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Unusual records of marine organisms in the Neretva River (Croatia and Bosnia and Herzegovina)

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This paper presents a review of the unusual occurrences of various marine species found upstream in the Neretva River and its wider delta zone in the last two decades. The occurrences of at least eight different marine species were reported by local fishermen, representing very rare records of these species in the upstream areas of rivers. Although some of these species generally inhabit both saltwater and brackish waters, their occurrences high upstream are probably the consequence of changes in hydrological conditions in Neretva River. Namely, more intense saltwater intrusion into the river observed in the last two decades provides suitable conditions for mass penetration of euryhaline organisms high into the Neretva River. In this biodiversity rich area which hosts a significant number of endemic species, such phenomena can threaten the local freshwater communities.

Key words: saltwater intrusion; indicator species; east Adriatic watershed

INTRODUCTION

Species that normally inhabit river mouth areas are usually adapted to withstand varying salinity conditions and can occasionally be found deep upstream inland, but in relatively small numbers when compared to their abundance in more saline waters. However, the unusual presence of marine species in untypical habitats like rivers deep inland, usually indicates significant habitat alterations that are often conditioned by anthropogenic or natural processes (ROMAÑACH *et al.,* 2019). This is especially indicative when marine species which are not adapted to tolerate highly fluctuating environmental salinity levels due to their physiological tolerances are found in upstream portions of rivers.

Saltwater intrusion represents the flow of seawater into coastal river flows as a result of natural processes or human activities and is

one of the most significant global challenges for coastal water resource managers, industries, and agriculture (MONTANARI, 2015). The impact of the saltwater intrusion on local biodiversity in brackish and freshwater ecosystems is a subject of increasing international concern because of its adverse environmental impacts (*see in* NICHOLLS & CAZENAVE, 2010). This concern arises mainly because saltwater intrusion has negative impacts on coastal environments, including loss of habitat for freshwater biota such as vegetation, phyto- and zooplankton and fishes, as well as the associated penetration of brackish and saltwater organisms (LOVE *et al*., 2008). Despite the evident influence caused by changes in salinity in many coastal areas (CALVACHE & PULIDO-BOSCH, 2017) and their impacts on local biodiversity (LOVE *et al*., 2008, PIZANO-TORRES *et al*., 2017), studies relating to individual records of marine species in areas of reduced salinity are mostly lacking (ABDUL-RAZAK & INTISAR, 2019). Nevertheless, observations of strictly marine species in upstream portions of rivers could indicate alterations in riverine hydrological conditions and provide insight into geographical extent of such phenomena.

The Neretva River and its delta are one of the most important biodiversity and agricultural areas in the Mediterranean karst area of Croatia (MRAKOVČIĆ *et al*., 2006) and Bosnia and Herzegovina (GLAMUZINA *et al*., 2013). Relatively shallow area of its wide delta supports a rich faunal diversity and hosts important spawning and nursery grounds for many fish species which makes it also a very important fishing area (GLAMUZINA, 2010, DULČIĆ & GLAMUZINA, 2010; MATIĆ-SKOKO *et al*., 2010). This area also hosts several protected ornithological and ichthyological reserves and is considered one of the most important wetlands in Europe as a resting and wintering place for migratory birds (SMITH & DARWAL, 2006; STUMBERGER & SCHNEIDER-JACOBY, 2010). In 1991, the Neretva River Delta was listed as a Wetland of International Importance under the Ramsar Convention. This area is also one of the eight Specially Protected Areas under the Barcelona Convention, as well as an important area for birds in Europe which hosts at least 115 nesting species (TUTIŠ *et al*., 2013). However, in the last decades, due to modifications in salinity regimes of the surface and ground waters, the lower Neretva River has undergone numerous environmental changes (ROMIĆ *et al*., 2008, 2018, 2019). This area was additionally impacted by recurrent droughts, increased levels of urban pollution (GLAMUZINA, 2010) and the effects of the uncontrolled introduction of freshwater and marine non-native species (GLAMUZINA *et al*., 2020). It was found that seawater penetrates along the Neretva riverbed in a separate bottom layer of saltwater upstream up to about 25 km from the river mouth (LJUBENKOV & VRANJEŠ, 2012, ROMIĆ *et al*., 2018, 2019). The water quality of the lower course of Neretva is influenced by the complex water regime in the lower course of Neretva River which is a consequence of various factors such as hydroelectric system on the upstream side, reduction of groundwater inflow from river Trebišnjica and deepening of the Neretva riverbed. Also, sea-level rise due to global warming is an additional factor causing increased salinity in the Neretva basin (IVANKOVIĆ *et al*., 2017).

