Mariculture in Croatia: A Spatial Perspective
Marikultura u Hrvatskoj: prostorna perspektiva

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Abstract

Croatia has a highly indented coastline, favourable ecological conditions, proximity to the markets, and potential for further mariculture development. This research aims to determine the status of Croatian mariculture considering: distribution of fish and bivalve farms, total mariculture area, buffer zone, Internal Waters Utilization, nominal intensity, number of registered operators, and employees in the industry. The spatial database was created using manual vectorization from recent (2022/2024) Google Earth satellite imagery. The results show that marine farms in Croatia occupy 0.056% of the area of internal marine waters. Out of this, 53 % of the surface is dedicated to bivalve and 47% to fish farming. Croatia's total nominal intensity is 3.3 t/km of coastline in 2022. Farms are located in all coastal counties, with the largest occupied area in Zadar County (38.1%) and Dubrovnik-Neretva County (37.5%). Most of the national fish farming area is located in Zadar County (71%), while the largest area of bivalve farming (68%) is found in Dubrovnik-Neretva County. In Primorje-Gorski Kotar County, despite having the largest area of internal marine waters, only 4.3% of the total mariculture area is present. The analysis indicates that mariculture currently occurs in a tiny portion of internal marine waters and has generally lower nominal intensity than other Mediterranean countries. Although mariculture is present in all coastal counties, the distribution and productivity of farms is uneven. For future development, we suggest focusing on optimizing current production capacities and exploring innovative aquaculture practices to enhance sustainability and economic viability.

KEY WORDS
Mariculture
Spatial Analysis
GIS mapping
Counties
Croatia

Sažetak

Hrvatska ima izrazito razvedenu obalu, povoljne ekološke uvjete, blizinu tržišta i potencijal za daljnji razvoj marikulture. Ovim istraživanjem želi se utvrditi stanje hrvatske marikulture s obzirom na: distribuciju uzgajališta ribe i školjkaša, ukupnu marikulturnu površinu, zaštićenu zonu, korištenje unutarnjim vodama, nominalni intenzitet, broj registriranih subjekata i zaposlenih u industriji. Prostorna baza podataka stvorena je ručnom vektorizacijom iz nedavnih (2022./2024.) satelitskih slika Google Eartha. Rezultati pokazuju da morska uzgajališta u Hrvatskoj zauzimaju 0,056% površine unutarnjih morskih voda. Od toga je 53% površine namijenjeno školjkašima, a 47% uzgoju ribe. Ukupni nominalni intenzitet Hrvatske iznosi 3,3 t/km obale u 2022. Uzgajališta su smještena u svim priobalnim županijama, a najveću površinu zauzimaju u Zadarskoj (38,1%) i Dubrovačko-neretvanskoj županiji (37,5%). Najveći dio nacionalnog uzgojnog područja ribe nalazi se u Zadarskoj županiji (71%), dok je najveće područje uzgoja školjkaša (68%) u Dubrovačko-neretvanskoj županiji. U Primorsko-goranskoj županiji, iako ima najveću površinu unutarnjih morskih voda, zastupljeno je samo 4,3% ukupne površine marikulture. Analiza pokazuje da je marikultura trenutačno zastupljena u malom dijelu unutarnjih morskih voda i općenito ima manji nominalni intenzitet od ostalih mediteranskih zemalja. Iako je marikultura prisutna u svim obalnim županijama, raspored i produktivnost farmi neujednačen je. Za budući razvoj predlažemo fokus na optimizaciju trenutnih proizvodnih kapaciteta i istraživanje inovativnih praksi akvakulture kako bi se poboljšala održivost i gospodarska isplativost.

KLJUČNE RIJEČI
marikultura
prostorna analiza
GIS kartiranje
županije
Hrvatska

1. INTRODUCTION / *Uvod*

With global capture fisheries reaching their maximum and the demand for seafood rising, marine aquaculture presents an opportunity to meet growing needs and balance the supply and demand for protein. As a result, over the past 20 years, it has become one of the fastest-growing sectors worldwide [1 - 4] driven by governmental support and technological advancements [5]. This is also evident in the Republic of Croatia, a Mediterranean country with a relatively long tradition of cultivating marine organisms [6]. Croatia benefited from highly favourable marine environmental conditions and was among the pioneers in Europe in cultivating specific species for food and commercial purposes [7].

Today, mariculture is a highly strategic sector of the Croatian economy, supporting coastal and islands communities through year-round employment, and producing valuable highly nutritional products. It accounts for 87% of Croatia's total aquaculture production by volume and 95% by value. Between 2013 and 2022, production has a notable increase of 38%, reaching 23.101 tons [8]. Croatian mariculture encompasses the farming of finfish and bivalves. The crucial species of finfish are European

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sea bass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*), meagre (*Argyrosomus regius*) (classified as "White fish" in Croatia), and Atlantic bluefin tuna (*Thunnus thynnus*) [8]. Among bivalves, the most notable are the Mediterranean mussel (*Mytilus galloprovincialis*) and the European flat oyster (*Ostrea edulis*). White fish farming primarily occurs in floating cages, and involves a closed farming cycle, from controlled breeding to the final product [8]. Atlantic bluefin tuna farming is exclusively carried out in floating cages within Zadar, Šibenik-Knin and Split-Dalmatia counties [9], where captured juvenile wild tuna are cultivated to the market size. Bivalve farming is predominantly a small-scale, family-run activity, utilizing traditional methods such as longlines [10]. This sector is based on the collection of spat from the wild, reflecting a more sustainable, low-intensity approach to mariculture. Mariculture products are sold on the local, or exported to the international markets (predominantly Italian and Japanese) [10].

Croatia's indented coastline, marine ecological conditions, high-quality seawater, and proximity to key markets provide significant potential for mariculture development. Recognizing this potential, significant efforts have been made to improve the administrative and legal framework governing the sector. The industry is regulated by *Aquaculture Act*, along with the *National Aquaculture Development Plan (2021-2027)*, with the main strategic goals to enhance competitiveness and increase overall production, while adhering to the principles of economic, social, and ecological sustainability [10, 11]. The licensing process has been simplified, and potential mariculture sites have been assessed and integrated into spatial plans. Furthermore, *Integrated Coastal Zone Management* has been implemented in most of the counties to avoid conflicts with other activities, such as tourism [12, 14]. Despite the sector's substantial growth, detailed public maps of mariculture production sites are still scarce [4].

Mapping and analysing the spatial distribution and capacity of mariculture are crucial for understanding the interactions between the farming and environment, optimizing farm locations, and planning the sector's further sustainable development [4]. This article describes the current status of marine aquaculture in Croatia, and explores the spatial distribution of different mariculture activities across all coastal counties with the goal to contribute to a more informed foundation for future spatial planning and sustainable development.

2. STUDY AREA / *Područje istraživanja*

Croatia's coast lies along the eastern coast of the Adriatic Sea, the northernmost and semi-closed part of the Mediterranean (Figure 1) divided into three distinct zones based on depth: the shallow Northern (less than 35 meters), the Central (less than 140 meters), and the Southern Adriatic, where depths can reach up to 1.228 meters [15]

Variations in depth influence the sea's physical, chemical, and biological characteristics. The salinity of the Adriatic Sea is higher than the global average, at 38‰ (Kraus et al., 2018). Southern and Central Adriatic has a typical Mediterranean climate with hot summers (Csa), while the Northern Adriatic has a prevailing humid subtropical climate (Cfa). Surface water temperatures range from 22 to 25 °C in summer and 6 to 15 °C in winter. Despite these seasonal temperature fluctuations, deeper waters maintain a stable temperature of 11 to 12 °C year-round due to the constant exchange of water with the Mediterranean Sea. Sea currents in the Adriatic are of low intensity, flowing along the Greek, Albanian, Montenegrin, and Croatian coasts and returning along the Italian coast. The dominant winter winds are from the south (jugo/*sirocco*) and north-east (bura/*bora*). The average warming rate in the Mediterranean Sea from 1980's was 0.38 °C per decade, more than three times higher than the global average of 0.11 °C per decade, and correlated to several mass mortality of wild organism events in the region [16].

