Shellfisheries in Croatia: From Manual Collection to Contemporary Practices

Školjkarstvo u Hrvata: od ručnog prikupljanja do suvremene prakse

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Abstract

Shellfish farming, the oldest form of mariculture, plays an important role in coastal areas all over the world, including Croatia. While around 15 species of bivalves have been traditionally consumed locally, only the European flat oyster (*Ostrea edulis*) and the Mediterranean mussel (*Mytilus galloprovincialis*) are commercially interesting for farming. Oyster farming in Mali Ston Bay has been regulated since the 16th century, with modern farming technologies being introduced in the early 20th century. Despite efforts to expand shellfish farming in Croatia, production has stagnated at a few thousand tons since the 1990s. Today, legal regulations govern production, product quality and consumer safety, including traceability monitoring. Farming is still based on the collection of natural spat, although future supply from hatcheries should improve the production efficiency.

KEY WORDS

bivalves
farming
Adriatic Sea
mariculture

Sažetak

Uzgoj školjkaša, najstariji oblik marikulture, ima važnu ulogu u obalnim područjima širom svijeta, pa tako i u Hrvatskoj. Dok se u priobalju oko 15 vrsta školjkaša tradicionalno konzumira, samo su europska plosnata kamenica (Ostrea edulis) i sredozemna dagnja (Mytilus galloprovincialis) zanimljive za komercijalni uzgoj. Od 16. stoljeća školjkarstvo u Malostonskom zaljevu zakonski je regulirano, a novije tehnologije uzgoja uvedene su početkom 20. stoljeća. Unatoč naporima da se uzgoj školjkaša u Hrvatskoj poveća, proizvodnja od 1990-ih godina stagnira na nekoliko tisuća tona. Danas je zakonski regulirana ne samo proizvodnja nego i kvaliteta proizvoda i sigurnost potrošača, uključujući nadzor sljedljivosti. Uzgoj se još uvijek temelji na sakupljanju mlađi iz prirode, a buduća opskrba iz mrijestilišta trebala bi poboljšati učinkovitost proizvodnje.

KLJUČNE RIJEČI

školjkaši
uzgoj
Jadransko more
marikultura

1. INTRODUCTION / *Uvod*

Bivalve shellfish were a food source for early humans due to their accessibility, nutritional value, and ease of collection, providing proteins, vitamins, and minerals [1, 2]. Bivalves are an integral part of their ecosystems, interacting with both living and non-living components. These sedentary invertebrates are widely distributed in benthic marine areas, living on or burrowing into the seafloor or attaching to surfaces with cement or byssal threads. Scallops can even swim thanks to their strong adductor muscles [3]. Bivalves are adaptable to various environmental conditions such as temperature, salinity, and oxygen levels, allowing them to thrive in a wide range of habitats—from the intertidal zone to the deep sea [4]. They are filter feeders that consume phytoplankton, bacteria, detritus, and zooplankton. The availability and quality of food are key factors influencing their growth, reproduction, and abundance [5]. There are around 9,500 bivalve species worldwide [6], 252 of them in the Adriatic [7]. Depending on local diets, culinary traditions, and the availability of species in different regions of the world, approximately 100 to 200 species of bivalves are commonly harvested and eaten [8]. It is documented that 66 species of shellfish were used as food in the Adriatic region, 16 of which were marketable [9].

Although the history of shellfisheries in Croatia is deeply rooted in the country's culture, only two species have been successfully cultivated to date: the European flat oyster *Ostrea edulis* and the Mediterranean mussel *Mytilus galloprovincialis* [10,11, 12].

2. MILLENNIA-OLD SHELLFISH HARVEST IN THE EASTERN ADRIATIC / *Tisućljetni izlov školjkaša u istočnom Jadranu*

Shell middens, similar to those found in Portugal, Spain and Denmark [13, 14, 15] have been discovered along the Croatian coast, suggesting that prehistoric people collected shellfish extensively. These shell mounds were mainly found in caves, e.g. in the Grapčeva Cave on the island of Hvar, in Gudnja and Nakovana on the Pelješac peninsula, in Danilo Bitinj near Šibenik and near Bay of Mali Ston, in the Roman town of Narona and in the Illyrian remains in Oślje. These sites offer valuable insights into the dietary and lifestyle strategies of people in ancient times, dating back to around 5000 BC [16, 17, 18]. The long history of the use of shellfish in the eastern Adriatic is documented by various historical figures, including writers, naturalists and teachers. For example, the Croatian poet and historian Juraj Šižgorić praised the oysters from Šibenik Channel in 1487 [19]. In the 16th century, Jakov Sorkočević, rector of Ston, wrote to the naturalist Aldrovandi about the properties of scallops, date mussels and other edible shellfish. He made detailed observations about oysters, including their biology, breeding methods and preservation by smoking and drying [20]. Spiridon Brusina, the founder of Croatian marine biology, published numerous works on molluscs of the Adriatic. In his travelogue, he described mussels (*Mytilus galloprovincialis*) from Novigrad Sea and their importance for the local diet and trade [21, 22]. Bivalves were often a vital source of food or income

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for people of limited means, helping to sustain communities in times of scarcity and economic hardship [23].

As the collecting of mollusks from natural stocks was rare and often associated with trawling or dredging or for domestic use, trade in shellfish was rare in local markets, so there were no statistical data. In the middle of the 19th century, the fisheries expert d'Erco wrote about the fishing of oysters of the species *Ostrea edulis* and noted that they were collected in various locations. The most famous fishing areas were Novigrad (in Karin Sea) and Bay of Mali Ston. These oysters were marketed in Zadar and Dubrovnik, but also in other places. The oysters from Bay of Mali Ston were transported to Venice [24]. In a report on Austro-Hungarian sea fishing from 1883, the oyster harvest was recorded in the vicinity of Pula and Novigrad, east of Zadar, along the coast of Sukošan, on the islands of Oštarije and Galešnjak, also in the vicinity of Šibenik and in the Ston area [25].

