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REVIEW PAPER

A review of reproduction biology and spawning/ nursery grounds of the most important Adriatic commercial fish species in the last two decades

Barbara ZORICA^{1*}, Vanja ČIKEŠ KEČ¹, Nedo VRGOČ¹, Igor ISAJLOVIĆ¹, Corrado PICCINETTI², Milica MANDIĆ³, Bojan MARČETA⁴ and Ana PEŠIĆ³

¹*Institute of Oceanography and fisheries, Šet. I. Meštrovića 63, 21000 Split, Croatia*

²*Laboratorio di biologia marina e pesca – Fano, Italy*

³*University of Montenegro - Institute of Marine Biology, Dobrota bb, P Box 69, 85330 Kotor, Montenegro*

⁴*Fisheries Research Institute of Slovenia, Spodnje Gameljne 61a, 1211 Ljubljana - Šmartno, Slovenia*

*Corresponding author: zorica@izor.hr

*Recently, despite long-term systematic research of the Adriatic Sea ecosystem, the necessity to improve the existing protection of commercially exploited species occurred since the status of many renewable marine stocks were not in good state. In order to realise that review of scientific knowledge gather within the last two decades was required. In this paper emphasis has been placed on all the scientific knowledge concerning the reproductive biology, spawning and nursery grounds of four ecologically and economically important Adriatic fish species – sardine *Sardina pilchardus*, anchovy *Engraulis encrasicolus*, European hake *Merluccius merluccius*, Common pandora, *Pagellus erythrinus*.*

Main aim of this review was to establish new scientific platform that in near future should result with better conservation measures that will insure long-term sustainability of exploited marine living resources.

Key words: sardine, anchovy, hake, Common pandora, spawning, Adriatic Sea

INTRODUCTION

In the Adriatic Sea, the northernmost shallow semi-enclosed basin in the Mediterranean, fishery is generally well developed and represent an important branch of its coastline countries economy. According to available official catch data within this area all fleet segments

(from small-scale fishery vessels to large trawlers) are present but due to obtained catches and its commercial values three types of fishing gears are highlighted – purse seiners and midwater trawlers targeting small pelagics and bottom trawlers targeting demersal fish (UNEP-MAP-RAC/SPA., 2014).

The Adriatic pelagic fleet targeting small pelagic fish species is consisted of purse seiners (eastern Adriatic) and midwater pelagic pair trawlers (western Adriatic). Two of the most abundant, ecologically and economically important small pelagic fish species are the sardine, *Sardina pilchardus*, and the anchovy, *Engraulis encrasicolus*. Both of them are widely distributed throughout the whole Adriatic Sea as well as in Mediterranean basin and along the area of the north-eastern Atlantic (WHITEHEAD *et al.*, 1988). Those small pelagic fish species are known as short-lived and fast-growing fish with protracted spawning season during which they tend to release their spawning products multiple times (MORELLO & ARNERI, 2009).

Contrary to pelagic fishery, Adriatic demersal fishery is targeting more than two species actually this type of fishery is known as multispecies. Among many targeted demersal fish species, the most important, by far, is European hake, *Merluccius merluccius* (Linnaeus, 1758), along with red mullet (*Mullus barbatus*), common sole (*Solea vulgaris*) and Norway lobster (*Nephrops norvegicus*). This nectobenthonic species is distributed throughout the Adriatic and entire Mediterranean Sea, while in the Atlantic region it is found from Norway to Mauritania (JARDAS, 1996; RELINI *et al.*, 1999). It is long-lived species and as a batch spawner (MURUA & SABORIDO-REY, 2003) tend to spawn throughout the year with two spawning peaks (KARLOVAC, 1965; JUKIĆ & PICCINETTI, 1987). Apart from European hake, within this review Common pandora, *Pagellus erythrinus* (Linnaeus, 1758), is analysed as commercially important benthopelagic fish species. Common pandora is widely distributed in the Mediterranean Sea, including its adjunct seas, and in the area of Atlantic from Norway to Angola. During the year it spawns between spring and autumn, with two spawning peaks (BAUCHOT & HUREAU, 1986).