Islands in the Croatian part of the Adriatic Sea are distributed unevenly along seven coastal counties: Istria (IST), Primorje-Gorski Kotar (PG), Lika-Senj (LS), Zadar (ZD), Šibenik-Knin (SK), Split-Dalmatia (ST), and Dubrovnik-Neretva county (DU). Total coastline length is 5.835 km, with approximately 70% attributed to islands and 30% to the mainland [17]. The Croatian internal waters have an estimated area of 12.845 km^2 and surround 1.246 islands, two peninsulas (Pelješac and Istria), and numerous islets, reefs, bays, and coves [18]. The diversity and extent of the coastline offer a variety of environments suitable for different types of mariculture. The main nutrient inputs to the Adriatic Sea come from surface runoff, underground water and urban discharges, and aeolian inputs [15, 19]. Main rivers that flow to the Adriatic basin are the Krka (ŠK), Zrmanja (ZD), Neretva and Cetina (ST), Raša, Mirna, and Dragonja (IST). The influx of freshwater from these rivers can influence salinity levels and nutrient concentrations in the coastal waters supporting the growth of certain mariculture species [20].

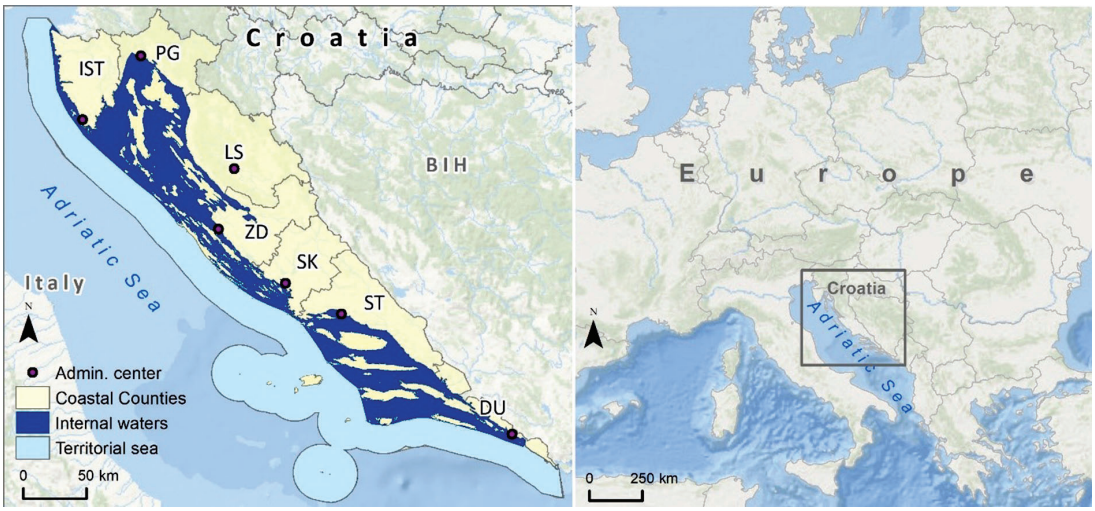

Figure 1 Study area, seven coastal counties (IST – Istria, PG – Primorje-Gorski Kotar, ZD – Zadar, DU – Dubrovnik-Neretva, ST – Split-Dalmatia and ŠK – Šibenik-Knin County)

Slika 1. Područje istraživanja, sedam obalnih županija (IST – Istarska, PG – Primorsko-goranska, ZD – Zadarska, DU – Dubrovačko-neretvanska, ST – Splitsko-dalmatinska i ŠK – Šibensko-kninska županija)

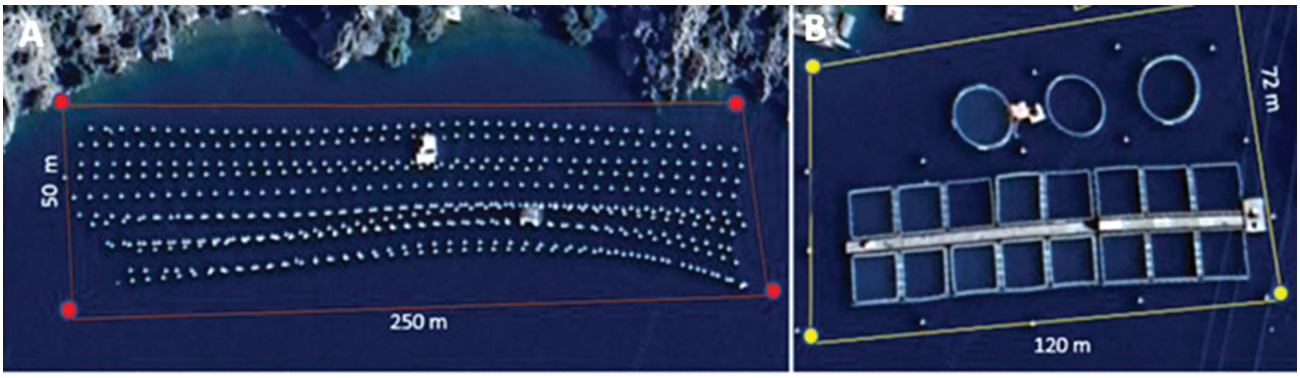

Figure 2 Examples of vectorised polygons from good celerity satellite imagery (A - bivalve farm, B - fish farm)
Slika 2. Primjeri vektoriziranih poligona iz satelitskih snimaka dobre brzine (A – uzgajalište školjkaša, B – uzgajalište riba)

3. METHODOLOGY / *Metodologija*

To assess and consolidate the distribution and utilization of mariculture in Croatia within a GIS framework, information on mariculture sites was systematically collected and centralized in ArcMap 10.1 using manual vectorization from recent Google Earth (GE) satellite imagery (2023/2024). The primary goal was to centralize spatial data within GIS to support spatial analysis. ArcMap enables the integration of databases and spatial analysis providing an effective platform for managing and analysing the status and distribution of mariculture. In instances where most recent imagery was compromised by cloud cover or other visibility issues, earlier images with superior clarity from the period from 2020 to 2023 were utilized. Mapping was conducted at a scale of 1:3000 and presented in HTRS96 coordinate system. Each mariculture site, regardless of ownership or operator, was delineated as a separate polygon (Figure 2) except in Bistrina Bay (DU) where almost the whole bay utilized for maricultue, so is treated as one polygon. The boundaries of each site were determined based on the edges i.e. positions (x,y) of buoys visible in the GE imagery (Figure 2). The polygons were classified into two categories based on the type of mariculture production: fish farms and bivalve farms.

