ISSN: 0001-5113 AADRAY	ACTA ADRIAT., 63 (1): 35 - 44, 2022	ORIGINAL SCIENTIFIC PAPER

The study of European eel, *Anguilla anguilla* in the River Neretva estuary (Eastern Adriatic Sea, Croatia) using traditional fishery gear

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The article is dedicated to Prof Tonko Šoljan and Dr. Dinko Morović, scientists from the Institute of Oceanography and Fisheries in Split, Croatia. From 1940 to 1970, they investigated European eel in the River Neretva estuary and provided first data on their biology, ecology and fisheries for this area.

Prof Tonko Šoljan

European eel sampling by Prof Šoljan

Dr.sc. Dinko Morović

Samples of the European eel, Anguilla anguilla *from two different habitats in the River Neretva estuary region were analysed using two different traditional fishery gear, in the period from 2016 to 2019. The monthly eel catches in ten traditional fyke nets in Parila lagoon varied from 4.4 to 12.7 kg (±2.45 kg) in 2016 and 2.4 to 9.6 kg (±2.01 kg) in 2019. There were no statistical differences between monthly and total weights recorded in 2016 and 2019 (t=1.04; p=0.312). The b-coefficient of the length-weight (LW) relationship for the freshwater eel samples varied from 3,1036 to 3,3206 during two-year period of the sampling. The LW relationship for the brackish population was significantly lower (b-coefficient 2,6513). The dominant eel stage in both sites was yellow eel, while silver stage*

was scarce. The fishery with traditional devices revealed that efficiency of these artisanal tools is low, pointing to poor abundance of eel in their common habitats. The recorded catch using bigger traditional eel trap gear during autumn spawning migrations was also dominated with yellow stage, while silver eel represented only 15,4% of the catch. The infestation of eels with the parasite, Anguillicoloides crassus *was significantly higher in freshwater habitat (41% of eel specimens infested) than in brackish, Parila lagoon (7%). Poor efficiency of traditional gear, bad length and weight structure of the population and low b-coefficients of eels in their most important habitat, indicate poor status of European eel population and River Neretva estuarine ecosystems.*

Key words: *European eel, traditional fishery gear, length-weight relationship, parasite,* Anguillicoloides crassus, *Neretva estuary*

INTRODUCTION

The dramatic decline of the European eel, *Anguilla anguilla* has been reported in the whole distribution range over the last decades (GUHL *et al.*, 2014) and the species recruitment has decreased by about 95%, while current population levels are outside safe biological limits in many parts of the range (WGEEL, 2008). The similar recent findings on eel recruitment decline was reported for the Mediterranean (AALTO *et al.*, 2016). The decline of the European eel population should be explained as a result of different natural and anthropogenic factors (COSTA-DIAS *et al.*, 2010). The most important being increased commercial and artisanal fisheries as well as habitat loss and construction of dams and weirs, followed with other human activities such as environmental pollution and climate change (DUDGEON *et al.*, 2006). Furthermore, impacts on the reproductive success of eels, such as the reduction of spawner quality due to high contaminant loads (FREESE *et al.*, 2016, 2017) or changes in oceanic conditions potentially resulting in increased larval mortalities (e.g. KNIGHTS 2003; BONHOMMEAU *et al.*, 2008), contribute to already jeopardized eel populations. One potential decline factor is infection with parasite *Anguillicoloides crassus* (HAN *et al.*, 2008). This nematode is a native parasite of the Japanese eel, *Anguilla japonica*, and was introduced accidentally in Europe with Japanese eels from Asia at the beginning of 1980s (KOOPS & HARTMANN, 1989). When presented in high numbers, parasites compromise eels health, specifically during spawning migrations (WÜRTZ & TARASCHEWSKI, 2000; CREAN *et al.*, 2003).