Majority of commercially important fish species, among which the above-mentioned ones, are shared between the Adriatic countries. Studied fish stocks, except Common pandora, therefore are assessed and managed at the

regional level (GSA 17, GSA 18) by STECF and GFCM. Their biomass levels as well as their catches had fluctuated over the last two decades. Those fish abundance alternations observed in Adriatic and worldwide might be linked to many anthropogenic (JENNINGS *et al.*, 2001) and environmental factors (GRBEC *et al.*, 2015; BROSSET *et al.*, 2017). In order to comprehend those oscillations and to insure sustainable fisheries, scientists are rebuilding their knowledge concerning fish species biology, ecology and marine ecosystem in general. Since studied species are ecologically and economically important it is not possible to make comprehensive review covering all the issues and topics within one review paper. Hence, the main goal of this review was to investigate potential spawning and nursery grounds specified in the last two decades (since no literature review was given in the period) for herein reviewed Adriatic fish species.

The spawning and nursery grounds are essential areas where survival of early fish life stages is the most likely to occur. Selection of such geographical area is complex task that depends on numerous constraints referring to ecology and evolution (CIANNELLI *et al.*, 2014). Bearing in mind that climatic conditions have changed during the last couple of decades in the Adriatic (GRBEC *et al.*, 2015, 2018; ZVERYAEV & HANNACHI, 2017) devotion of the studied species to the same geographical area for spawning it was interrogative. This kind of investigation should also point out the possible gaps, changes and limitations in existing knowledge regarding the distribution of their early life stages in the Adriatic Sea. Gathered information might bring us closer to better understanding of the success and output of spawning at the end resulting with recruitment, that largely define renewal of fish population.

Study area

The Adriatic Sea (Fig. 1) is the northernmost semi-enclosed basin in the Mediterranean with a cyclonic circulation. The cyclonic circulation pathway is caused by the estuarine conditions, which are regulated by the northern Adriatic rivers (CUSHMAN-ROISIN *et al.*, 2001). Therefore,

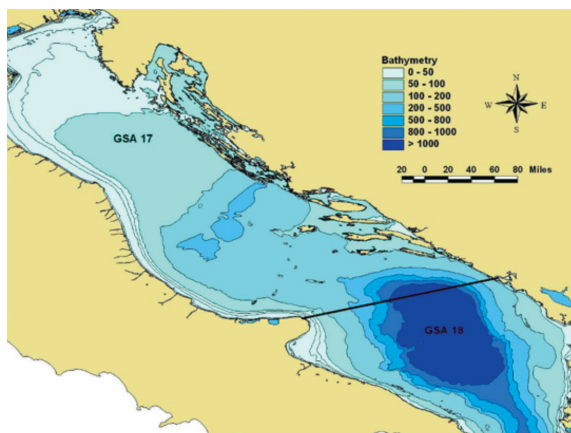


Fig. 1. Bathymetric map of Adriatic Sea with marked separation between GSA 17 and GSA 18

along the western side of Adriatic out flowing West Adriatic Current is noticed, while on its eastern side East Adriatic Current (ORLIĆ *et al.*, 2007) is bringing Levantine Intermediate Water (ROBINSON *et al.*, 1992; MALANOTTE-RIZZOLI *et al.*, 1997) from the Ionian and Levantine Seas. From time to time Levantine Intermediate Water can flood the Adriatic in so-called ingressions years (BULJAN, 1953) when increase in salinity, temperature and nutrients in intermediate layers are detected (BULJAN & ZORE-ARMANDA, 1979; TZIPERMAN & MALANOTTE-RIZZOLI, 1991; VILIBIĆ & ORLIĆ, 2001, 2002). In the Adriatic during the winter water column is homogenized due to substantial wind-mixing and winter surface cooling, while in summer, when wind mixing is very mild, Adriatic waters become highly stratified (BULJAN & ZORE-ARMANDA, 1976). This area due to its geographical position, previously described circulation pattern and the fact that is oligotrophic (MOZETIĆ *et al.*, 2010; KOVAČ *et al.*, 2018) is recognized as climate sensitive one. From 1950 to 2010 two climatic turning points (around 1987 and 1998) that separate relatively stable climate regimes were detected (GRBEC *et al.*, 2015).