To support analysis GIS vector data was combined with data derived from the *Mariculture Permit Register* (2022), an official Croatian database (Excel) that provides an overview of mariculture licences, type of mariculture, species, locations of cages, maximum annual allowable production etc. The created spatial database was used to conduct a comparative analysis of mariculture sites in seven coastal counties (Figure 1), considering the following variables:

- Mariculture Area and Buffer Zone (50 and 300 meters)
- Internal Waters Utilization (IWU) for mariculture (%)
- Nominal intensity of the mariculture (tones per km of coastline)
- Number of registered operators
- Number of employed persons in industry per County

The mariculture area was calculated based on each type of mariculture farm. To represent the protection zones around farms, linear buffers were created in GIS, with a 50-meter buffer for bivalve farms and a 300-meter buffer for fish farms. This zones are regulated by the Act on Sea Fisheries (Official Gazette, 62/17, 130/17, 14/19, 30/23, 14/24) and represents restriction areas surrounding mariculture sites, established to protect marine ecosystems [21]. Within these zones, activities such as fishing and tourism are restricted, aligning with ecosystem preservation objectives. To ensure the accuracy of the buffer zones, areas overlapping with land were removed using the *Erase* tool. Additionally, to compare the area of the mariculture buffer with the buffer zones of other areas that have similar restrictions, the National Parks layer was derived by the manual vectorization from WMS service Bioportal [22].

Internal Waters Utilization (IWU) was calculated to assess the level of exploitation by mariculture and is expressed as percentage. Internal waters are usually highly suitable for mariculture due to numerous shelters and proximity to harbours [23]. However, this zone is under significant pressure from various coastal and marine activities, making their management crucial. Data on Internal Waters were obtained in the form of a shapefile created by the Flanders Marine Institute [24].

The nominal intensity of coastline used for mariculture is measured as tonnes of production per kilometre of coastline. Although this is crude measure on the national level due to uneven distribution of mariculture farms, it provides a baseline for minimum coastal utilization for mariculture activities at a county level [2]. To estimate nominal intensity, data on annual mariculture production per county for the year 2022 was obtained from the *Ministry of Agriculture, Forestry, and Fisheries*. While data was received for all other counties, the information for ST and LS County has been aggregated for reporting purposes, in accordance with the Official Statistics Act (NN no. 25/2020). The coastline length was obtained from the SRPJ created by the Administrative Geodetic Organization (DGU) [25].

Number of registered operators is derived from *Mariculture Permit Register* (2022) using filters to extract active operators [9]. Number of employed persons in industry was obtained from the *Ministry of Agriculture, Forestry, and Fisheries* for the 2022 [8]. This number refers exclusively to individuals directly employed in mariculture (involved in the production processes). Data for ZD, ST and LS in table was aggregated. This type of data combined with mariculture income, production, and area is used usually for estimating efficiency of the sector [26].

4. RESULTS / *Rezultati*

4.1. Mariculture Area and Internal Waters Utilization / *Područje marikulture i korištenje unutarnjim vodama*

Mariculture in Croatia shows distinct regional variations, reflecting the diverse ecological and economic landscapes. The

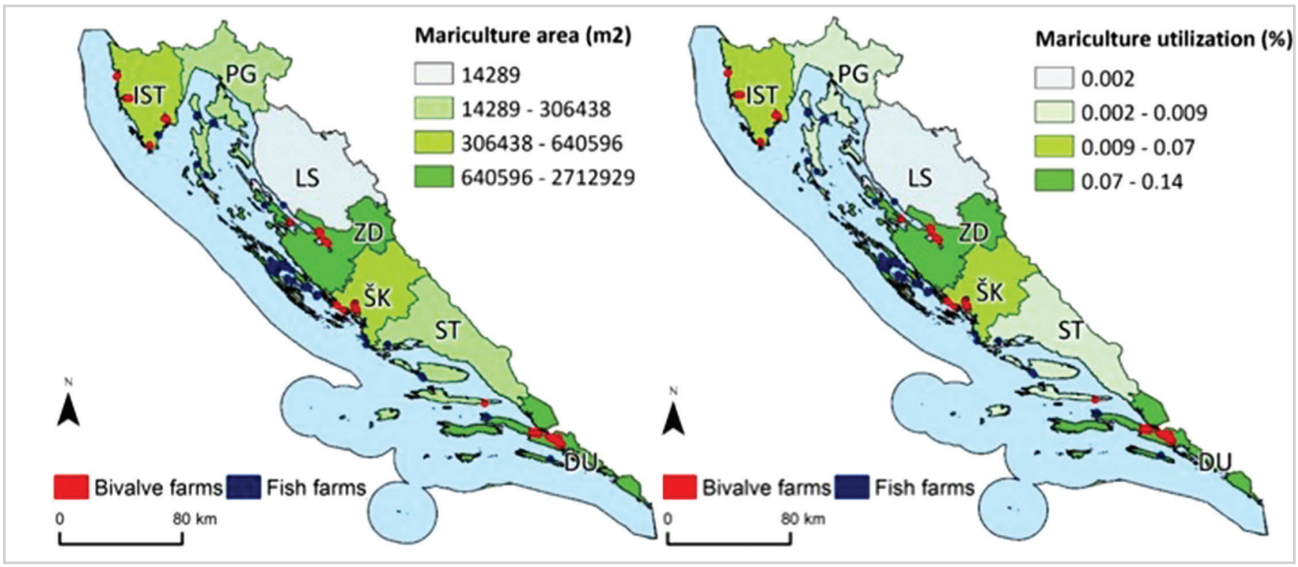

Figure 3 Mariculture area per County (left), and Utilization of Internal Waters (IWU) by mariculture
Slika 3. Marikulturno područje po županijama (lijevo) i korištenje unutarnjim vodama (IWU) prema marikulturi

total area dedicated to mariculture spans approximately 7.12 million m^2, with notable differences in practices and outputs among the seven coastal counties (Figure 3). At national level bivalve farming slightly predominates, occuping 53% of mariculture area, while fish farming is represented with 47%. In total, mariculture is occupying 0.056% of the internal coastal waters (Table 1). However, including the buffer area around fish (300 m) and bivalve farms (50 m) the total area of mariculture zone is 40.33 million m^2, which is 0.3% IWU. From this point of view fish farming is dominant in mariculture landscape (75%). In comparison, buffer zone of marine national parks (Kornati, Mljet, Brijuni) stands with IWU of 1.9%.

ZD holds the largest mariculture area in Croatia, accounting for 38.1% of the total. It leads in fish farming, with 70% of Croatia's fish farms located within its borders, and it also has the highest IWU at 0.14%. DU County nearly matches Zadar in mariculture area, with 37.5% of the total. However, its industry predominantly focuses on bivalve farming, representing 67% of the national bivalve farms, and IWU at 0.11%. Although Istria comprises only 9% of Croatia's total mariculture area, it is the second-largest region for bivalve farming, encompassing 14% of the country's bivalve farm area, with IWU of 0.07%. PG County has the largest area of internal marine waters, yet it contributes just 4.3% to the total mariculture area, with a low IWU of 0.009%. In contrast, LS County possesses the smallest share of internal coastal waters, limiting its potential for large-scale mariculture. It hosts only one farm, accounting for just 0.2% of Croatia's total mariculture area, with an IWU at 0.002%.