2.1. Favorite Croatian bivalves / *Omiljeni hrvatski školjkaši*

The most commonly caught species include the following: Noah's Ark *Arca noae*, which lives firmly attached to the rocky substrate, often heavily overgrown with epibionts. It is usually caught with rakes from the boats or by hand. The commercial harvesting of Noah's Ark is done with mechanical or hydraulic dredges called *kunjkara* [26]. Despite occasional mass mortalities, it is mainly caught in Istria, in the Zadar area and in the seabed of Mali Ston Bay [27, 28]. *Brganja*, traditional tool for harvesting Noah's Ark in Šibenik area (island of Murter), made of a square metal construction with a strong net for the shellfish, was made out of copper wire, while today it is made of a fishing net and used for harvesting not only Noah's Ark but other shellfish or even sponges [29]. The bearded mussel *Modiolus barbatus* was collected below a depth of 2 m, mostly with rakes or with the hands from the rocks in the bays of Split (Kaštela Bay) or in the bay of Mali Ston as well as with *brganja* in Murter. Great Mediterranean scallop *Pecten jacobaeus* was collected mainly in the Zadar area and in Hvar Channel on the surface of sandy bottoms at a depth of 8-30 m by diving or with trawls, as well as in Istria where nowadays dredge called *rampon* is used for commercial fishing of *Pecten jacobaeus* [31,32,33,34] The *rampon* consists of a metal frame to which a net is attached. On the lower part of the metal frame there are rakes that scrape the seabed, and on the upper part there is a depressor attached at an angle [35]. Queen scallop *Aequipecten opercularis* mostly present in Northern Adriatic can be harvested by *rampons* bottom trawl nets [39], as well as *Mimachlamys varia* which is abundand in Krka estuary [37]. The hydraulic dredger *vongolara* is used for the commercial fishing of shellfish, especially venerids. It pulls the shellfish out of the sediment using pressurized water. During the catch, the *vongolara* is pulled over the sandy seabed with a winch [26]. The warty venus, *Venus verucosa*, which is often found in the sandy sediments of the Adriatic Sea at a depth of 1-15 m, was mainly collected in the warm season [27,30]. The striped venus, *Chamelea gallina*, was commercially exploited for a short time in the sandy estuary of the Neretva. It is also abundant in the waters of Nin and Novigrad, in Cetina estuary and in the sands of the islands of Brač, Rab and Susak [30]. Other bivalves that live more or less buried in the sandy seabed include the grooved carpet shell, *Ruditapes decussatus*, the tuberous mussel, *Acanthocardia tuberculata*, the poorly ribbed cockle, *Aranthocardia paucicostatum*, the olive cockle, *Cerastoderma glaucum*, and the grooved razor clam, *Solen marginatus*. Rare on the tables, but not a rare species, is the European thorny oyster, *Spondylus gaederophus*, which lives attached to the rocks with a valve, usually overgrown by epiphytes [27].

2.1.1. Edible but protected / *Jestivi, ali zaštićeni*

Two protected species, *Lithophaga lithophaga* (commonly known as the date mussel) and *Pinna nobilis* (noble pen shell), are particularly important due to their historical importance as a food source. The illegal harvesting of date mussel is of particular concern due to the methods used to extract it. Date mussels live embedded in rocky substrates, and in order to collect them, the rocks in which they live often have to be broken open. This highly destructive practice severely damages the rocky habitats. The impact on the environment is long-lasting and ecosystems take several decades to fully recover from this disturbance [40]. Date mussels have been protected by the Nature Conservation Law since 1994 [38], and according to the Ordinance on the protection of the date mussel *Lithophaga lithophaga*, it is prohibited to catch, keep, kill, buy, sell, acquire or otherwise dispose of date mussels, to export or import date mussels and to damage or destroy their habitat [39]. Date mussels have been found in various places in Dalmatia, but mainly in Bay of Mali Ston, especially in its eastern part [23, 24]. Interestingly, d'Erco found that there were no date mussels in Klek area [24]. In contrast, date mussels are constantly sold today in nearby Neum (Bosnia and Herzegovina), which leads to the question of their origin.

The noble pen shell, *Pinna nobilis*, was often used in traditional cuisine. On the island of Mljet, the once abundant and easily accessible stocks were regularly prepared as popara (stew), sauce or fried. Pen shell is endemic and the largest Mediterranean species endangered by illegal collection, accidental trawling and drilling, and habitat destruction, especially in *Posidonia* meadows, so illegal harvesting of individuals has been prohibited in Croatia since 1977. Unfortunately, the noble pen shells along the eastern Adriatic were affected by a pathogen-caused mass mortality that started on the Spanish Mediterranean coast, spread eastwards and reached the Adriatic in 2019 [41]. Due to the drastic decline in population size, *Pinna nobilis* is under threat of extinction, and has been classified as "critically endangered" on the IUCN Red List of Threatened Species since 2019 [42].

2.2. Harvesting bivalve shellfish from natural habitats / *Prikupljanje školjkaša iz prirodnih staništa*

Most of the sites where shellfish were collected in the past are close to areas where they are still harvested commercially today [10,11,24,25,26,27]. These sites provide favorable conditions for shellfish growth and support populations that can be harvested sustainably depending on their density. The collecting of shellfish from natural stocks today requires a permit. The Marine Fisheries Act [43] and other legal specifies the areas and conditions in what artisanal and commercial fishing for live bivalve mollusks may be carried out. According to official data from the European Statistical Office [44], 10 species of shellfish were collected commercially in the Republic of Croatia from 2013 to 2022: grooved carpet shell *Ruditapes decussatus*, warty venus *Venus verrucosa*. striped venus *Chamelea gallina,* smooth callista *Callista chione*, Noah's Ark *Arca noae,* great Mediterranean scallop *Pecten jacobaeus*, smooth scallop *Flexopecten glaber*, flexuous scallop *Flexopecten flexuosus*, European flat oyster *Ostrea edulis* and Mediterranean mussel *Mytilus galloprovincialis*. Among the mentioned species, by far the most oysters were collected, a total of 1874.19 tons, followed by warty venuses, 886.17 tons and Great Mediterranean scallop 609.88 tons, while the total catch of both species of *Flexopecten* amounted to a negligible 4.40 tons (Figure 1). This is understandable not only because oysters and scallops are present in dense populations, but

also because they are the most valuable on the market.

Production data is collected by the Ministry of Agriculture-Directorate of fisheries of but it is assumed that illegal catches might be much higher than the official data evidence.