The recent research data on the European eel along the Eastern Adriatic coast is scarce and limited, evaluating length-weight relationships of eels from karstic streams (TUTMAN *et al.,* 2007; PIRIA *et al.*, 2014) and status of freshwater eel in the Hutovo blato wetlands in Bosnia and Herzegovina (GLAMUZINA *et al.*, 2008). Although Neretva Estuary represents traditionally most important European eel habitat in Croatia, the last research activity was reported sixty years ago, discussing statistics on annual catches (MOROVIĆ, 1976). The official data from the period 1931-1940 reported average annual catch in the Neretva River Delta to be approximately 200 tons, reaching the market as live or smoked goods (MOROVIĆ, 1948). The official data after large lagoons and wetlands reclamations showed significant decline, and in the period 1960-1969 the reported annual catches fluctuated from lowest 46.3 tons in 1969 to highest 68,5 tons in 1961, with a mean annual catch of 55 tons (MOROVIĆ, 1970). The eel fishery data for the last decade reported annual eel catch in Croatia to be less than 500 kg yearly (Eurostat, 2021). Today, the Neretva estuary eel fishery is composed of 13 legal fishers restricted to autumn fishing of migrating silver eel, while yellow eel fishery is performed in the local communities using traditional gears.

This article reports recent data on the catch structure of European eel from two different Neretva estuary habitats, considers efficiency of traditional eel fishery gear and evaluates the

presence of parasite, *A. crassus* in the Neretva Estuary.

MATERIAL AND METHODS

Description of the research area

The area of Neretva Estuary is a unique natural geographic area, a lowland surrounded by a circumferential karstic rock massif. It is characterized by a mild Mediterranean climate. The collection of data on eel population was conducted in two important areas of the estuary. The first area was Parila lagoon, situated at the contact zone with sea water, and it is a traditional eel fishery ground. The second site was an outlet of Baćinska Lakes to the sea, represented by a 500 meters long channel, impacted with seawater intrusion during most of the year (Fig.1).

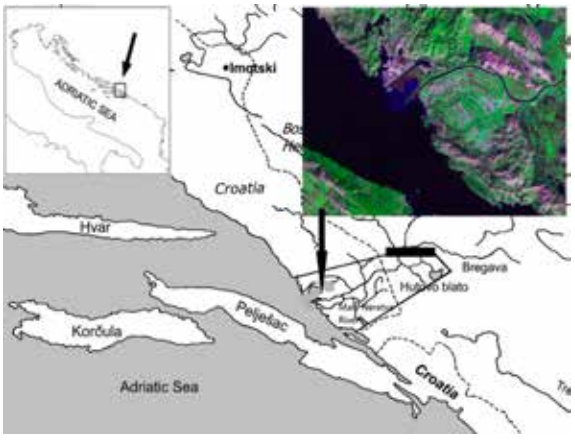

Fig. 1. River Neretva estuary (Eastern Adriatic, Croatia) with marked locations where scientific collection of data was executed: circle- Parila lagoon and triangle- Baćinska Lakes outlet

Sampling

Ten small traditional eel traps (local term "tratun") (Fig. 2a) were used during years 2016 and 2019 in the Parila lagoon, and they were inspected three times weekly. The two-day catch from all ten traps was combined then weighted and measured as one sample. The weight and length measurements were collected using scale (g) and ichtyometer (mm). The traditional device for silver eel fishing (local name "trata")