Spawning and nursery grounds

Sardine, *Sardina pilchardus*

Sardine specimens inhabiting the Adriatic Sea tend to spawn from the beginning of the

October till the end of April and this has not changed over the last two or more decades (MORELLO & ARNERI, 2009; MUSTAĆ & SINOVIĆ, 2009; PEŠIĆ *et al.*, 2010; ZORICA *et al.*, 2016, 2017). The peak of sardine spawning, which mostly depends on environmental parameters such as temperature (11-16°C; MORELLO & ARNERI, 2009), occurs between November and February (SINOVIĆ *et al.*, 2008; PEŠIĆ *et al.*, 2010; PEŠIĆ, 2011; ZORICA *et al.*, 2017; 2019). As many other clupeid species, sardine is a “batch” spawner with indeterminate fecundity which individuals reached their sexual maturity at 8.0 cm of total length (SINOVIĆ *et al.*, 2003). During the reviewed period few studies on early life stages were done and their results are presented in Table 1. Bearing in mind peaking of sardine spawning, it was expected and also confirmed that the largest number of eggs and larvae were found during the colder part of the year (Table 1). Although sardine early life stages were found along the whole eastern part some areas with their higher abundances were noted and defined as most probable sardine spawning grounds like Kvarner area, area beyond the Island of Dugi otok, outer part of mid-Dalmatian islands and area of Boka Kotorska Bay (MANDIĆ, 2011, ZORICA *et al.*, 2015; 2019).

Those areas were in accordance with results published in review by MORELLO & ARNERI (2009) except the area of Boka Kotorska Bay. Namely, in the Boka Kotorska Bay, only one ichthyoplankton survey was done in the colder part of the year (December 2006) and intense sardine spawning was noted due to stable environmental conditions, and it might be considered as possible spawning ground that should be further investigated so that it can be verified or not in future. Since sardine eggs and larvae appeared in almost the same areas, at least on the eastern Adriatic, those areas could also be considered as nursery areas. Beside those nursery areas detected via ichthyoplankton sampling, SINOVIĆ *et al.* (2009) defined Krka river estuary as nursery area of sardine. Regarding the western Adriatic in the recent paper given by SCIASCIA *et al.* (2018) as well as in paper published before (MORELLO & ARNERI 2009; BORME *et al.*, 2013; CARPI *et al.*,

Table 1. Sardine, *Sardina pilchardus* - overview of early life stages abundances in the Adriatic Sea over the last two decades

Author	Geographical area	Month/Year	Eggs abundance (egg/m ²)		Larvae abundance (larvae/m ²)	
			Range	Mean	Range	Mean
MANDIĆ (2011)	Boko Kotorska Bay, eastern Adriatic	December/2006	11.9 - 158.4	59.60	-	40.00
		April/2007	3.9 - 29.4	10.05	-	-
		April/2008	3.2 - 13.3	8.10	-	-
		January/2009	4.0 - 4.0	4.00	-	16.00
BORME <i>et al.</i> (2013)	Gulf of Manfredonia, western Adriatic	February/2008	-	-	27 – 35*	-
ZORICA <i>et al.</i> (2015)	Eastern Adriatic (Croatia)	January/2012	4.0 - 396.0	57.80	4.0 - 108.0	28.41
HORVAT (2017)	Northern eastern Adriatic (Slovenia)	September/2014	-	11.00	-	-
		November/2014	-	19.00	-	-
		December/2014	-	7.00	-	-
		January/2015	-	6.00	-	-
		February/2015	-	8.00	-	-
		March/2015	-	4.00	-	-
		April/2015	-	4.00	-	-
ZORICA <i>et al.</i> (2019)	Middle eastern Adriatic (Croatia)	November/2017	12.0 – 240.0	56.22	4.0 – 56.0	19.20

*given values are the numbers of collected sardine larvae

2017) the Gulf of Manfredonia was defined as a sardine nursery area. According to reported data sardine larvae and juveniles are transported by the southward boundary current WAC (Western Adriatic Current) from its spawning ground into the Gulf of Manfredonia (SCIASCIA *et al.*, 2018). Previously mentioned authors in their papers indicate that sardine spawning grounds on the western Adriatic part are located north (Gulf of Trieste, Po River Delta, northern Italian coastline, the central Italian coastline, the northern Gargano) of the above-mentioned nursery ground.