Commercial shellfish fishing is only permitted in areas where the plan for monitoring the quality of the sea and bivalve mollusks is implemented [45]. These areas are the west and east coast of Istria including Bay of Savudrija, Vabriga, Bay of Lim, Bay of Medulin, Bay of Budava and Bay of Raša, then Velebit Channel, the bays of island of Pag – Dinjiška, Povljana, Stara Povljana and Bay of Pag, the areas of Modrič – Seline and Novigrad Sea; Bay of Pirovac, Sveti Ante Channel and Krka estuary near Šibenik, Marina and the

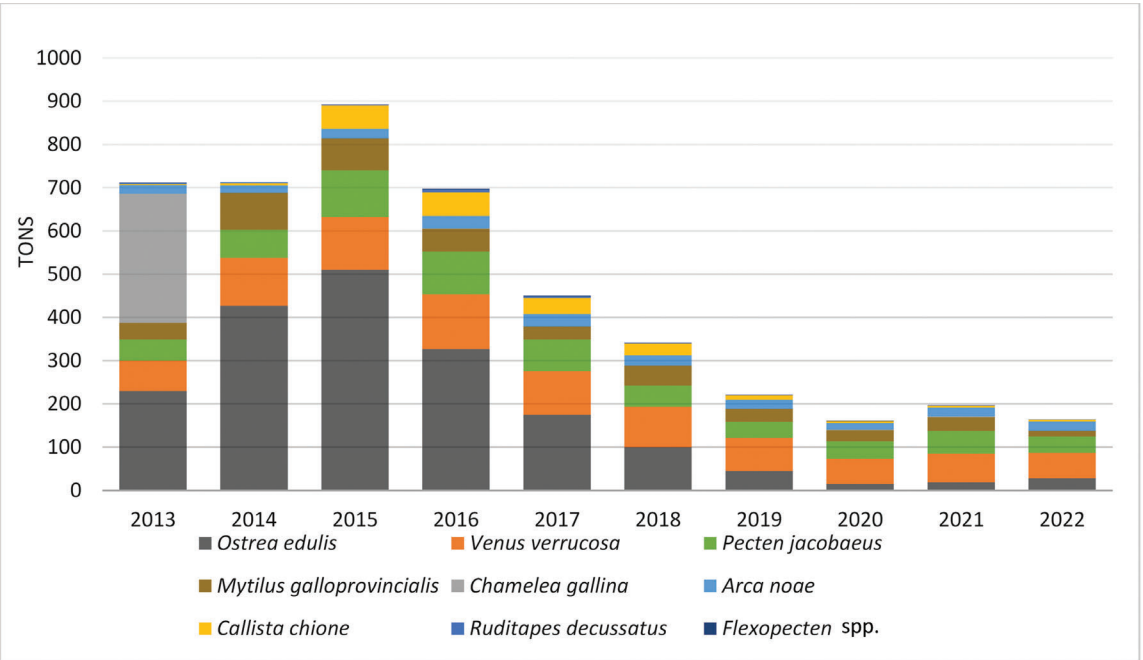

Figure 1 Captured bivalve production in Croatia 2013-2022 (according to EUSTAT [44]).
Slika 1. Proizvodnja školjkaša u Hrvatskoj 2013. – 2022. (prema EUSTAT-u [44]).

Figure 2 Bivalve shellfish fishing and farming areas in Croatia [according to10, 12, 23, 24, 26]
Slika 2. Područja ribolova i uzgoja školjkaša u Hrvatskoj (prema 10, 12, 23, 24, 26)

Bay of Kaštela near Split, Škoj in Neretva estuary and Bay of Mali Ston [45] (Figure 2). Nowadays, the most oysters are caught in the area of the west coast of Istria by fishing boats fishing with dredge type *rampon*, and the exploited oyster settlements are located at a depth of about 35 meters [46]. Scallop fishing in the Krka estuary is sporadic and unorganized, while in the sandy areas of western Istria it is very dense and regularly exploited commercially with dredges [32,33,34].

3. FROM WILD CATCHES TO SUSTAINABLE FARMING / *Od divljeg ulova do održivog uzgoja*

Even Aristotle recognized the economic value of oysters as early as 350 BC, noting in his work Historia Animalium (History of Animals) that they were collected and consumed by humans of that time [47]. The detailed accounts of Pliny the Elder around 100 BC provide valuable insight into the practices and importance of oyster farming in ancient Roman society, as well as their biological characteristics. He noted that oysters grow by attaching themselves to rocks or other hard surfaces and feed by filtering water, and discussed the environmental conditions favorable to oyster growth [48]. This proves that shellfish farming can be considered the oldest form of mariculture.

The demand for bivalves has often exceeded the supply from natural populations. As filter feeders, bivalves are dependent on organic matter and plankton suspended in the water column. Therefore, farming bivalves in their natural habitats remains the most practical and cost-effective method, although modern farming methods continue to rely on these natural food sources. In these typically eutrophic environments, spat for aquaculture can be collected [8]. The accessibility of bivalves in shallow waters has allowed a study of their life cycles and facilitated the development of techniques for efficient management and restoration of oyster populations [1,3,7,8].

3.1. Beginning of management / *Početak upravljanja*

After centuries of shellfish collecting in numerous locations along the Adriatic coast, the legally regulated cultivation and management of oysters in Bay of Mali Ston as early as the 16th century was already established [49]. Following a study visit by Riccardo d'Erco to France in 1863 to find the most suitable methods for cultivating shellfish, the Ministry of Maritime Affairs made funds available for this purpose [50].

The cultivation trials were carried out in the northern Adriatic Sea, mainly in sheltered and easily accessible areas with favorable ecological conditions and abundant natural shellfish populations. The methods and technologies used were tailored to the specific characteristics of these areas and the available resources. Most attempts to cultivate oysters, driven by the evident inability of natural stocks to meet demand, did not result in sustainable, long-term commercial farming. These efforts were primarily concentrated in locations such as Novigrad, Ribnjak-Fažana, and the Raša Channel in Istria, as well as in Osor, Mali Lošinj, Rovenska, Cres, Punat, Bakar, Kraljevica, and Žrnovnica in Kvarner Bay. [10,11].