The presence of certain euryhaline marine species which can tolerate lower salinity is usual in river deltas and transitional waters, however, the presence of stenohaline, or strictly marine species, in lower river course can indicate significant hydrological alterations. Such species generally very rarely enter waters of reduced salinity due to their physiological limitations. In this paper, we present the review of the unusual occurrences of some typical marine species found far upstream in the Neretva River in Croatia and Bosnia and Herzegovina. Due to lack of monitoring programmes in the area which could provide data collected *in situ* and in such a way shed more light on the extent of penetration of marine species in the area, data on these occurrences were collected mostly through direct contacts with local citizens and by searching social networking sites and internet news portals for reports on unusual occurrences. Such way of data collection has already proven to be valuable in the early detection of alien species in the area (DULČIĆ *et al*., 2018, TUTMAN *et al*., 2021).

Here we will provide a brief outline of species whose presence has been reported and discussed in the paper. Common jellyfish *Aurelia aurita* (Linnaeus, 1758) is a cosmopolitan organism of oceanic and coastal waters as well as warm tropical waters ranging from North and South America, Eurasia, southern Greenland, and likely all coasts of Australia (BREKHMAN *et al*., 2015). European squid *Loligo vulgaris* Lamarck, 1798 occurs abundantly in coastal waters from the North Sea to at least the west coast of Africa from sea level to depths of 500 m including the Mediterranean Sea (JEREB *et al*., 2010). European cuttlefish *Sepia officinalis* Linnaeus, 1758 is generally found from the eastern North Atlantic south into the Mediterranean Sea, along the west coast of Africa as far to South Africa, dwelling in sandy or muddy substrates from subtidal waters to depths of 200 meters (JEREB & ROPER, 2005). The common octopus *Octopus vulgaris* Cuvier, 1797 is a mollusk species with worldwide distribution; abundant in coastal waters and the upper part of the continental shelf of tropical, subtropical, and temperate waters between the surface and a depth of 100 to 150 meters in the Mediterranean Sea, the Eastern Atlantic Ocean, and in Japanese waters (MANGOLD, 1983). The brown ray *Raja miraletus*, Linnaeus 1758 is distributed subtropically in the eastern Atlantic Ocean from northern Portugal and throughout the Mediterranean, south to Madeira and South Africa. It is quite common on the continental shelf from Portugal throughout the Mediterranean and along the western and southeastern coasts of Africa. This benthic fish is found in brackish and marine waters up to depths of 300 m, most commonly from 50-150 m. The brown ray resides over soft bottom habitats along the coastal shelf and the uppermost slope. It is a common species in the wider area of the Neretvanski channel into which the Neretva River flows (MATIĆ-SKOKO *et al*., 2010). The common pandora *Pagellus erythrinus* (Linnaeus, 1758) is fish species found up to 200-300 m of depth on various bottoms from Eastern Atlantic and the Mediterranean to Guinea-Bissau (BAUCHOT & HUREAU, 1990). The annular sea-bream *Diplodus annularis* (Linnaeus, 1758) is a gregarious fish species widespread in the Mediterranean Sea and the Eastern Atlantic Ocean; it inhabits rocky, sandy bottoms and seagrass beds (BAUCHOT & HUREAU, 1990). Family Soleidae consists of widely distributed flatfish species of which some also occur in the Adriatic Sea. The majority of Soleidae species inhabit saltwater soft bottoms but can also be found in brackish waters (DULČIĆ & KOVAČIĆ, 2020). There is currently no information on the entry of these species high inland into upstream portions of rivers.

MATERIAL AND METHODS

Occasional records of marine species found upstream in the Neretva River in the last two decades were obtained opportunistically directly by the authors (V. BUKVIĆ, P. TUTMAN & L. GLAMUZINA.) who were contacted by local citizens after collecting or catching the species. In such a way records of *Solea* sp., *Aurelia aurita*, *Pagellus erythrinus*, *Sepia officinalis*, *Diplodus vulgaris* and *Loligo vulgaris* were collected. Reports of unusual catches made by the local fishermen were usually accompanied with additional data such as the temporal and spatial extent of observations of marine species in Neretva river.