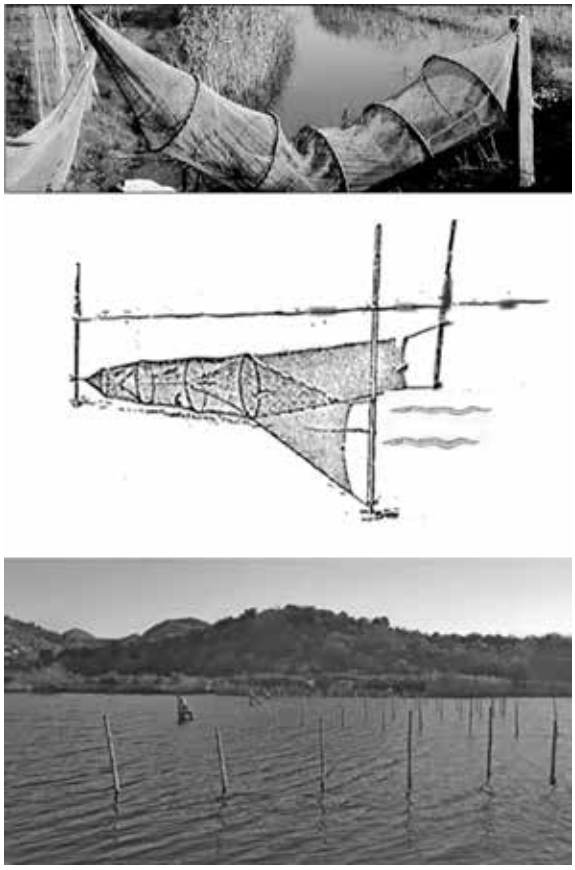

Fig. 2. Traditional gear for European eel, Anguilla anguilla capture in the River Neretva estuary: small gear for the capture of yellow eel (upper picture), construction of local eel fyke net (middle) and larger gear (locally "trata") for capture of silver eel (lower picture)

(Fig. 2c) was used during 2017 and 2018, in the Baćinska Lakes outlet, from beginning of November to the end of January. The fishing gear was inspected daily, every morning and the total weight was measured per sampling day, while 50% of the catch was measured for the specimen weight and length. Only 20% of silver eels, separated on the basis of colour and weight (> 150 grams), were used for the analysis, while the rest of the sample was released. Selected samples (fifty from both investigated sites per year of sampling) were inspected for infestation with *A. crassus*; after stomach dissection and swim bladder removal, the presence and number of parasites were counted and recorded. Microsoft Excel 2010 was used for descriptive statistical analysis (means, standard deviations, minimum and maximum values). *t*-test (Statis-

tica v.7 (StatSoftLtd)) was used to determine the statistical difference between the data obtained.

RESULTS

The fishing data from the Parila lagoon where traditional fyke net traps were used, during 2016 and 2019, showed similar patterns. The total monthly capture values in ten traditional eel traps, during two years are presented in Fig.3. The total eel captures in 2016 were 91,7 kg representing 1464 specimens. The total eel captures in 2019 was 80,4 kg, and 1124 specimens respectively. The monthly eel catches profiles exhibit similar trend, with greater values recorded during autumn-winter period, from October to January. The lowest eel catches in both years were recorded in February, March and September. The total monthly weight varied from 4.4 to 12.7 kg (±2.45 kg) in 2016 and from 2.4 to 9.6 kg (±2.01 kg) in 2019. The lowest monthly weights were recorded in July (2016) and September (2019), and the highest were recorded in November (2016) and January (2019). There was no statistical difference between monthly and total weights recorded in 2016 and 2019 (t=1.04; p=0.312).

The total of 150 eel specimens was measured during 2016 and an equal number during year 2019. The mass and length structure of the population showed a dominance of smaller eel (mass around 50 grams), while those larger than 200 grams were rare. The dominant length classes were from 30 to 45 cm, while longer

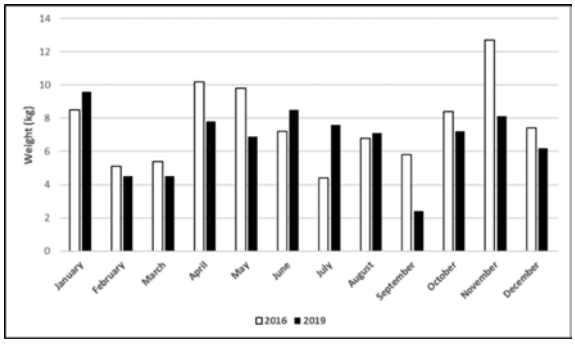

Fig. 3. Total monthly catches in 10 traditional eel fyke net traps of the European eel, Anguilla anguilla in the Parila lagoon (Neretva Estuary, Croatia) during years 2016 (white columns) and 2019 (black columns)