Oyster farming in Bay of Lim, a protected marine area and characteristic karst valley on the west coast of Istria [48], began as early as 1888, when fishermen from Rovinj placed oak branches under water to collect oyster spat, marking the beginning of semi-cultivation in the area. This method was soon abandoned, however, and in 1895 a more structured approach was taken with the construction of wooden structures modeled on the Taranto system. These initial efforts encountered difficulties, probably due to the depth of the bay and the disruption of ecological conditions. Between the two world wars, oyster farming was switched to buoy systems. Throughout the 20th century, production fluctuated and was even interrupted at times. Since the 1980s, smaller but steady quantities of oysters and mussels have been cultivated in Lim Bay [10,11].

In the twentieth century, there were several attempts to cultivate oysters in the areas of Zadar (Novigrad Sea, Sukošan, Pašman), Šibenik (Pirovac Bay) and Split (Veli Rat, Vranjic), as well as in Mljet Lakes, but these were short-lived [10,11]. Shellfish farming was more successful in Novigrad Sea, a deeply indented eutrophic bay that is strongly influenced by a karst river and numerous underwater freshwater springs [52].

The Krka estuary, a eutrophic area rich in shellfish, is today one of the largest mussel farming areas in Croatia. Owing to the dense natural beds of mussels in this estuary which naturally produce spat [53]. The first mussel farms were established in 1983. After the interruption caused by the Homeland War, mussel production was resumed in 1995. The mussels are farmed in mesh tubes - *pergolari*. The farms consist of floating longlines made up of a series of buoys with a rope anchored to the ends. The *pergolari* are suspended from the ropes so that the mussels can grow. Scallops were also farmed for a short time in the late 1980s - the spat was collected in the wild using PVC nets. After six months, the spat was transferred to the so-called pearl nets, which were hung in rows of six from fish farming cages at a depth of 12-13 meters. [37].

3.1.1. Bay of Mali Ston – from Dubrovnik Republic to the Republic of Croatia / *Malostonski zaljev – od Dubrovačke Republike do Republike Hrvatske*

Bay of Mali Ston is considered the cradle of oyster farming in the eastern Adriatic and until recently accounted for 90% of Croatian shellfish farming [10, 26, 54,55]

The first archival mention of oyster farming in Bay of Mali Ston, the most favorable area of the Adriatic for shellfish farming, dates back to 1573. In the 16th and 17th centuries, the Rector of Ston, as the representative of the Republic of Dubrovnik, had the exclusive right to regulate the oyster business by granting concessions for oyster farming, which were linked to the obligation to cede a share to the state. Parts of the bay that were used for oyster farming were divided into plots that were leased by private individuals. The calibration of commercially available oysters was also regulated [49]. The fame of oysters from Dubrovnik area spread far beyond the country's borders - as early as 1667, a Spanish newspaper described the use of interconnected wooden constructions that were loaded with stones, submerged in the sea and retrieved after a certain time full of oysters. In the 18th century, Dubrovnik Senate had to intervene in the conflict between the rector and the farmers in order to save production. Control over the oyster business was strengthened by measures such as granting loans to farmers, exempting them from fees and setting a fixed price for oysters. Regulations were also issued to penalize farmers who damaged oak trees while collecting branches. During the Austro-Hungarian Monarchy, the municipality of Ston leased Bistrina

Bay and granted concessions to individuals who undertook to throw 700 oak branches into the sea every year [49].

3.1.1.1. Rational growing / *Racionalni uzgoj*

While the first attempts at oyster farming were taking place in the north of the Adriatic, Captain Stijepo Bjelovučić founded the "First commercial oyster and scallop farm in Dalmatia" in Sutvid in the bay of Mali Ston in 1889. He introduced an improved oyster farming technique, increased production and exported oysters to Vienna, Prague and even Paris. Until then, oak, spruce or olive branches had been sunk in the shallows along the coast to make them heavier and then thrown into the sea in places that were favorable for the spat attacment. After two to three years, the oysters that had grown on the branches were removed and sold. This method of farming was unsafe, as the amount of spat was unpredictable and the number of branches found after some time was also unpredictable. Captain Bjelovučić combined the then known techniques of oyster farming in the Mediterranean: French and Taranto, i.e. Italian. Tiles and branches were used to collect the spat. Branches with oysters were later wrapped in coconut twine and hung on tarred wooden poles driven into the seabed. A large number of such pillars formed the so-called park or sea garden [10,56].

After the First World War, the oyster farms were completely destroyed. In the period from 1926 to the Second World War, there was intensive and active participation by individuals, who have further improved production. The innovative farmer Luka Maškarić constructed frames from simple wood for hanging oyster bunches. He was the first in Europe to build farms out of concrete and iron. He also introduced the technique of cementing oysters on wooden sticks and expanded the oyster markets. Maškarić was followed by other growers, including Niko Buško and Antun Pavlović, who were also pioneers of oyster cementing [11].

The crowning achievement of this dynamic in the production of Maloston oysters is winning a gold medal and "Grand Prix" award in 1936 in London and production in 1941 amounted to 770,000 oyster pieces, 740,000 of them were sold [11].

3.1.1.2. From the middle of the twentieth century / *Od sredine dvadesetog stoljeća*

After the Second World War, heavily damaged farms in the bay of Mali Ston were repaired and oyster farming was continued more intensively than before. State companies were founded for cultivation, research and the improvement of farming techniques [49]. From the Second World War to 1980, the average annual production was around 1 500 000 oysters, and 159 tons of mussels [11]. From 1980 to 1990, annual production was between 1,500,000 and 2 000 000 oysters. Mussel production in that decade reached 3 000 tons [27]. This increase was the result of the introduction of modern farming technologies, which are still used today, and the linking of state companies with private farmers [54]

In the early 1990s, Mali Ston Bay area is threatened by war and is even temporarily occupied. Farms were destroyed and production was interrupted. The events of the war led to a decline in shellfish production throughout Croatia. After the war, shellfish farming was slowly resumed by small family businesses. A lack of capital to increase production, disorganized spatial plans that made it impossible to plan concessions for sea plots and relatively high fees for concessions made production progress even more difficult [56]

Since then, bivalve farmers have joined forces in the Association of Shellfish Farmers of Ston (2006) and in cooperatives that are still active and committed to the development of the sector, maintaining the position of Mali Ston Bay, one of the largest production areas of *Ostrea edulis* in Europe.