Table 1 Area of bivalve farms, fish farms, total mariculture and Internal marine waters per County
Tablica 1. Površina uzgajališta školjkaša, ribogojilišta, ukupne marikulture i unutarnjih morskih voda po županijama

	Mariculture in Croatia						
	Bivalve farms		Fish farms		Total		Internal Waters
County	m^2	%	m^2	%	m^2	% *	m^2 % * *
Dubrovnik-Neretva	2540035.2	94.9	136191.6	5.1	2676227	37.6	2419101092 19.2
Istria	525792	82.1	114804.2	17.9	640596	9.0	908857127 7.2
Lika-Senj	0	0.0	14289.8	100	14290	0.2	649975258 5.2
Primorje-G.Kotar	0	0.0	306438.3	100	306438	4.3	3339405759 26.5
Šibenik-Knin	294085.8	54.0	250755.6	46.0	544841	7.7	958943927 7.6
Split-Dalmatia	59145.2	26.5	164409.9	73.5	223555	3.1	2348071281 18.7
Zadar	338605.6	12.5	2374323.9	87.5	2712930	38.1	1960551541 15.6
Total	3757663.9	**52.8**	3361213.3	**47.2**	7118877	**100**	12584905985 **100**
Buffer	5428540	**16.3**	27780225.7	**83.7**	33208766	**100**	
Farms with buffer	9186204.0	**22.8**	31141439.0	**75.7**	40327643	**100**	

* Percentage of mariculture of each county in total mariculture area
* * Percentage of internal waters of each county in total internal waters

Table 2 Mariculture direct Workforce, Active Licenses, and Production by County (2022)
Tablica 2. Izravna radna snaga u marikulturi, aktivne licence i proizvodnja po županiji (2022.)

	Direct work force		Active Licences		Production in 2022		
County	**Permanent**	**Seasonal**	**N**	**%**	**Fish (t)**	**Bivalve (t)**	**Total (t)**
Dubrovnik-Neretva	77	22	77	53	257	540	796
Istria	60	7	21	15	1470	308	1778.7
Lika-Senj	*	*	1	1	1518**	0	1518.3**
Primorje-G.Kotar	57	5	4	3	1720	0	1720.3
Šibenik-Knin	164	8	16	11	1428	72	1499.3
Split-Dalmatia	*	*	3	2	**	0	**
Zadar	576*	16*	22	15	15611	176	15787.3
Total	**934**	**58**	**144**	**100**	**22005**	**1096**	**23100**

* Value is aggregated (ST, ZD,LS)

* * Value is aggregated (ST and LS)

4.2. Mariculture Workforce, Licences and Production / *Radna snaga u marikulturi, licence i proizvodnja*

The distribution of mariculture workforce, licenses, and production across Croatia is uneven. The total production of mariculture in Croatia amounted to 23,100 tons in 2022, of which 95% was fish (Table 2). In total, Croatia has 144 registered mariculture operators (active licences), with the highest concentration in DU County (53%), where bivalve farming predominates (Table 2). The total number of directly permanently employed workers in mariculture production activities is 934. It must be noted that this number refers exclusively to individuals directly employed in mariculture, i.e., involved in the production processes. However, mariculture also relies on support from sectors such as logistics, distribution, fish and bivalve processing. ZD far surpasses all other counties, producing 15,611 tons of fish and 176 tons of bivalves, contributing nearly 68% of the total production (Table 2). This clearly positions ZD as the leading county in mariculture, particularly in fish farming. ZD aggregated with ST and LS has 576 permanent employees, which is significantly more than in all other counties together. This reflects a major hub of mariculture activity, supported by a moderate number of seasonal workers (16), suggesting both a large and stable mariculture.

DU has the highest production of bivalve in Croatia (540 t), however, in total it has produced 756 tons of products, representing only 3.4% of the country's total mariculture output (Table 2). DU stands out with 77 permanent employees and 22 seasonal workers, indicating a stable workforce. The equal number of permanent staff and concession holders (77) suggests that each concession may directly manage their labour force, with a reliance on seasonal employment to support peak period.

IST is the second most productive region in Croatia. It has smaller mariculture area compared to DU, but still boasts substantial production of 1,779 tons. This is primarily due to fish farms, which account for 83% of production. IST has 60 permanent employees and seven seasonal workers, which reflects a stable workforce (Table 2). Other counties, such as ŠK and PG, also contribute significantly to national production. ŠK achieved 1,499 tons, representing 6.5% of the total output, while PG produced 1,720.3 tons i.e., 7.4% (Table 2). In PG there are four active licences, 57 permanently employed staff and 5 seasonal workers. The low number of concession holders relative to employees' hints at larger maricultural operations per concession, potentially requiring a more consistent workforce with less need for seasonal adjustment. ŠK has a remarkably high number of permanent employees (164) and 16 concession holders (Table 2). Despite its size, the county relies less on seasonal workers (8). LS, despite having only a single license and minimal employment, reports aggregated production of 1,518 tons of fish. However, it is important to note that this value is aggregated, which obscure more detailed insights.

4.3. Nominal intensity of mariculture / *Nominalni intenzitet marikulture*

Croatia's total mariculture intensity in 2022 stood at 3.3 tons per kilometre of coastline, but this broad figure hides significant regional variation. ZD dominates in production with 10.5 t/km, underscoring its role as a national mariculture hub (Figure 4). In contrast, despite its vast mariculture area, DU County shows a modest intensity of just 0.7 t/km, highlighting the potential underutilization of its resources. In IST, mariculture intensity is at 3.1 t/km, while ŠK maintains a moderate intensity of 1.7 t/km. PG, focusing exclusively on fish farms, records a similar figure at 1.63 t/km. The aggregated regions of SD and LS counties lag slightly, with a combined intensity of 0.87 t/km (Figure 4), reflecting lower overall production than other regions (Figure 4).

4.4. Spatial distribution of Mariculture / *Prostorni raspored marikulture*

4.4.1. Zadar County / *Zadarska županija*

ZD County is the leader in fish farming. Out of a total of 2.71 million m^2 used for mariculture, 88% is allocated to fish farms, which is the largest proportion compared to other counties (Figure 5). In contrast, bivalve farming occupies only 12% of mariculture in Zadar, which is a relatively small share when compared to other regions**.**

Fish farms in ZD are predominantly located around Dugi Otok, Ugljan, Pašman, and Iž islands (Figure 5). The zone of high mariculture intensity (Z_1) is encompassing the waters around the islands of Košara and Žižanj, within the region of Pašman.

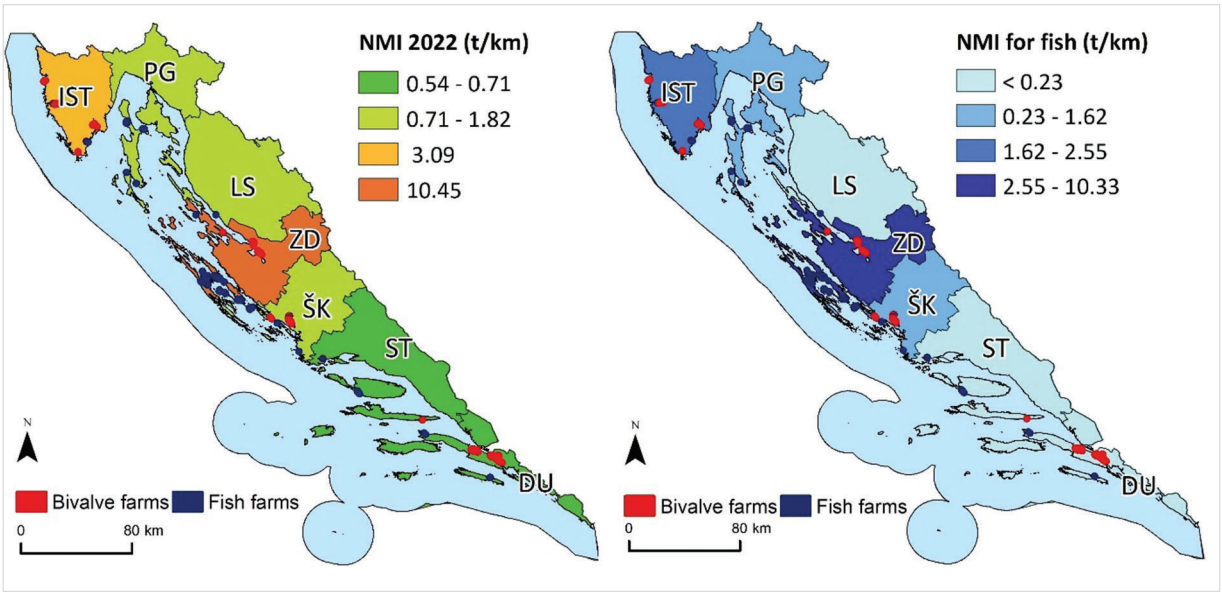

Figure 4 Total Nominal Intensity per County (left), and nominal intensity of fish production (right)
Slika 4. Ukupni nominalni intenzitet po županiji (lijevo) i nominalni intenzitet proizvodnje ribe (desno)

