ANNALES

Anali za istrske in mediteranske študije
Annali di Studi istriani e mediterranei
Annals for Istrian and Mediterranean Studies
Series Historia Naturalis, 29, 2019, 1

UDK 5 Annales, Ser. hist. nat., 29, 2019, 1, pp. 1-158, Koper 2019 ISSN1408-533X

UDK 5

ISSN 1408-533X (Print)
ISSN 2591-1783 (Online)

ANNALES

Anali za istrske in mediteranske študije
Annali di Studi istriani e mediterranei
Annals for Istrian and Mediterranean Studies

Series Historia Naturalis, 29, 2019, 1

KOPER 2019

ISSN 1408-533X (Tiskana izd.)
ISSN 2591-1783 (Spletna izd.)

UDK 5

Letnik 29, leto 2019, številka 1

Izdajatelja/*Editori/Published by:*

Zgodovinsko društvo za južno Primorsko - Koper / *Società storica del Litorale - Capodistria*©
Inštitut IRRIS za raziskave, razvoj in strategije družbe, kulture in okolja / *Institute IRRIS for Research, Development and Strategies of Society, Culture and Environment / Istituto IRRIS di ricerca, sviluppo e strategie della societa, cultura e ambiente*©

Sedež uredništva/*Sede della redazione/*
Address of Editorial Board:

Nacionalni inštitut za biologijo, Morska biološka postaja Piran / *Istituto nazionale di biologia, Stazione di biologia marina di Pirano / National Institute of Biology, Marine Biology Station Piran*
SI-6330 Piran /*Pirano*, Fornače/*Fornace* 41, tel.: +386 5 671 2900, fax 671 2901;
e-mail: annales@mbss.org, ***internet:*** www.zdjp.si

Redakcija te številke je bila zaključena 21. 6. 2019.

Sofinancirajo/*Supporto finanziario/*
Financially supported by: Javna agencija za raziskovalno dejavnost Republike Slovenije (ARRS), Luka Koper in Mestna občina Koper

Annales - Series Historia Naturalis izhaja dvakrat letno.

Naklada/*Tiratura/Circulation:* 300 izvodov/copie/copies

Revija Annales, Series Historia Naturalis je vključena v naslednje podatkovne baze / *La rivista Annales, series Historia Naturalis è inserita nei seguenti data base / Articles appearing in this journal are abstracted and indexed in*: BIOSIS-Zoological Record (UK); Aquatic Sciences and Fisheries Abstracts (ASFA); Elsevier B.V.: SCOPUS (NL).

Vsi članki so v barvni verziji prosto dostopni na spletni strani: http://zdjp.si/p/annalesshn/
All articles are freely available in color via website: http://zdjp.si/en/p/annalesshn/

ANNALES · Ser. hist. nat. · 29 · 2019 · 1

Anali za istrske in mediteranske študije - Annali di Studi istriani e mediterranei - Annals for Istrian and Mediterranean Studies

UDK 5 Letnik 29, Koper 2019, številka 1 ISSN 1408-533X (Print)
ISSN 2591-1783 (Online)

VSEBINA / *INDICE GENERALE / CONTENTS 2019(1)*

received: 2018-11-20 DOI 10.19233/ASHN.2019.08

SPATIAL AND TEMPORAL DISTRIBUTION OF ANCHOVY (*ENGRAULIS ENCRASICOLUS*) AND SARDINE (*SARDINA PILCHARDUS*) EGGS IN SLOVENIAN TERRITORIAL WATERS (NORTHERN ADRIATIC)

Polona PENGAL
REVIVO, Institute for ichthyological and ecological research PE Ljubljana, Staretova 1, 1233 Dob, Slovenia
e-mail: polona.pengal@ozivimo.si

Eva HORVAT
REVIVO, Institute for ichthyological and ecological research, Šmartno 172, 2383 Šmartno pri Slovenj Gradcu, Slovenia
e-mail: eva.horvat@ozivimo.si

Mihael J. TOMAN
Department of Biology, Biotechnical faculty of University of Ljubljana, Jamnikarjeva ulica 101, 1000 Ljubljana, Slovenia
e-mail: mihaeljozef.toman@bf.uni-lj.si