3.2. Current Practices and Sustainability in a Traditional Industry / *Trenutačne prakse i održivost u tradicionalnoj industriji*

Although there have been attempts to farm scallops in Krka estuary [32, 53] and Novigrad Sea [7], only two species have been commercially cultivated: the European flat oyster and the Mediterranean mussel. The available data on bivalve farming in Croatia since 1950 are shown in the Figure 3 [59]. The long-term revival of shellfish farming along the entire Croatian coast was associated with numerous economic problems during the transition period. The bivalve farmers of Mali Ston Bay, whose production accounted for 90-95% of total Croatian shellfish production, were joined by the bivalve farmers of Krka estuary (Šibenik), the Novigrad Sea (Zadar) and the Lim Channel (Istria), who faced the similar problems in this sector.

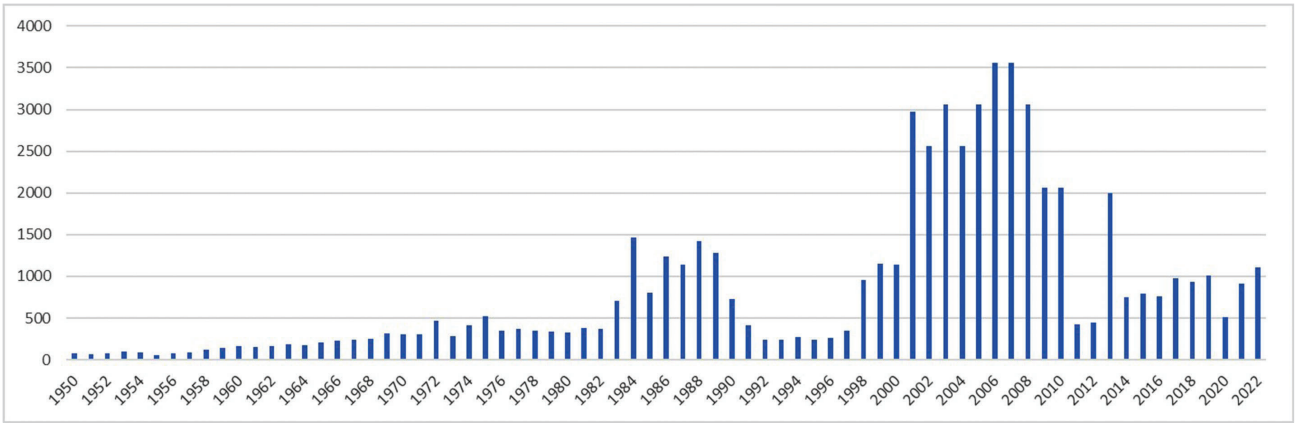

Figure 3 Bivalve aquaculture production in Croatia from 1950 to 2022 (according to FisFAO [59])
Slika 3. Proizvodnja školjkaša u akvakulturi u Hrvatskoj od 1950. do 2022. (prema FisFAO [59])

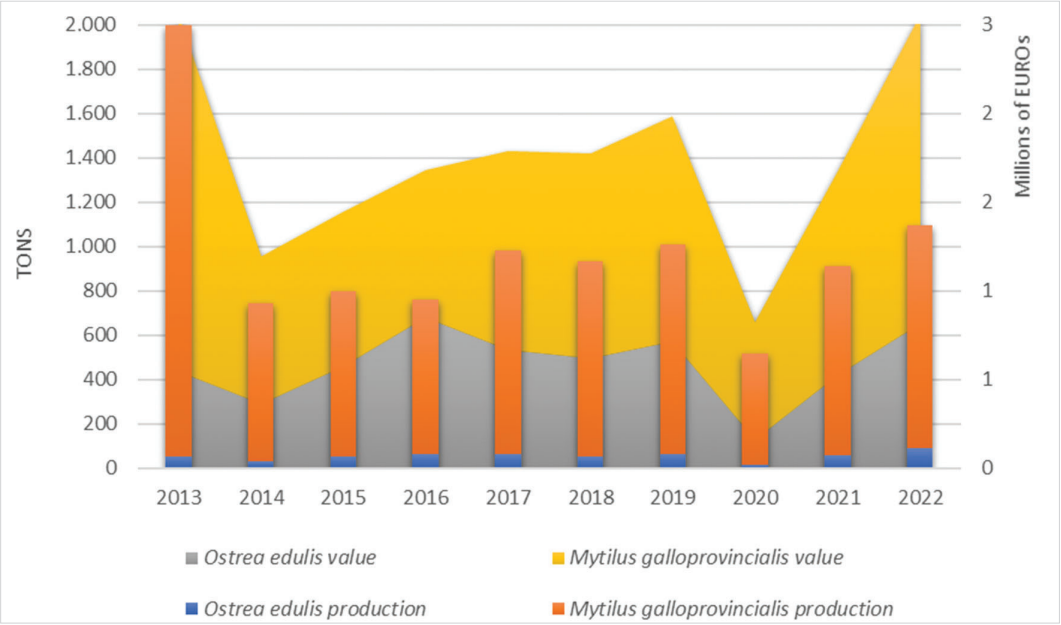

Figure 4 Bivalve aquaculture production in Croatia 2013-2022 – live weight and value by species (according to EUSTAT [44])
Slika 4. Proizvodnja školjkaša u akvakulturi u Hrvatskoj 2013.-2022. – težina i vrijednost po vrstama (prema EUSTAT-u [44])

Data on production, i.e. the quantity of shellfish sold, are collected from registered producers by the Ministry of Agriculture-Directorate of fisheries of the Republic of Croatia on the basis of Regulation (EU) 2017/1004 of the European Parliament [57]. This methodology differs from the methodology used before EU accession, which is reflected in the Figure 3 by a decrease and lower production since 2013. It is assumed that this data differs from the actual situation, as it does not consider shellfish that do not enter the market legally.

Quantitatively, much more mussels are farmed in Croatia than oysters, but since oysters fetch a significantly higher price on the market, they account for a significant share of aquaculture profits. The price ratio of mussels to oysters is relatively stable (Figure 2). Most of the production is sold on local markets, especially in restaurants in tourist centers close to the farming areas.

In Croatia, only holders of an aquaculture license can operate a farm, regardless of whether it is a family company, a cooperative, a limited liability company or a joint stock company.