Anchovy, *Engraulis encrasicolus*

Anchovy has an extended spawning season that starts at the end of March and lasts until October with reproductive activity peaking from April to July noted by SINOVIĆ & ZORICA (2006), ĐUROVIĆ (2012), ZORICA *et al.* (2013) and ĐUROVIĆ

et al. (2018). The total length at which 50% of anchovy population attain maturity ranged from 7.5 cm to 9.0 cm of total length (SINOVIĆ & ZORICA, 2006; MORELLO & ARNERI 2009), while in the area of Boka Kotorska Bay it was calculated as 9.28 cm for females and 9.02 cm for males (MANDIĆ *et al.*, 2015). Histological examination of anchovy gonad tissue confirmed that this species is a batch spawner with asynchronous oocyte development and indetermined fecundity (RADONIĆ *et al.*, 2018; ĐUROVIĆ *et al.*, 2018). Within each batch Adriatic anchovy released approximately 3336.8 to 19875.1 eggs/g (MANDIĆ *et al.*, 2015; RADONIĆ *et al.*, 2018). The value of batch fecundity is known to vary annually and it is affected mostly by the different environmental conditions (temperature, available food) (MURUA *et al.*, 2003; GANIAS, 2009).

During the last two decades several scientific surveys were done during the warmer part of the year (July – September, Table 2). Since the

Table 2. Anchovy, *Engrulis encrasicolus* - overview of early life stages abundances in the Adriatic Sea over the last two decades

Author	Geographical area	Month/Year	Eggs abundance (egg/m ²)		Larvae abundance (larvae/m ²)	
			Range	Mean	Range	Mean
MANDIĆ (2011; 2015)	Boko Kotorska Bay, eastern Adriatic	July/2006	25.59 – 565.05	163.35	4.6 – 97.9	
		April/2007	10.39 – 823.11	131.37	1.07 – 145.2	
		August/2007	13.72 – 581.11	99.19	5.52 – 57.86	
		April/2008	9.07 – 267.90	60.37		
		July/2008	23.84 – 1039.17	293.52		
TIRELLI <i>et al.</i> (2013)	Gulf of Trieste-Gargano Promontory, western Adriatic	September/2011	0 – 477.75			
ZORICA <i>et al.</i> (2015)	Eastern Adriatic (Croatia)	July/2013	4.0 - 800.0	145.26	8.0 - 952.0	115.11
HORVAT (2017)	Northern eastern Adriatic (Slovenia)	August/2014 – July/2015	8.0 – 629.0			
MALAVOLTI <i>et al.</i> (2018)	western continental shelf of Adriatic (GSA 18)	June – July/2012		39.49*		52.78*
		June – July/2013		26.99*		40.04*
		June – July/2014		20.51*		24.47*
		June – July/2015		25.61*		44.66*
ZORICA <i>et al.</i> (2018)	Whole eastern Adriatic	July/2013	2.61 - 1040.24	25.43*	2.73 – 611.14	17.07*
ZORICA <i>et al.</i> (2019)	Middle eastern Adriatic (Croatia)	July/2017	8.0 – 140.0	37.18	4.0 – 136.0	44.88
ZORICA <i>et al.</i> (2019)	Eastern Adriatic (Croatia)	July/2018	4.0 – 228.0	34.56*	4.0 – 60.0	10.58*

*given values are the numbers of collected sardine larva

time of those surveys overlapped with anchovy spawning from collected ichthyoplankton samples scientists managed to isolate, count and define abundances of anchovy early life stages as it is shown in Table 2. Highest abundances of anchovy eggs/ larvae were noted during the July as it was expected considering the fact that at that month Adriatic anchovy reach its spawning peak. In the whole Adriatic, areas with the higher abundances of its early life stages are mostly placed northern, precisely in GSA 17 - the Gulf of Trieste (TIRELLI *et al.*, 2013, HORVAT, 2017), the Gulf of Venice (TIRELLI *et al.*,