All farms are strategically sheltered from the wind, with none oriented towards the open sea. In ZD it is allowed to cultivate European sea bass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*), common dentex (*Dentex dentex*), red porgy (*Pagrus pagrus*), meagre (*Argyrosomus regius*), sharpsnout seabream (*Diplodus puntazzo*), greater amberjack (*Seriola dumerili*), and European flounder (*Platichthys flesus*) [9]. For years, ZD has been the leading region in Croatia for Atlantic bluefin tuna (*Thunnus thynnus*) production which is currently operated under concessions granted to two companies, Jadran Tuna d.o.o. and Kali Tuna d.o.o. Atlantic bluefin tuna mariculture sites are primarily located on the southwest side of island Ugljan, near islands Zverinac and Lavdara Vela (Figure 5). Bivalve farming is concentrated solely in the Novigrad Sea, in the Velebit channel, and near the Pag Bridge. ZD is the only region in Croatia where the farming of sea sponge (*Spongia officinalis*) is registered, with this activity taking place near the island of Olib.

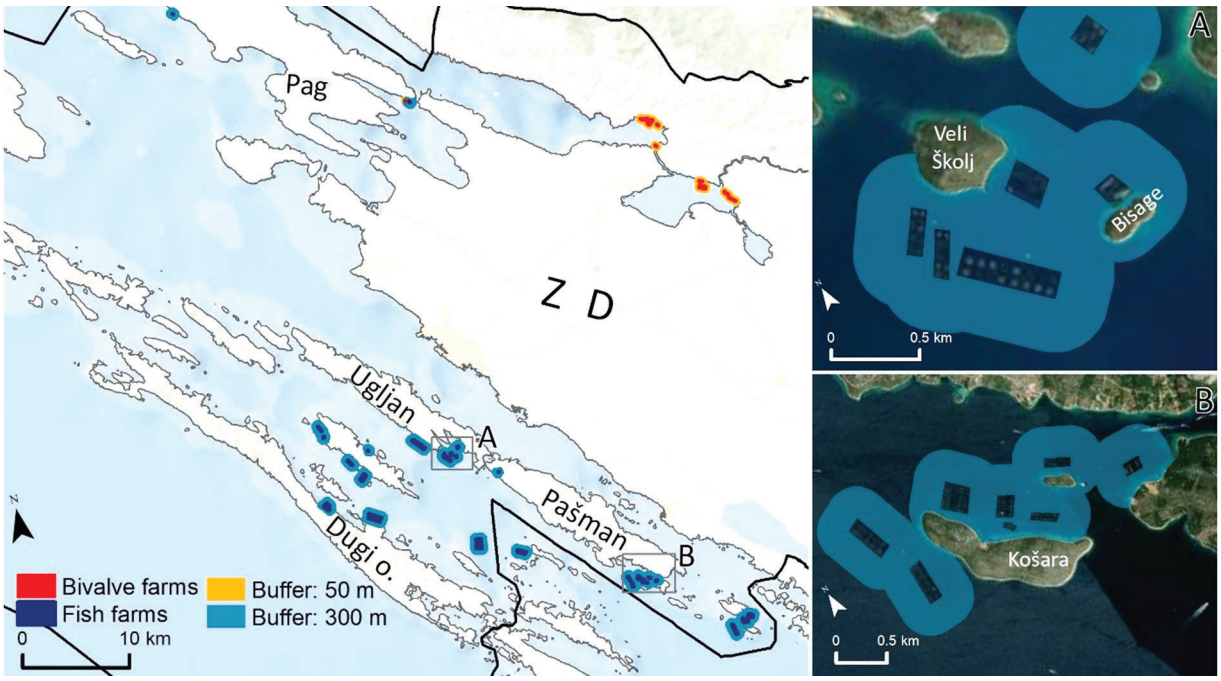

Figure 5 Mariculture in Zadar County
Slika 5. Marikultura u Zadarskoj županiji

4.4.2. Dubrovnik-Neretva County and Split-Dalmatia County / *Dubrovačko-neretvanska županija i Splitsko-dalmatinska županija*

In DU County, mariculture is covering 2.68 million m^2. Of this area, 95% is designated for bivalve farming, while only 5% is used for fish farming (Figure 6). The primary bivalve species farmed are Mediterranean mussels and oysters, with most farms located in Mali Ston Bay. Fish farms are located in the north-western part of the Pelješac Peninsula and on the northern side of the island of Mljet, near the small island of Galičnjak, which is within zone H2 (Figure 6). Zone H2 is an area where mariculture is given high priority, but other activities are also permitted [27]. In DU, among fish species, the following are permitted for cultivation: European sea bass, gilthead seabream, common dentex, meagre [9].

In ST County total mariculture area is 223,555 m2. Of this, 74% is allocated for fish farming and 26% for bivalve farming (Figure 7). Most fish farms are located on the southwestern side of the island of Brač. The allowed fish species for cultivation are mainly European sea bass, gilthead seabream, Atlantic bluefin tuna rainbow trout (*Oncorhynchus mykiss*), and brook trout (*Salvelinus fontinalis*), while bivalve farming in this region focuses on mussels and oysters [9], with the farms situated on the southeaster side of the island of Hvar. Tuna farming in this region is operated by one operator, Sardina d.o.o.