According to the Register of Aquaculture Licenses of the Directorate of Fisheries, 108 shellfish farmers were registered in 2022, 74 of them in the Dubrovnik area (Bay of Mali Ston), 20 in Istria (including Lim Channel), 9 in Zadar (Novigrad Sea), 4 in Šibenik (Krka estuary) and 1 in Split. The farms have a total area of 2,655,538 square meters, on which they were able to grow 11,136.27 tons of bivalves (Figure 3) [58]. The authorizations primarily list oysters and mussels as well as several scallop species. One grower is authorized to cultivate a number of bivalve species that live in marine sediments, but there are no conditions nor technologies for cultivation those species.

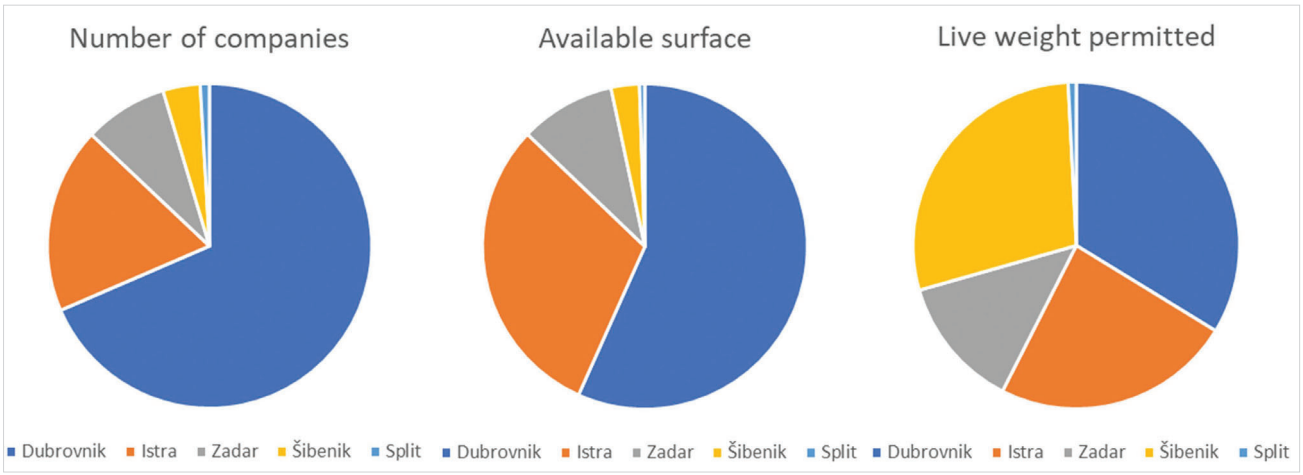

Figure 5 Companies, areas and quantities authorized for shellfish farming by zone (According to [58].)
Slika 5. Tvrtke, područja i količine ovlaštene za uzgoj školjkaša po zonama (prema [58].)

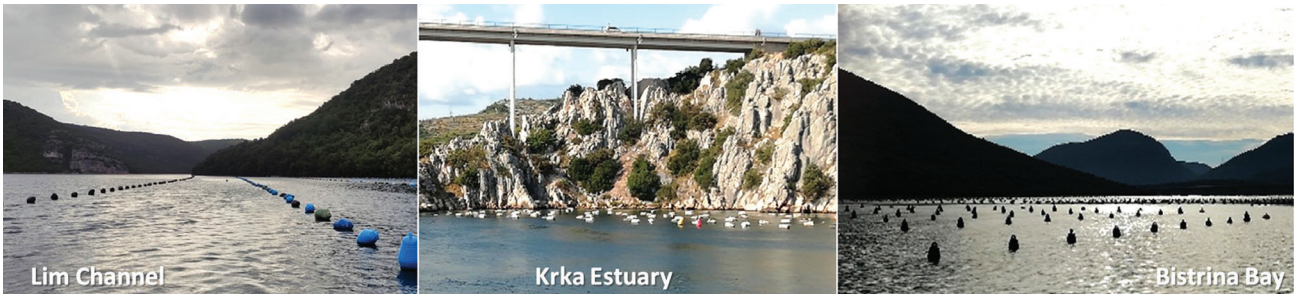

Figure 6 Long-lines along Croatian coast
Slika 6. Linije za uzgoj školjkaša duž hrvatske obale

Source: author archive

In the mentioned areas with favorable ecological conditions for bivalves, only the off-bottom is used – consisting of longlines (Figure 6) with various types of plastic bags, trays, lanterns or *pergolari* - oysters cemented to the ropes or mussels in plastic mesh tubes "socks" hanging from the suspended ropes which are also called *pergolari*.

As production is still based on wild spat, different types of collectors, are also being hung on the longlines. At the beginning of the 2nd millennium, the twig bundle *fashio* was still used to collect oyster spat; since the end of the 1980s, various plastic nets, plates and discs have been used regularly (Figure 7). The introduction of machines to remove the spat from the plastic disc collectors made it possible to collect a larger quantity of spawn and reduce the amount of work involved. For example, two women used to spend 8 hours removing oysters from a full *koltrina* (up to 15,000). With the introduction of disc collectors on a bar and a machine that simultaneously processes five collectors with well-populated discs, 25,000 oysters are separated and cleaned on the barge in site in 3 hours (M. Franušić pers. comm.).

As mussel spat is negatively geotropic, thick ropes suspended at the water surface are used to collect the mussel spat (Figure 7.d).

Although attempts to reproduce oysters in a controlled manner have been made, farming is still based on taking juveniles from natural populations, so the supply of spat is uncertain and fluctuates according to natural conditions, including the risks of ecosystem disturbance, that are becoming increasingly common. It is expected that the supply of hatchery spat will be secured in the future, which would allow for more predictable and efficient production.