2013), Kvarnerić area, area beyond the Island of Dugi otok, outer part of mid-Dalmatian islands (ZORICA *et al.*, 2015, 2018, 2019) and Zrmanja River estuary (SINOVIĆ, 2004, SINOVIĆ & ZORICA, 2006). Those anchovies spawning and/or nursery areas were previously characterised as nutrient-enriched areas due to the river inputs or upwelling (MARASOVIĆ *et al.*, 1988; REVELANTE & GLIMARTIN, 1992; GAČIĆ *et al.*, 1997; MAURI & PAULAIN, 2001; KRŠINIĆ, 2010), hence occurrence of anchovy early life stages were expected there. As far as the southern Adriatic is concerned, somewhat lower values of anchovy eggs/larvae

abundance were noted in the last two decades (ZORICA *et al.*, 2019) as well as before (MORELLO & ARNERI, 2009), few favourable areas for early life stages were distinguished - the Gulf of Manfredonia (MALAVOLTI *et al.*, 2018), area of Boka Kotorska Bay (MANDIĆ, 2011; MANDIĆ *et al.*, 2011, 2013, 2015; 2017; ZORICA *et al.*, 2019) and the area in front of the northern Albania coastline (ZORICA *et al.*, 2019).

According to ZORICA *et al.* (2019) findings it seems that anchovy tend to shift its spawning centres during its protracted spawning linked to achieving favourable environmental conditions. Precisely, it seems that Adriatic anchovy population firstly starts to spawn in northern and shallower part of Adriatic, where favourable conditions are reached first, and as summer progress anchovy shift its spawning towards the southern areas. Furthermore, over the last two decades' analysis of ichthyoplankton samples reveal that anchovy for its spawning in the area of middle and southern Adriatic preferred the areas with sea depths from 70 m to 120 m (MALAVOLTI *et al.*, 2018; ZORICA *et al.*, 2019).

European hake, *Merluccius merluccius*

According to monthly changes of maturity stages, gonadosomatic indices and gonad weight of European hake from the Adriatic Sea it is obvious that this species spawns all year round (VRGOČ *et al.*, 2004; 2005) and reaches its first maturity at 20.5 cm (females)/22.5 cm (males) (VRGOČ *et al.*, 2005). This protracted spawning period has been one of the known characteristics of genus *Merluccius* since it was reported previously for *M. merluccius* (RECASENS *et al.*, 2008), *M. capensis* (KAINGE *et al.*, 2007) and *M. hubbsi* (MACCHI *et al.*, 2004).

Even though all reproductive traits of this species oscillated over the years in this area somewhat higher spawning activity was reported between May and October (VRGOČ *et al.*, 2004; 2005). Due to that spawning activity recruitment peak in winter period was noted. Beside this one another recruitment peak was reported in summer period that indicated spawning activity during the winter (VRGOČ *et al.*, *ibid*). Essen-

tial habitats (spawning and nursery grounds) for this commercially highly important species were detected regarding the systematic scientific research done throughout MEDITS surveys in Adriatic Sea since 1996. According to data collected through that surveys and published by PICCINETTI *et al.* (2012) the most important spawning and nursery area of hake was the area of open middle Adriatic. Considering the importance of central Adriatic in the repopulation of hake population, as well as of Norway lobster population, General Fisheries Commission of Mediterranean established in 2017 a Fisheries Restricted Area in the Jabuka pit (GFCM, 2017). Apart from Jabuka/Pomo pit and middle Adriatic area few smaller spawning areas were located in channel areas of the north eastern Adriatic including the deepest parts of Kvarnerić and part of Velebit channel (VRGOČ *et al.*, 2004; 2005; PICCINETTI *et al.*, 2012), while on the western side nursery area off the Gargano peninsula in the South Adriatic Sea was identified by CARLUCCI *et al.* (2009).