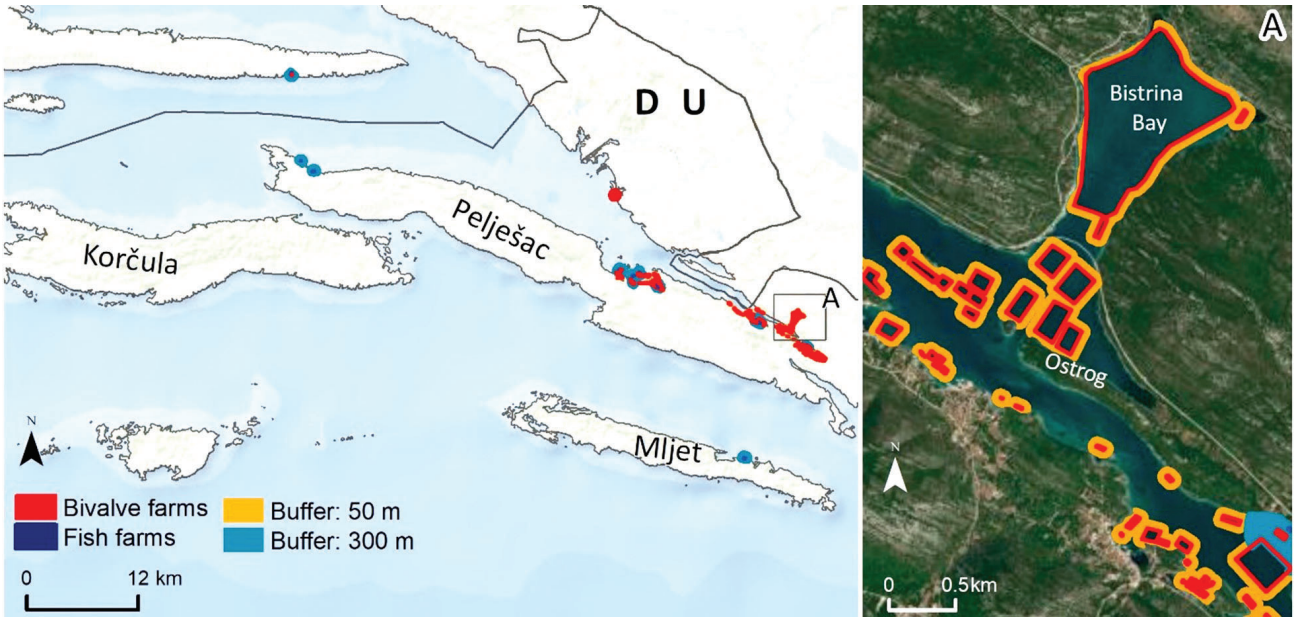

Figure 6 Mariculture in Dubrovnik-Neretva County
Slika 6. Marikultura u Dubrovačko-neretvanskoj županiji

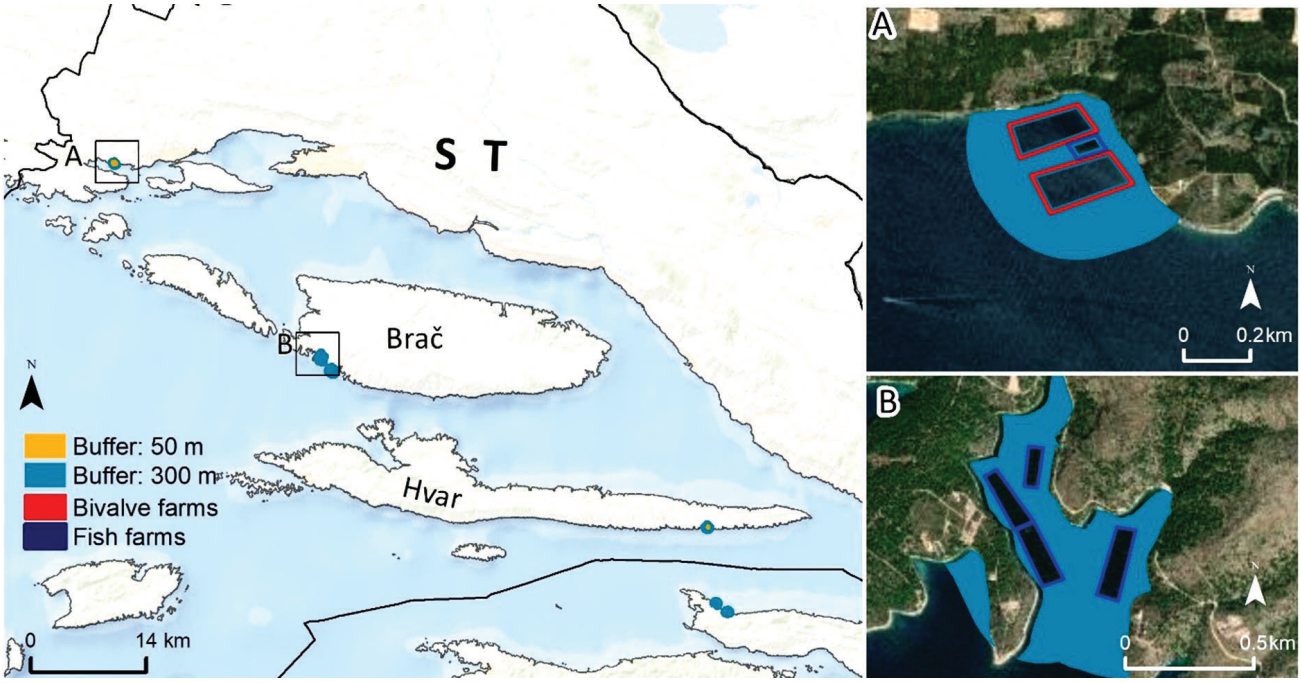

Figure 7 Mariculture in Split-Dalmatia (ST) and Dubrovnik-Neretva (DU)
Slika 7. Marikultura u Splitsko-dalmatinskoj (ST) i Dubrovačko-neretvanskoj županiji (DU)

4.4.3. Istria and Primorje-Gorski Kotar Counties / *Istarska i Primorsko-goranska županija*

In IST, mariculture is covering a total area of 640.596 m^2. It predominantly focuses on bivalve farming, which accounts for 74% of the total mariculture area (Table 1). The main species farmed include Mediterranean mussels and oysters primarily in Lim Bay, Medulin Bay, and Raša Bay (Figure 8). Additionally, small scallops are cultivated in Savudrija Bay. The allowed bivalve species for cultivation include Mediterranean mussel, flat oyster, warty venus clams, Mediterranean clam, creamy clams, and grooved carpet clam [9]. The permitted fish species are European sea bass, gilthead seabream, common dentex, red porgy, meagre, sharpsnout seabream, and European flounder. However, not all allowed species are cultivated [9].

In PG County, mariculture is covering 306.438 m^2 and is exclusively dedicated to fish farming, with farms located along the north-eastern and south-eastern coasts of the island of Cres and around Plavnik which is situated between Krk and Cres (Figure 8). The permitted species include European sea bass, gilthead seabream and rainbow trout [9].

4.4.4. Mariculture in Šibenik-Knin County / *Marikultura u Šibensko-kninskoj županiji*

In SK County, mariculture covers a total area of 544.841 m^2. Here is a balanced proportion of bivalve and fish farming, with a slight predominance of bivalve farming (52%) (Figure 9). Almost all bivalve farms are located in the submerged estuary of the Krka River, near Zaton, Šibenik, and Skradin. In the area of the municipality of Pirovac, bivalve is also cultivated, while in the municipality of Rogoznica, fish farms are present (Figure 9). The allowed species in this region include European sea bass, gilthead seabream, Mediterranean mussel, flat oyster and Atlantic tuna. South of island Balabra in municipality of Murter, tuna farms of high capacity is situated (max. allowed 1200 t) [9]. Tuna is operated by Pelagos Net Farma d.o.o company [9].

4.4.5. Mariculture in Lika Senj County / *Marikultura u Ličko-senjskoj županiji*

LS County is unique in the context of mariculture in Croatia, as it has the smallest area of internal waters and only one mariculture site dedicated to fish farming. This mariculture site is situated near Lukovo Šugarje (Figure 10) and covers a total area of 14.289,8 m^2, with the permitted species for cultivation being Rainbow trout and Atlantic salmon [9]. Despite its limited scale, the county represents a distinct aspect of Croatia's aquaculture landscape.