Figure 7 Spat collectors: fashio (a bundle of branches), b. koltrine (curtains- a bunch of plastic nets between two iron bars; c. plastic discs on bars; d. a rope suspended on the sea surface with collected mussels
Slika 7. Kolektori za prikupljanje mlađi: fashio (svežanj grana), b. koltrine (zavjese – svežanj plastičnih mreža između dvije željezne šipke; c. plastični diskovi na šipkama; d. konop na površini mora sa skupljenim dagnjama

Source: author archive

Figure 8 Oysters in baskets and pergolari
Slika 8. Kamenice u košarama i na pergolarima

Source: author archive

The small oysters are separated from the collector after at least six months. Then, depending on their size and the conditions on the farm, they are either cemented on the pergolari or placed in various plastic baskets, sacks, trays or lanterns (Figure 8). Until they have reached market size, which takes 2-3 years, the oysters that are not on the pergolari must be thinned out. The usual market weight of an oyster is 80 grams (dozen in kilogram), but for some time now smaller oysters have also been sold (about 15 in kilogram). Oysters are only sold alive.

The spat of mussels remain on the collectors (suspended thick rope) for 6 months until it is 2 to 3 cm in size. It is then removed and placed in net tubes (*pergolari*) which are hung from long-lines. After about 6 months, the grown mussels are cleaned, sorted according to size and placed in net tubes with a larger mesh diameter and left in the sea until they have reached a marketable size of 5-7 cm. Depending on the location, it takes between 18 months and three years. After harvesting, the mussels are cleaned of impurities and biofouling, packaged and dispatched alive.

3.3. Consumers safety and bivalve's health / *Sigurnost potrošača i zdravlje školjkaša*

To ensure consumers safety and enable sustainable production of quality mussels, a procedure for monitoring measurable changes in the environment relevant to mariculture must be established to ensure the quality and health of the cultured organisms and to determine the quality of the farming environment. This includes monitoring measurable data indicating a source of pollution or measuring the impact of its influence on biological, chemical or physical changes in the environment.

In mollusk farming and rearing areas, monitoring is carried out in accordance with the Plan for monitoring the quality of the sea and mollusks in live bivalve mollusk production and rearing areas. The Plan is submitted each year [45]. It determines the microbiological quality, phytoplankton, biotoxins, metals, benzopyrenes, benzoanthracenes, benzofluoranthenes, chrysenes. The national program to monitor the prevalence of norovirus in oysters (*Ostrea edulis*) is carried out to prevent disease in consumers of raw oysters. To monitor the health of farmed bivalves themselves, the Health Surveillance Program for Aquatic Animals Susceptible to Infection with *Bonamia ostreae* and the Health Surveillance Program for Aquatic Animals Susceptible to Infection with *Marteilia refringens* are conducted. This is of great importance because the European production of *O. edulis* was almost exhausted when two diseases (*Marteilia refringens* and *Bonamia ostreae*) spread along the coasts in almost all traditional European farming areas in the early 1970s and 1980s. It's not known whether the flat oyster in Croatia is resistant or disease-free, but disease-related mortalities have never occurred [60,61].

All Croatian farms are subject to the national surveillance program for the detection of *Bonamia ostreae* and *Marteilia refringens* according to the Council Directive 2006/88/EC. The parasite *Bonamia exitiosa* was found in 13 samples of *Ostrea edulis* in different production areas in the north and south of the eastern Adriatic coast and in two samples of *Magallana gigas* in north, but no mortalities were reported from the infected sites. It therefore appears that the infection of flat oysters with *B. exitiosa* does not affect their health [60].

3. 4. Environmental issues / *Problemi zaštite okoliša*

Croatian shellfish farms are located in easily accessible, relatively shallow and sheltered places, rich in nutrient salts and with strong sea currents. Bivalve farming is generally considered to be ecologically sustainable. Bivalves filter and consume phytoplankton, excess nutrients, and suspended particles from the water. They also store carbon in their shells, which are composed of calcium carbonate. This process helps reduce carbon dioxide levels in seawater, making a small but positive contribution to mitigating ocean acidification [50].

However, biological waste and marine litter from shellfish farms can have a significant impact on the environment, especially if they are not managed properly. Shellfish farms sometimes accumulate broken or discarded shells, which can alter the composition of the seabed. This can smother benthic habitats and disrupt the natural ecosystem, especially for species that rely on soft sediments. In addition, biofouling macrofauna can cause organic enrichment, which can lead to nutrient overload, promote anaerobic conditions and affect benthic organisms [62]. Controlling the density of shellfish farms can prevent excessive accumulation of organic waste and reduce nutrient overload [63].

As shellfish farms today often rely on plastic infrastructure such as ropes, nets, trays and buoys, these sometimes become marine litter. During extreme weather events such as swells, which are not uncommon in Mali Ston Bay, shellfish farms can become detached and be washed away. When plastic decomposes, it can break down into microplastics, which can be ingested by marine organisms and enter the food chain. Non-biodegradable materials that are frequently used and remain in the environment contribute to long-lasting pollution that affects ecosystems for years [64,65]. To reduce the environmental impact of marine litter, regular cleaning and maintenance of agricultural equipment could prevent the degradation of plastics and the accumulation of litter.

The impact of bivalve farming on the environment depends on the intensity of production and the management practices of the farms [63]. Although shellfish farming is often considered environmentally sustainable, it requires careful management to avoid negative impacts.

3.5. The Complexities and Challenges / *Složenosti i izazovi*

Apart from the occasional lack of a spat, the most pressing problem in recent years has been the gilthead sea bream (*Sparus aurata*). Although the gilthead sea bream has long been known as a major predator of oysters and mussels in Croatian farms [23, 66], it has caused enormous damage over the last twenty years. Farmers throughout the Mediterranean have reported massive losses of 90 to 100 % [67]. In addition to adapting farming techniques by protecting the bivalves with efficient nets (Figure 9), it would make sense to reduce predation pressure. In order to mitigate the damage to mussel farmers, the Republic of Croatia pays them compensation in accordance with the Regulation on the conditions, criteria and procedure for granting state aid for damage to mussel farms [68].