An online search was also performed in order to extract additional records which appeared on the internet. In such a way, records of *Raja miraletus* and *Octopus vulgaris* were detected as they appeared in online news articles.

All species described herein were identified from provided photos of specimens. Unfortunately, neither of the listed species have been preserved for analysis and data such as water salinity and temperature were not collected.

RESULTS AND DISCUSSION

In total, occurrences of eight marine species have been recorded in the upstream areas of Neretva River. In Table 1 details on the occurrences as well as the indication of the source of information are provided. In Fig. 1 geographical locations of records are presented. Majority of records were communicated directly to the sci-

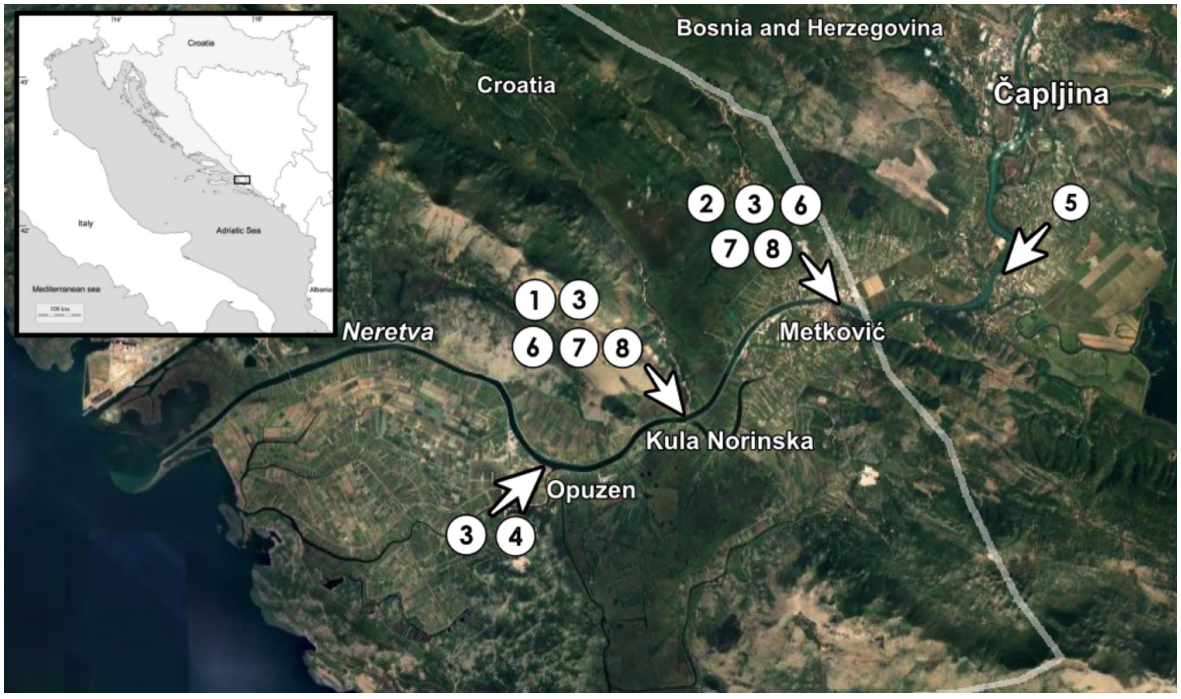

Fig. 1. Locations of records: (1) Aurelia aurita, (2) Loligo vulgaris, (3) Sepia officinalis, (4) Octopus vulgaris, (5) Raja miraletus, (6) Pagellus erythrinus, (7) Diplodus vulgaris, (8) Solea sp.

entists by the local citizens, mainly recreational fishermen, who are regularly fishing in the area.

More frequent appearances of marine species in the area of Neretva river began about 15 years ago with the occasional occurrences of *Solea* sp. in the town of Metković, 20 km upstream and the unusual finding of *Octopus vulgaris* near the Kula Norinska settlement about 15 km upstream from the river mouth. Afterwards, occasional findings of *Loligo vulgaris* and *Sepia officinalis* were reported from the area. It should be noted that these species are known to inhabit brackish waters, however, no scientific publication has previously reported their occurrence from any European upstream freshwater ecosystem.