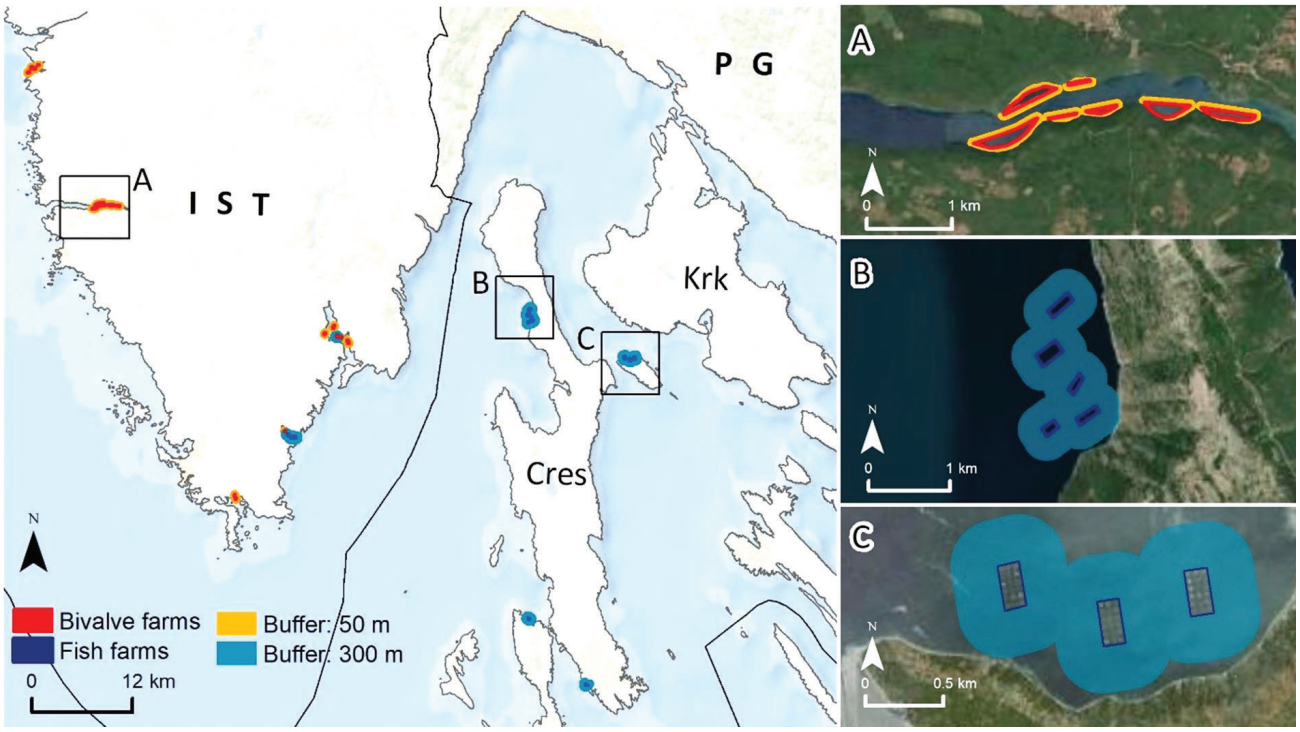

Figure 8 Mariculture in Istria (IST) and Primorje-Gorski Kotor (PG)
Slika 8. Marikultura u Istarskoj (IST) i Primorsko-goranskoj županiji (PG)

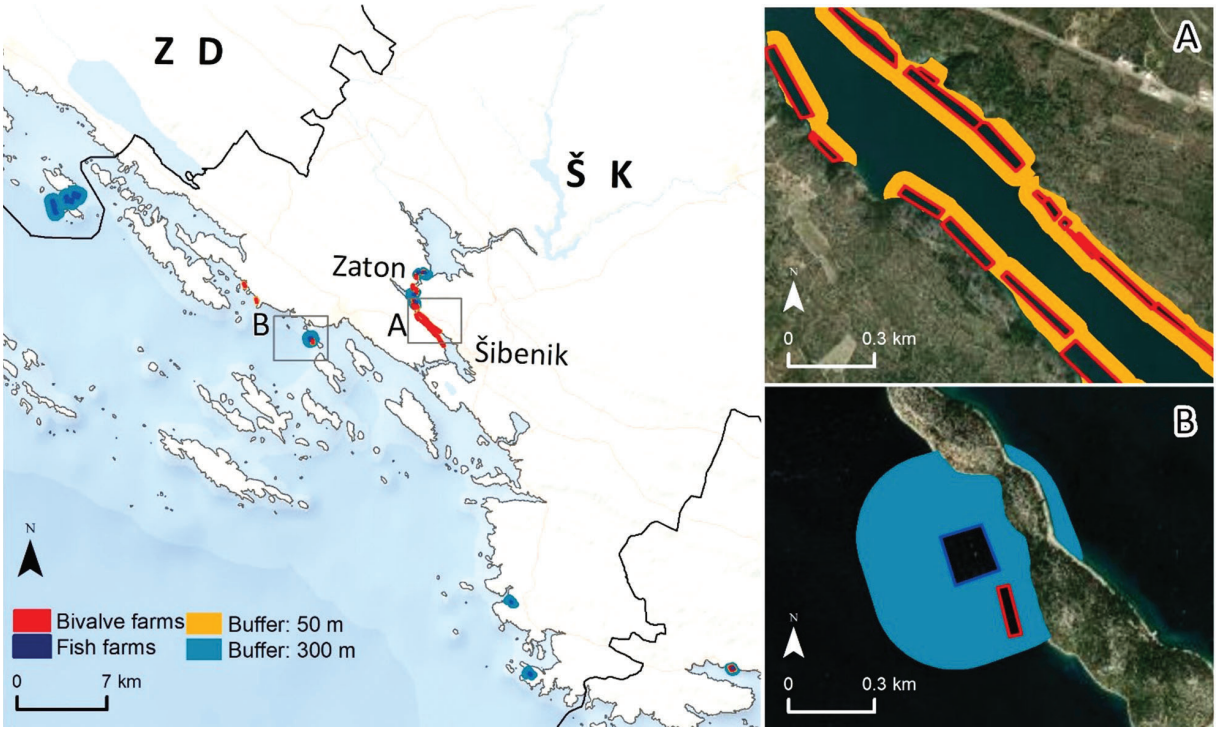

Figure 9 Mariculture in Šibenik-Knin (SK)
Slika 9. Marikultura u Šibensko-kninskoj županiji (SK)

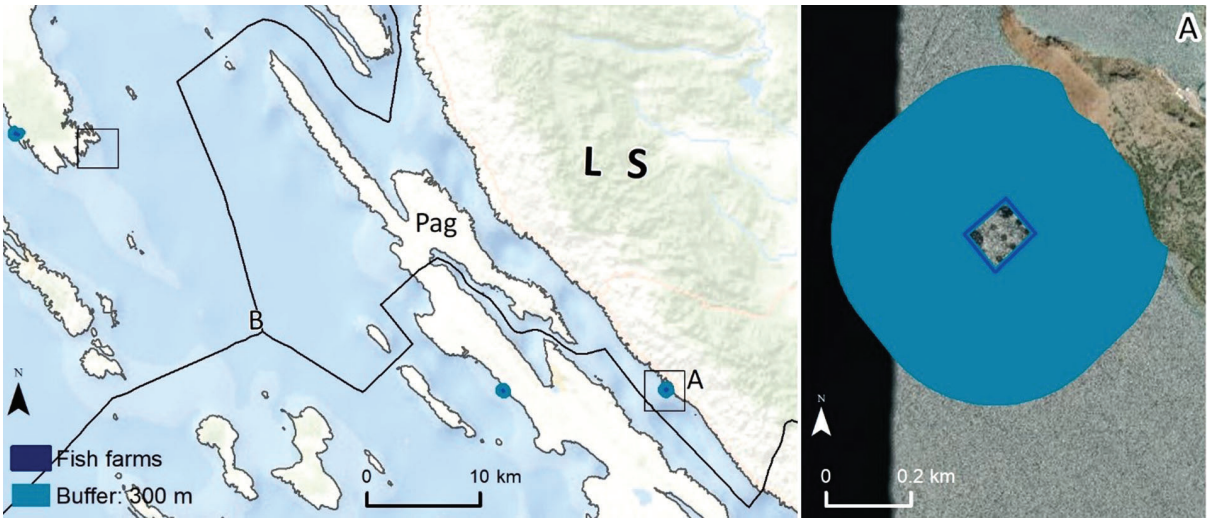

Figure 10 Mariculture in Lika-Senj County
Slika 10. Marikultura u Ličko-senjskoj županiji