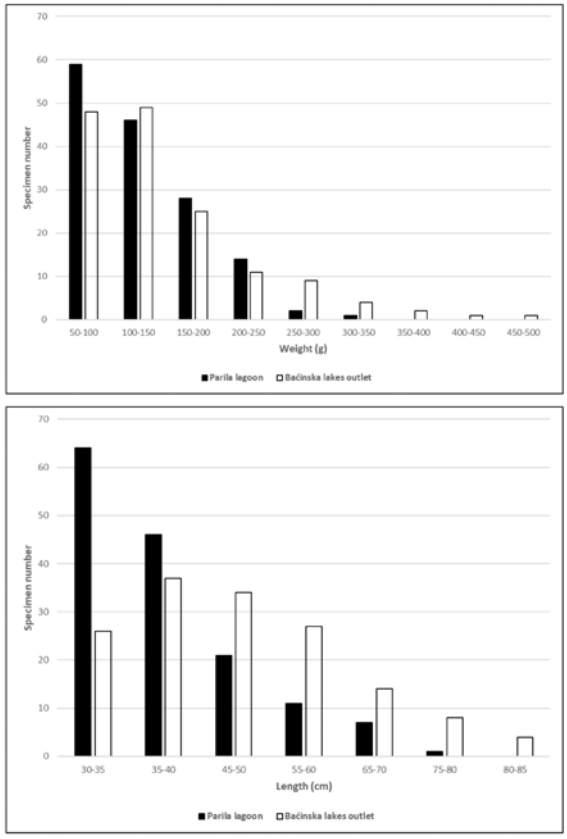

Fig. 4. Length and weight distribution of the European eel, Anguilla anguilla from two habitats (Parila lagoon and Bačinska Lakes outlet) in the Neretva Estuary, Croatia

individuals were rare (Fig. 4). The dominant eel stage in the Parila lagoon was yellow eel, while silver eels were caught only during autumn in lesser numbers.

During three months of sampling with traditional "trata" gear in the Bačinska Lakes outlet the total eel captures of 21.6 kg in 2018, and 18.8 kg were recorded. The catch was composed of 252 eels in 2018 and 208 in year 2019. There were no statistical differences among total catch values during the two years. Autumn catch was composed of 16,4% silver eels in 2018 and 9.8% in year 2019. The rest of the catch was composed of yellow eels, with a mass range of 54.2-128.6 grams. The weight structure of the Bačinska lake outlet site exhibited a dominance of smaller eel (50-150 grams), while the dominant length classes were from 30 to 45 cm. The heavier and longer individuals all belonging to silver eel stage and were abundant during autumn/winter period. (Fig.4).

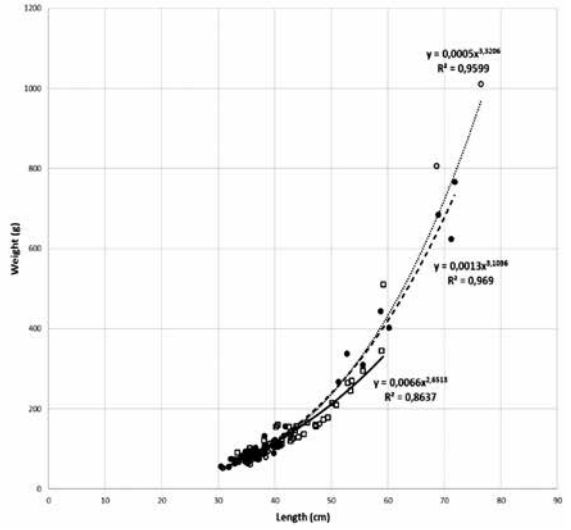

Fig. 5. Length-weight relationships of the European eel, Anguilla anguilla in different habitats of the River Neretva estuary: brackish Parila lagoon (white square), freshwater/slightly brackish Baćinska lake outlet (black circle - sample from year 2017; white circle - sample from year 2018)