In November 2019, an interesting catch of a specimen of ray species has been reported on a website of local radio Čapljina (Bosnia and Herzegovina). The specimen was caught in the Neretva River near the small settlement Višići (Bosnia and Herzegovina), about 25 km upstream off Neretva River mouth (43°03'38.50 N, 17°42'00.19 E; Fig. 2). The specimen was found alive in the shallow water on the muddy bottom and was caught by hand. It was identi-

Fig. 2. Specimen of Brown ray Raja miraletus *caught on 7th November 2019 in Neretva River near town of Čapljina, approximately 25 km inland in Bosnia and Herzegovina. White arrow indicates the specimen (Photo: Radio Čapljina).*

fied from the photo as Brown ray, *Raja miraletus* on the basis of visible morphological characters described by STEHMANN & BÜRKEL (1984). It measured approx. 40 cm in total length and weighed approx. 400 g. The record of *R. miraletus* so high upstream inland in the Neretva River represents also a curiosity in the context of the distribution of this species. Although according to FROESE & PAULY (2021) this species can be found in brackish waters, there is no evidence of it being recorded in rivers high upstream.

Fig. 3. Specimen of European squid Loligo vulgaris caught on 19th April 2020 in Neretva River near town of Metković, approximately 20 km inland in Croatia. (Photo: Višnja Bukvić)

Table 1. Details on the marine species records observed in the upstream portions of Neretva River

No.	Classification	Scientific name	Locations of catch	Date of record	Remarks	Source	Fishermen perceptions of trends
1.	Cnidaria/ Scyphozoa	*Aurelia aurita* (Linnaeus, 1758)	Kula Norinska (Croatia)	21.7.2012	4 specimens caught	Fisherman report	From 2012, now relatively common
2.	Mollusca/ Cephalopoda	*Loligo vulgaris* Lamarck, 1798	Metković (Croatia)	19.4.2020	1 specimen caught	Fisherman report	First observed in 2010, now very common, regular occurrence
3.	Mollusca/ Cephalopoda	*Sepia officinalis* Linnaeus 1758	Opuzen, Kula Norinska, Metković (Croatia)	21.7.2019	n/a	Fisherman report	Present from 2017, appears periodically and is caught in moderate quantities in the area
4.	Mollusca/ Cephalopoda	*Octopus vulgaris* Cuvier, 1797	Opuzen (Croatia)	July, 2014	1 specimen	Internet portal	Periodical appearance since 2014, several records
5.	Elasmobranchii/ Rajiformes	*Raja miraletus* Linnaeus, 1758	Višići (B&H)	8.11.2019	1 specimen	Internet portal	Single record in 2019
6.	Actinopterygii/ Perciformes	*Pagellus erythrinus,* Linnaeus, 1758.	Kula Norinska, Metković (Croatia)	15.4.2020	Caught in set gill nets	Fisherman report	From 2016 relatively common; appears regularly in the nets in small but persistent numbers
7.	Actinopterygii/ Perciformes	*Diplodus annularis*, Linnaeus 1758.	Kula Norinska, Metković (Croatia)	17.5.2020.	n/a	Fisherman report	From 2017; not in substantial numbers, but regular appearance
8.	Actinopterygii/ Pleurinectiformes	*Solea sp.* (Linnaeus, 1758)	Kula Norinska, Metković (Croatia)	7.6.2020.	n/a	Fisherman report	From 2008 appears regularly, increasing in numbers

In the vicinity of the Metković bridge, on 19th April 2020, a fisherman caught a large specimen of *Loligo vulgaris* (Fig. 3), which measuired 36 cm in length and weighed 650 g. According to fisherman, this species is also occasionally caught near Kula Norinska in larger numbers and smaller sizes. This specimen was caught about 20 km upstream from the Neretva river mouth.