5. DISCUSSION / *Rasprava*

The combination of high-resolution satellite imagery, manual vectorization, and available official data provides a robust framework for analysing the Status of mariculture in Croatia. However, certain limitations, such as visibility issues in satellite imagery and data aggregation in specific counties, must be addressed in future research. Additionally, limitations arise from the generated coastal line layers and the representation of internal waters. When vectorization is performed with a higher level of detail, it can sometimes result in discrepancies in measuring the length of the coastline or the area of coastal waters. These discrepancies occur because the detailed vectorization might capture the intricate shapes and features of the coastline more accurately than the official data. As a result, the lengths and areas derived from the vectorised data may not align with the measurements provided by official sources, which might use broader approximations or simpler methods for defining these boundaries. Consequently, the absolute values of the coastline length or coastal area may differ between the vectorized data and official sources due to discrepancies in detail, the proportional relationships among different areas, such as the size of fish farms relative to bivalve farms, are likely to remain unchanged.

The nominal intensity of mariculture production in Croatia is 3.3 t/km. In comparison to other Mediterranean countries, Italy has an intensity of 13.41 t/km, Greece 9.39 t/km, Portugal 2.67 t/km, and Bosnia and Herzegovina 6.91 t/km. On a global scale, the highest intensity is found in China (946 t/km) [28]. Mariculture

directly occupies 0.056% of Croatia's internal marine waters, however, the spatial footprint of mariculture extends beyond the farming areas themselves. It also encompasses broader zones aimed at protecting ecosystems and restricting other activities. This buffer zone area is higher than the mariculture area itself and occupies 0.3% of IWU. Additionally, when buffer zones are included, the area occupied by fish farms is significantly more extensive than bivalve farms.

This study highlights regional variations in the distribution and utilization of mariculture in Croatia, emphasizing the differences in farming types, spatial impact, and production output across coastal counties. ZD and DU counties leads in the mariculture area but with significant differences in production intensity and type of farming. ZD already has substantial mariculture intensity (10.4 t/km) while DU has significantly lower level (0.7 t/km), indicating untapped potential for future development. Generally, bivalve farms directly occupy larger coastal area but with a very low output in total production (52% of the total area but less than 5% of the total production). Bivalve production is challenged by several problems that have resulted in the long-term stagnation of the total production. In the EU, main challenges in mussel production include severe predation by gilthead seabream [29], harmful algal blooms, adverse weather, diseases, parasites, poor water quality, and pollution [30, 31]. The challenges are compounded by high summer temperatures and extremely low salinity in certain areas, which are a result of climate change [32]. Total output is only 1096 tons of registered production at farming area of 3.8 million $m^{2.}$ This is quite low, extremely extensive type of production, and one of the largest potentials for further development of aquaculture lies into more efficient use of this large areas with conditions that are suitable for bivalve farming. One of the potential ways to increase the bivalve production in the Adriatic Sea is the utilization of the IMTA concept [33], where filter feeders such as bivalve can be produced together within the fish farms. In the oligotrophic conditions of the Adriatic, several research proved the concept, and found equal production period for mussels grown close to the farms as in the commercial sites, and with higher condition index of Noah's ark (*Arca noae*) in the vicinity of the cages [34, 35]. This way, many problems such as predation and high temperatures that are present in current locations for bivalve could be mitigated. Additional benefits through remediation of a part of the nutrient loads from the farm, although more research is needed to provide the input of the potential of this concept to improve the ecological impact of the farms.

However, one of the challenges that should be addressed is the accuracy and consistency of production reporting, particularly in bivalve farming. Only accurate or complete reporting can lead to underestimating actual production levels, hindering proper assessment of the industry's potential and capacity for growth. Improved reporting practices would not only provide a clearer picture of the sector's performance but also enable more effective planning and management for sustainable development in mariculture.

ZD County effectively utilizes its available internal waters for mariculture, reflecting its dominant position in Croatia's fish farming industry. It is evident that the sea bass/ sea bream / meagre farming sector in Croatia made a significant progress during the last decade, while the tuna farming is slightly improved as the quotas for the wild stocks are increased. However, Atlantic bluefin tuna production is relatively stable, but with limited potential for full growth. Reasons are increasing production costs (feed, raw material, monitoring programmes) which potentially could impact the industry in future, especially with the lower price and fluctuation of the yen on the bluefin tuna major Japanese market [36]. Meagre, as a relatively new species in Croatian aquaculture, appears to be well adapted following initial cultivation challenges in cages [37] and is now produced in significant quantities.

Sustainable development of marine aquaculture will require minimization of its impacts on coastal activities and the environment. One of the ways to achieve is foreseen through moving the farms at more distance from the coastline – off shore aquaculture, which requires adaptation to the rougher environmental conditions through scientifically informed spatial planning and technology development [23]. So far, only one zone has been designated for offshore farming, with plans for testing in the coming years.

6. CONCLUSION / *Zaključak*

The significance of this paper lies in establishing a foundational spatial framework and creating a comprehensive spatial database for mariculture in Croatia. This data serves to understand the sector's current state and identify areas for improvement. The analysis reveals substantial regional disparities in the distribution and scale of mariculture, driven by environmental factors and local economic practices. The study particularly highlights the differences between ZD and DU counties, where most of the mariculture area is located. ZD more effectively utilizes its resources, while DU shows significant potential for growth, particularly in bivalve farming, which currently faces stagnation due to ecological challenges.

While the nominal intensity of mariculture production in Croatia remains lower than in other Mediterranean countries, it has improved compared to previous years. Currently, mariculture occupies only 0.056% of internal waters. However, the ecological footprint expands to 0.3% when considering buffer zones, underscoring the need for sustainable management practices.

Overall, the findings suggest that region-specific strategies are needed to optimize mariculture production, particularly in underutilized regions, while balancing environmental conservation efforts. The limited use of Croatia's internal waters for mariculture indicates significant potential for expansion, especially in underutilized regions. However, to enhance the development of aquaculture, we propose optimizing existing production capacities at first place rather than merely expanding mariculture areas. The emphasis on sustainability is crucial in balancing economic growth with environmental conservation in the mariculture sector. Implementing Integrated Multi-Trophic Aquaculture (IMTA) could facilitate the co-cultivation of bivalve and fish, optimizing resource use and improving ecological outcomes. Moreover, transitioning to offshore aquaculture may mitigate environmental impacts and enhance resilience in the face of climate change threats. Strategic investments in technology and sustainable practices could enhance production efficiency, support biodiversity, and bolster the economic impact of mariculture across the Adriatic coast.

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