The length-weight relationship of the eels from two different habitats of Neretva estuary is presented in Fig. 5. The *b*-coefficient was significantly higher for the eels from the Baćinska Lakes outlet site and varied from 3,1036 (2017) to 3,3206 (2018). The *b*-coefficient for the eels from Parila lagoon was 2,6513. However, when migrating larger silver eels caught during November-December period, were eliminated from the L-W analysis, the *b*-coefficient decreased even more to a value of 2,4401. Similarly, the removal of bigger silver eels from the sample from lake's outlet site, also significantly affected *b*-coefficient lowering its value to 2,964. The difference between *b*-coefficients among eels from two different sites is statistically significant (t-test=-16.4, d.f. 2; $P=0.00 \leq 0.01$), showing a significant difference of the eel condition in these two areas.

Higher infestation of European eel with *A, crassus* was found among individuals caught in a dominantly freshwater area than specimens caught in a typically brackish lagoon. The percentage of infected individuals in the Baćinska Lakes site was 41% of the total two-year sample, corresponding to 44% (22 out of 50 eels analysed) in 2018 and 38% (19 out of 50) in year

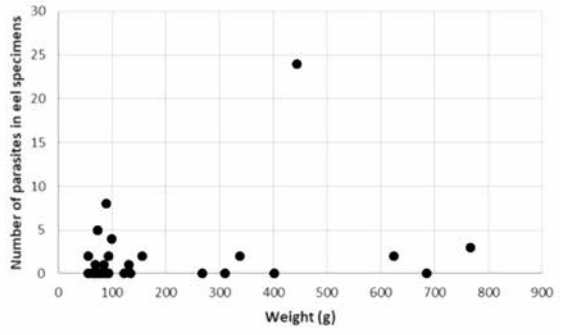

Fig. 6. Number of parasites, Angullicola crasus in abdominal cavity and swimbladder of European eel, Anguilla anguilla caught at the outlet of Baćinska Lakes (River Neretva estuary, Croatia)a

2019. The recorded values of parasite numbers varied from one to twenty individuals in the swim bladder. The parasites were not found in the abdominal cavity. The parasites infested all age classes equally, but their numbers did not increase with age. The highest parasite number (24) was found in one silver eel female (Fig. 6). The infestation with parasites was significantly lower in the brackish site, 7 % of the total two-year sample. In the 2016 sample from fyke nets, the percentage of eels infested with parasites was 6% (3 out of 50 analysed), while in 2019 it was 8% (4 out of 50). The recorded numbers from this site varied from one to three individual parasites per swim bladder. The difference in percentages of infected eels between two sites is statistically significant.

DISCUSSION

The European eel along the Eastern Adriatic coast, if compared with other European areas, is not widely investigated. Although several areas like Skadarsko Lake in Montenegro or River Neretva estuary in Croatia are famous for the traditional eel fishery, the official data and knowledge of populations are scarce. This also led to a situation where Croatia as an EU member, did not produce Eel Management Plan in accordance with the EU directive (Council Regulation (EC) No 1100/2007), providing an explanation that official catches are lower than 500 kg. The results of the present study on eel status in parts of the Neretva estuary provide new important pieces of information for the

future sustainable management of eel on the Eastern Adriatic coast.

The yearly catch per one traditional fyke net varied from 6.87 kg in 2016 to 5.76 kg in 2019. The estimate of numbers of these gears, which are traditional but not legal these days, in the Parila lagoon only for the year 2019 was 30, and an assessment of the yearly catch by these gears is approximately 200 kg. The number of other fishing gears in the Neretva Delta, like illegal smaller eel traps, is significantly higher and estimated at more than 10000 pieces laid-out in the water bodies permanently, but these captures were not evaluated. When captures by legal concessionaires for the silver eel capture is added to the numbers of illegal fisherman, the total estimated annual capture of eels in the Croatian part of the River Neretva Delta is approximately 6 tons, indicating that official statistics need upgrading. However, during the year 2021 most of these illegal tools were removed from the lagoon and other areas, after frequent actions of Fisheries Inspection and Coast Guard, stopping this illegal activity to some extent.