The unusual occurrences of marine species so high upstream are the possible indicators of changing riverine freshwater conditions. More frequent records of marine species in this area are most likely related to the ongoing process of more intense decline in freshwater flow and high saltwater intrusion observed in the last two decades (ROMIĆ *et al*., 2008, 2018, 2019). Saltwater intrusion is often followed by the penetration of typically marine species into freshwater zones of the delta. If salinity increases more frequently in the Neretva River, mass penetration of euryhaline organisms high into the Neretva River may soon be expected threatening the local freshwater fish community, among which there is a significant number of endemics (GLAMUZINA *et al*., 2013). The salinity in the delta section of the lower Neretva River has increased since the construction of a large hydroelectric project in upper Neretva River (so called Upper Horizons). As a result of the partial slowing of the river flow, the discharge of the Neretva River at its mouth is reduced by an average of 25% annually (ROMIĆ *et al*., 2008, 2018, 2019) which causes a shift of the upstream limit of the saltwater intrusion in the Neretva River. Hence, lower Neretva River has suffered from significant regression in freshwater water influx related to the decline in rates of discharge from upper areas during the past years. The saltwater intrusion upstream extends at least to settlement Gabela in Bosnia and Herzegovina where a specimen of sea lamprey *Petromyzon marinus* has beend recorded in 2013 (GLAMUZINA *et al*., 2019). During the period of increased salinity, an increase in the number of euryhaline species such as *Pomatomus saltatrix*, *Platichthys flesus*, *Sparus aurata* and *Dicentrarchus labrax* was recorded in the lower reaches of the Neretva (GLAMUZINA *et al*., 2020). However, the new reports and persistence of freshwater-dependent species in Neretva River delta (DULČIĆ *et al*., 2017, TUTMAN *et al*., 2021) suggests that there may be a time lag in the response of freshwater-dependent species to increasing salinities. Salinization is a widespread phenomenon in the environment, which threatens many taxa (CALVACHE & PULIDO-BOSCH, 2017, ABDULRAZAK & INTISAR, 2019).

Various online media and social networks can act as a potential source of information for documenting biodiversity, providing valuable information sources which can allow early detection of unusual species, that would otherwise go unnoticed (BARVE 2014, DULČIĆ *et al*., 2017, 2018). For example, occurrences of non-native *Micropterus salmoides* (DULČIĆ *et al*., 2017) and *Synodontis eupterus* (DULČIĆ *et al*., 2018) recorded in Neretva, have been brought to the attention of scientists through reports on the social network. Also, scientists should reach to local people as their knowledge on the local ecosystems usually contains a wealth of information that can complement other sources and improve monitoring and action plans in the context of aquatic invasions.

Records of marine species in a usually strictly freshwater ecosystem are a valuable indication of environment alteration which can indicate the extent to which saltwater intrusion phenomena influences local biodiversity. The result of a recent study (GLAMUZINA & DOBROSLAVIĆ, 2020) points to the fact that major Neretva flow of 20 km in length from the river mouth is under seasonal summer impact of seawater, which leads to salinization and complete marinization of this ecosystem during the warm period of the year.

Restoring freshwater flow in cooperation with hydroelectric power management to combat saltwater intrusion may help to retain a salinity balance that is essential for the preservation of the freshwater fish communities of the lower Neretva River. Results from this study are fundamental in enhancing the understanding and documentation of unusual biodiversity findings driven by saltwater intrusion effects, and can also serve as key information during the action and planning of the implementation of hydro-

logic restoration and management activities in the lower Neretva river and its delta. Additionally, as already stated by ARVELUND (2009) the shift in ecology and biogeography of marine fish species at the beginning of the 21st century may hypothetically be a useful indicator for climate change

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Neobični nalazi morskih organizama u rijeci Neretvi (Hrvatska i Bosna i Hercegovina)

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SAŽETAK

U radu je prikazan pregled neobičnih nalaza morskih vrsta u rijeci Neretvi te širem području njene delte u posljednja dva desetljeća. Pojava najmanje 8 različitih morskih vrsta prijavljena je od strane lokalnih ribara, a radi se o općenito rijetkim nalazima morskih organizama u uzvodnim dijelovima riječnih tokova. Iako neke od vrsta opisanih u radu obitavaju i u slanim i u bočatim vodama, njihova pojava visoko uzvodno vjerojatno je posljedica promjena hidroloških uvjeta u rijeci Neretvi.

Naime, intenzivniji prodor morske vode u rijeku u posljednja dva desetljeća omogućava masovno prodiranje eurihalnih organizama visoko u rijeku Neretvu. Na ovom području, bogatom biološkom raznolikošću sa značajnim brojem endemskih vrsta, takve pojave mogu ugroziti zajednice slatkovodnih organizama.

Ključne riječi: intruzija slane vode; indikatorska vrsta; sliv istočnog Jadrana