but important phenomena. This increased communication will aid in our understanding of both the prevalence of events, as well as the ecological impacts of these cross system movements. Additionally, this expanding database will allow us to assess whether and how changes in climate, landscape and habitat may interact to affect the frequency of

such phenomena. Continued studies and more coordinated collection efforts can provide tissues that will enable genetic and otolith microchemistry studies to better understand the source locations and relatedness of collected specimens. The consequences of such dispersal events on the stability of the endemic salmonid population from Neretva River are presently not known. However, what is problematic is the recent intensity of such events and the more often such changes occur with obvious impacts on the Neretva salmonids. Furthermore, the long-term effects of such dramatic weather conditions on fish populations and river community structure require further coordinated research, as such weather-induced events can be expected to become more frequent.

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