Common pandora, *Pagellus erythrinus*

Over the last two decades' studies concerning this species biology, particularly reproduction biology, are scarce. According to studies done in framework of Project DemMon (Croatian Fishing ground, summer 2002 – spring 2003) VRGOČ *et al.* (2004) confirmed common pandora as protogynous hermaphrodite, which females change sex at the size classes 17-20 cm of total length. Same authors reported based to its gonad macroscopic stages and the GSI value, that this species spawned from April to September (peak from May to August), although female specimens in stage of spawning (ripe gonads) were found almost during the whole year (except December and January; VRGOČ *et al.*, 2004). Observed specimens within the study area reached its first sexual maturity at 12.5 cm (VRGOČ, 2000). According to results of MEDITS surveys PICCINETTI *et al.* (2012), define that common pandora juveniles preferred shallow coastal waters as they were found mainly along western Istrian Coast, in channel areas of central Adriatic and estuary of Neretva River. Besides, those areas,

DULČIĆ *et al.* (2002) reported the area of Šibenik (middle Adriatic - in the vicinity of Lake Vran and River Krka estuary) as nursery area of many species among which were also noted juveniles of common pandora. COLLOCA *et al.* (2015) analysed the European Union Mediterranean waters using time series of bottom trawl survey data for the period 1994–2010 and confirmed central/northern Adriatic as nursery area. They also noted somewhat larger nursery area spreading from the north-eastern Italian coast to the eastern coast of Istria (Croatia) at a depth of 5–20 m and smaller ones near Neretva River estuary. As far as southern Adriatic concerned few smaller areas among which northern Albanian coast was distinguished (COLLOCA *et al.* 2015).

CONCLUSIONS

Envisaging above mentioned and previously published, it is obvious that Adriatic Sea and its resources were and still are in the focus of many scientific investigations. Despite scientific effort all biological and ecological aspects of many exploited Adriatic fishes are still unknown or scarcely investigated. This review study of reproductive biology that included examination of spawning and nursery areas for four economically and ecologically important fish species over the time period of last two decades pointed out area of open middle Adriatic as small pelagic fish species spawning and nursery ground and the area of European hake successful recruitment. Area of shallow northern Adriatic was highlighted as area significant for early life stages of anchovy and common pandora,

while on the southern part of Adriatic Gulf of Manfredonia distinguished itself as by far most important nursery area for both small pelagic fish species and European hake.

Nevertheless, all estuary areas (rivers Po, Zrmanja, Krka, Neretva, Bojana) or the upwelling areas (middle Adriatic) were also desirable for spawning or nursing of investigated fish species. Throughout this work it was evident that elemental reproductive biological parameters for two investigated demersal fish species are lacking, so this is something that should be covered in future. Ichthyoplanktonic survey are mainly done during the summer months due to better weather conditions, so, in future some effort should be invested in order to provide better information for species that spawn in colder part of the year such as sardine. All of this is needed in order to define, comprehend and protect ecologically sensitive areas of commercially exploited species that should become a baseline for improved management regulations in achieving optimal conservation of those renewable resources.

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Pregled saznanja o reproduktivnoj biologiji i mrijestilištima/rastilištima komercijalno važnih riba u Jadranskom moru tijekom zadnja dva desetljeća

Barbara ZORICA, Vanja ČIKEŠ KEČ, Nedo VRGOČ, Igor ISAJLOVIĆ,
Corrado PICCINETTI, Milica MANDIĆ, Bojan MARČETA i Ana PEŠIĆ

*Kontakt e-pošta: zorica@izor.hr

SAŽETAK

U novije vrijeme, unatoč dugoročnom sustavnom istraživanju ekosustava Jadranskog mora, a s obzirom da status većine obnovljivih morskih stokova nije u biološki dobrom stanju biomase, pojavila se nužnost proširenja postojeće zaštite komercijalno iskorištavanih vrsta. Kako bi se to realiziralo bilo je potrebno napraviti pregled svih znanstvenih spoznaja stečenih u posljednja dva desetljeća. Tako je u ovom preglednom radu naglasak stavljen na znanstvene činjenice vezane uz reproduktivnu biologiju kao i mrijestilišta i rastilišta četiriju ekološki i ekonomski važnih jadranskih vrsta riba – srdela *Sardina pilchardus*, brgljun *Engraulis encrasicolus*, oslić *Merluccius merluccius*, arbun *Pagellus erythrinus*.

Glavni cilj ovog preglednog rada je bio stvoriti novu znanstvenu platformu koja bi u bliskoj budućnosti trebala rezultirati boljim mjerama očuvanja koje bi nadalje rezultirale dugoročnim održivim iskorištavanjem živih morskih resursa u Jadranu.

Ključne riječi: srdela, brgljun, oslić, arbun, Jadran