The *b*-coefficients of the selected European eel populations in different European countries are presented in Table 1. The *b*-coefficient from Baćinska Lakes outlet represented as a more freshwater site is comparable to most other regions in the table and their mean values (3.078) in the Fishbase (www.fishbase.org, accessed on 10 December 2020). However, the *b*-coefficient in the Parila lagoon is among several lowest reported in the Fishbase and significantly lower than those of the similar lagoon ecosystems along the Adriatic Sea. In sites like Comacchio lagoon (CASTALDELLI *et al*., 2014), Lagoon Rossiada in Portugal (BESSA & PESTANA, 1981) and Northern Greece lagoons (KOUTRAKIS & TSIKLIRAS, 2003), *b*-coefficients are in the range 3.223-3.470. Such low *b*-coefficient should indicate poor trophic conditions or habitat alternations leading to bad biological characteristics of the local eel stock. The poor status of the Parila lagoon was documented earlier based on the analysis of benthic and fish communities (PRUSINA *et al*., 2016). This was recently enhanced with an establishment of the strong population of invasive blue crab, *Callinectes sapidus* and its competition for the food and shelter with native crab and fish species (MANCINELLI *et al*., 2016), as well as new and invasive fish species records (GLAMUZINA *et al*., 2017; GLAMUZINA *et al*., 2021a). The blue crab significantly impacted the estuarine environment and species composition (GLAMUZINA *et al*., 2021b) and preyed on similar prey consumed by European eel in this ecosystem (MOROVIĆ, 1970). In the freshwater ecosystems the establishment of the largemouth bass, *Micropterus salmoides* population, and its invasive potential (GLAMUZINA *et al*., 2021a) through competition for the food with native eel, should produce similar negative effects as the blue crab in a brackish environment. These invasive species present additional new biological factors and should have a similar negative impact on the local eel population comparable to devastated land reclamations sixty years ago.

The survey of parasite *A. crassus* showed that eels in the freshwater habitat have significantly higher infestation than in the brackish habitat. It was reported earlier that eels in saline environments also tend to have faster growth rates and reduced loads of the swim bladder parasite, *A. crassus* than those in freshwater (JAKOB *et al*., 2009). The study in pristine Portugal rivers highlighted the presence of the parasite and completion of the whole life cycle in eels from the Río Esva and the condition of eels was lower at upstream sites compared with downstream locations (COSTA-DIAS *et al*., 2010). Research on the European eel from the three river estuaries in Turkey showed that 65.7% specimens were infected by *A. crassus* (INALL *et al*., 2019). High infestation (61.7%) of the specimens from Vistonis Lake (Northern Aegean Sea) in Greece was also reported (MACNAMARA et al., 2014). The present research confirmed that eel in freshwater habitats are more prone to *A. crassus* infestation than brackish populations.

The present study on the European eel population in the River Neretva estuary confirmed most of the available knowledge on this species on the Mediterranean and European scale. This includes significant population collapse and decrease of traditional fisheries captures

Table 1. Length-weight relationship of European eel, Anguilla anguilla from various regions

Location	**Reference**	**b-coefficient**
Lagoon, France	Campillo, 1992	2.962
France	Bauchot and Bauchot, 1978	3.095
Caspian Sea	Sheikh, 2000	3.000
Italy	De Leo and Gatto, 1995	3.180
River Shannon, Ireland	Moriarty, 1986	3.220
Dorset, UK	Mann and Blackburn, 1991	3.313
Lagoon Rossiada, Portugal	Bessa and Pestana, 1981	3.319
Northern Greece	Koutrakis and Tsikliras, 2003	3.470
Hutovo blato wetlands Bosnia and Herzegovina	Glamuzina *et al.,* 2008	2.843
Eastern Adriatic Coast- karstic streams	Piria *et al*., 2014	2.5957-2.8155
Inland River Neretva major flow	Glamuzina and Dobroslavić, 2020	3.038
River Neretva Estuary Parila lagoon- brackish Baćinska Lakes- freshwater	This article	 2,6513 3,1036-3,3206