Although Croatian bivalve farms are off-bottom, which reduces the number of potential benthic predators of bivalves, there are numerous organisms that cause fouling. Biofouling is an undesirable accumulation of organisms on the shells of farmed bivalves and aquaculture equipment, which increases the weight, resulting in higher maintenance costs and the risk of equipment failure. The fouling competes with the bivalves for food and space and affects their growth rates and overall health. Some of these organisms weaken the mussels' position in the market and make them less attractive. These include the calcareous tubeworm *Spirobranchus triqueter*, which is firmly attached to the mussel shell and can hardly be removed, and more recently its invasive relative *Hydroides elegans*. Polycladic flatworms, a group of opportunistic animals, feed on commercial mussels and oysters and are considered pests in shellfish farming. The flatworm *Stylochus mediterraneus* was observed in a mussel farm in Istria, where it caused a high mortality rate [69]. Previously, an intensive invasion of the non-indigenous ascidian *Clavelina oblonga* was observed. *C. oblonga* interferes

Figure 9 Mussel protection with nets in Lim Bay
Slika 9. Zaštita dagnji mrežama u Limskom zaljevu

Source: author archive

with the opening of mussel valves, competes for food resources, impedes the acquisition of food and oxygen by reducing water flow, and increases the load on farm infrastructure [70].

More recently, the pergolari in the Lim Bay have been overgrown by a still undetermined green algae that prevents the free flow of water with oxygen and food, and the mussels are dying (E. Sošić pers. comm.).

Recently, there has been an increase in cases of shellfish mortality with an extremely high mortality rate, which is linked to the long-term increase in temperatures. Croatian bivalve farming depends on environmental conditions, which include food supply, water temperature and salinity. Temperatures of 30°C, which have been shown to affect *Mytilus galloprovincialis* and cause a mortality rate of up to 100 % [71] are not unknown in Adriatic coastal waters, so that could be a great challenge to Croatian shellfisheries.

Rising temperatures and ocean acidification are expected to increase the frequency and severity of mortality outbreaks, which could be triggered by the synergistic effects of two or more environmental stressors. Rising sea surface temperatures are thought to cause mass mortality in bivalves by reducing dissolved oxygen, promoting harmful diseases and increasing harmful algal blooms [72].

Although all Croatian coastal counties have included aquaculture in their spatial plans and have made progress in granting concessions at sea, there are still significant challenges remain in certain farming areas, particularly with regard to operational requirements on land, such as landing sites and working areas. These difficulties are largely due to competition for space and resources with other maritime activities such as fishing, tourism and recreation.

While shellfish farming often coexists well with tourism and agriculture, the shortage of labor is becoming an increasingly serious issue. Many shellfish farmers are associated with family businesses, which makes it even more challenging to find suitable workers. As in other sectors of the economy, solutions are being sought outside Croatia's borders and even outside Europe.

3.6. Celebrating Croatian Bivalves: Festivals and Traditions / *Obilježavanje važnosti hrvatskih školjkaša: svetkovine i običaji*

Croatian bivalves, especially oysters and mussels from the Adriatic Sea, are highly prized for their quality and flavor, as they benefit from the clean, nutrient-rich waters of the region. The commercial market for Croatian bivalves is primarily focused on local consumption and the almost insignificant export to neighboring countries. Branding often emphasizes the traditional, sustainable farming methods and the unique terroir of the Adriatic, especially in regions such as the Bay of Mali Ston, which is known for its valuable oysters. Mali Ston and Novigrad growers, aware of the importance of a strong brand identity, have completed the procedure for registering their products in the Register of Protected Designations of Origin and Protected Geographical Indications, which is valid for the entire territory of the European Union and guarantees consumers that they are buying an authentic product. Maloston oyster received a protected designation of origin in 2020 and Novigrad mussel in 2023. These labels will help position Croatian bivalves as high-quality and environmentally friendly products on the local and international market.

Croatia celebrates its rich shellfish heritage with various events focusing on local shellfish delicacies. The "St. Joseph's Day of Oysters" in Mali Ston, which takes place in March, is one of the most famous events where visitors can taste freshly harvested oysters. The festival showcases traditional oyster farming and offers wine tastings and cultural activities.

In Novigrad, "Novigrad Mussel Days" is all about the unique taste of Novigrad mussels, which are known for their slightly sweeter flavor thanks to the mixture of fresh and salt water in this area. The festival presents local culinary traditions and innovative ways of preparing mussels.

The Lim Bay "Oyster Day" is also dedicated to high-quality oysters. The event attracts gourmets who want to get to know the high-quality shellfish that thrive in the nutrient-rich waters of the Lim Bay.

These festivals promote Croatian bivalves and help to cement their reputation as first-class products on the local and international market.

4. CONCLUSION / *Zaključak*

The development of shellfisheries in Croatia, from prehistoric collection to modern aquaculture, illustrates the continued importance of shellfish in the region. Although bivalve farming faces challenges such as overfishing, habitat destruction and predation by species such as gilthead sea bream, it remains a valuable economic resource. The industry relies heavily on off-bottom techniques using longlines and collectors, with technological advances such as automated spat harvesting systems improving efficiency. However, the collection of natural spat remains critical and efforts to ensure a stable supply of hatchery spat will continue. Mussels are being farmed in larger quantities due to simpler and cheaper production methods, although oysters command higher market prices.

Strict regulations, including the Marine and Mollusk Quality Monitoring Plan, ensure sustainable production methods and consumer safety. Monitoring programs confirm that Croatian flat oysters are largely disease-free, making Croatia one of the few areas where *Ostrea edulis* is still produced. The shellfish farms are located in nutrient-rich waters with strong currents that support their ecological sustainability by filtering excess nutrients and sequestering carbon. However, if not managed properly, biological waste and marine litter from these farms can have a negative impact on the environment. Regular maintenance of the facilities is necessary to minimize the accumulation of organic waste and prevent plastic pollution.

In recent years, Croatian shellfish farms have had to deal with significant losses from gilthead sea bream, which has led to the use of protective nets and government compensation programs. Another major problem is the growth of organisms such as calcareous tubeworms and invasive green algae, which affect the operation of the farms and drive up maintenance costs. Rising temperatures have further exacerbated the situation by contributing to a high mortality rate in shellfish and increasing the presence of harmful microorganisms. In addition, the sector is facing operational difficulties on land, such as competition for space and labor shortages, which has prompted the industry to look for external solutions.

Despite these challenges, Croatian oysters and mussels, particularly those from Mali Ston and Novigrad, are renowned for their quality and enjoy Protected Designation of Origin and

Protected Geographical Indication status from the European Union. While Mali Ston and Novigrad have successfully marketed their products, increased production and marketing efforts in other regions could further improve the reputation of Croatian shellfish on local and international markets. Continuing sustainable practices and innovative solutions will be key to the long-term success of the Croatian shellfish industry.

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