and trends in the eel infestation with *A. crassus*. However, on the local level some interesting results dealing with the low performances of eels from lagoon ecosystems, opposite to findings in similar Mediterranean ecosystems, point that locally eel is not only affected by overfishing, but also with other factors including local habitat alternations, such as shallowing, water warming, and freshwater flow decrease (GLAMUZINA & DOBROSLAVIĆ, 2020), and with a recent invasion by new species such as the blue crab. These results highlight the need for new different measures which exceed the present EU measure of eel fishery restrictions during three selected months, to field infrastructure habitat works in order to provide more fresh water influx and deeper areas, to prevent fast summer water warming and oxygen depletion. This must be accompanied with eradication projects of invasive fish and crabs, as eel predators and competitors for shelter and food resources. Furthermore, according to EU directive (Council Regulation (EC) No 1100/2007, "for river basins extending beyond the boundaries of the Community, the Community should endeavour to ensure appropriate coordination with the third countries concerned", future activities on eel management should be executed in cooperation with official bodies and institutions of Bosna and Herzegovina, as most of the River Neretva catchment belong to this state.

ACKNOWLEDGEMENTS

The field work was financed by University of Dubrovnik, Croatia fund for the scientific research. We are thankful to local fishermen Slobodan "Beđo" Glamuzina for his field work assistance and gear maintenance.

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Received: 11 November 2021
Accepted: 22 February 2022

Istraživanje europske jegulje, *Anguilla anguilla* u ušću rijeke Neretve (istočni Jadran, Hrvatska) korištenjem tradicionalnih ribolovnih alata

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SAŽETAK

Europska jegulja, *Anguilla anguilla* analizirana je u dva različita staništa u delti Neretve pomoću dva različita tradicionalna ribolovna alata za jegulju u razdoblju od 2016. do 2019. Ulov jegulje u deset tradicionalnih vrša za jegulje u laguni Parila kolebao je mjesečno od 4,4 do 12,7 kg (± 2,45 kg) u 2016. godini i od 2,4 do 9,6 kg (± 2,01 kg) u 2019. godini. Nije bilo statističke razlike između mjesečnih i ukupnih masa zabilježenih u 2016. i 2019. godini ($t = 1,04$; $p = 0,312$). *b*-koeficijent odnosa duljine i mase (LW) za jegulje iz slatkovodnog područja kolebao je od 3,1036 do 3,3206 tijekom dvije godine uzorkovanja. Odnos LW za jegulje iz bočatog staništa bio je značajno niži (*b*-koeficijent 2.6513). Dominantni stadij jegulje u oba područja bila je žuta jegulja, dok je srebrna jegulja bila rijetka.

Ribolov tradicionalnim ribolovnim alatima pokazao je da je učinkovitost ovih alata niska, što ukazuje na malu brojnost jegulja u njihovim tradicionalnim staništima. Ulovom u "trati"- tradicionalnom alatu za ulov jegulje tijekom jesenskih migracija dominirala je također žuta jegulja, sa samo 15,4% ulova srebrne jegulje.

Zaraženost jegulja parazitom *Anguillicoloides crassus* bila je znatno veća u slatkovodnom staništu (41%), u usporedbi sa 7% jegulja iz bočate lagune Parila. Slaba ribolovna učinkovitost tradicionalnog ribolovnog alata, loša duljinska i masena struktura populacije i niski *b*-koeficijenti jegulja u najvažnijem staništu jegulje ukazuju na loš status populacije neretvanske jegulje i ekosustava ušća rijeke Neretve.

Ključne riječi: europska jegulja, tradicionalno ribarstvo, duljinsko-maseni odnos, *Anguillicoloides crassus*, delta Neretve