ABSTRACT

*Sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) have an important ecological role and are commercially the most important small pelagic species in the Adriatic. In the northern Adriatic Sea sardine and anchovy stocks are overexploited and in overexploitation. Understanding the ecology of these stocks through time is of crucial importance for their sustainable management. In the present work we recognized the most important sardine and anchovy spawning areas and periods in Slovenian territorial waters. Sampling was performed once a month for one year (August 2014–July 2015) at 10 sampling stations, evenly distributed around the Slovenian territorial waters following the Daily Egg Production Method (DEPM) protocol. Despite of low winter temperatures sardine eggs were recorded from September to April, with two spawning peaks, in November and February. The highest number of sardine and anchovy eggs were recorded in the north-western part of the Slovenian territorial waters and in the Koper Bay. Anchovy eggs were recorded from May to November, with the spawning peak in August.*

Key words: small pelagic, anchovy, sardine, spawning season, fish eggs, northern Adriatic Sea

DISTRIBUZIONE SPAZIALE E TEMPORALE DI UOVA DI ACCIUGA (*ENGRAULIS ENCRASICOLUS*) E SARDINA (*SARDINA PILCHARDUS*) IN ACQUE TERRITORIALI SLOVENE (ADRIATICO SETTENTRIONALE)

SINTESI

*La sardina (*Sardina pilchardus*) e l'acciuga (*Engraulis encrasicolus*) hanno un importante ruolo ecologico e sono le specie pelagiche commercialmente più importanti dell'Adriatico. Nell'Adriatico settentrionale le scorte di sardine e acciughe sono sovrasfruttate e in sovrasfruttamento. Comprendere l'ecologia di questi stock nel tempo è di cruciale importanza per la loro gestione sostenibile. Nel presente lavoro abbiamo riconosciuto le più importanti aree e periodi di deposizione delle sardine e delle acciughe nelle acque territoriali slovene. Il campionamento è stato eseguito una volta al mese per un anno (agosto 2014-luglio 2015) in 10 stazioni di campionamento, distribuite uniformemente nelle acque territoriali slovene, seguendo il protocollo del metodo di produzione giornaliera dell'uovo (DEPM). Nonostante le basse temperature invernali, le uova di sardine sono state ritrovate da settembre ad aprile, con due picchi di deposizione delle uova in novembre e febbraio. Il numero più elevato di uova di sardine e acciughe è stato registrato nella parte nord-occidentale delle acque territoriali slovene e nella baia di Capodistria. Le uova di acciuga sono state ritrovate da maggio a novembre, con il picco di deposizione delle uova nel mese di agosto.*

Parole chiave: piccolo pelagico, acciuga, sardina, stagione della deposizione delle uova, uova di pesce, Adriatico settentrionale

INTRODUCTION

Sardine (*Sardina pilchardus*; Walbaum, 1972) and anchovy (*Engraulis encrasicolus*; Linnaeus, 1758) dominate the pelagic environment in the northern and central Adriatic Sea and have a wide impact on its trophic web (Morello *et al.,* 2009). These small pelagic stocks also provide high economic yields for the fisheries sector of all countries around the Adriatic Sea. Coordinating and aligning interests and efforts among countries with such differences in economic and social importance of fisheries on the national level is complicated. For these reasons different management measures are difficult and slow to be implemented and meanwhile small pelagic stocks remain overexploited (COM, 2017). To understand and to be able to predict stock development through time, different stock assessment methods are continuously being developed and data are collected through scientific surveys as well as from the fisheries.

Daily Egg Production Method (DEPM) was developed in the late 1970s in California and has since been applied to several European anchovy stocks in the Mediterranean Sea (Alheit, 1993; Somarakis *et al*., 2004; Mandić *et al.,* 2015). An important contribution that enabled application of the DEPM method to the Adriatic anchovy stock was that of REGNER (1985), who determined the developmental parameters of anchovy in the Adriatic Sea. Following from his research, the DEPM protocol for the small pelagic species of the Adriatic Sea has recently been developed in the framework of the AdriaMed project (Mandić *et al*., 2014). According to the DEPM protocol, the full extent of the species' spawning area should be surveyed to enable valid stock assessment with this method Somarakis *et al*., 2004.

Anchovy and sardine have mirror like reproductive strategies and oceanographic parameters – especially salinity and temperature – are of crucial importance in explaining the coexistence of the two species (Morello *et al.,* 2009). *Štirn et al.,* (1974) pointed out that this two species have more or less spatially competitive relationship. When considering geological timescale it seems that abundant population of anchovy, inhabiting energetically rich western waters of Northern Adriatic and high food plasticity in sardine, who probably had to adapt to remaining available habitats, points out one of the clues that there is a competitive relationship among adult fish for feeding areas (Morello *et al.,* 2009). *Štirn et al.,* (1974) noticed that in late spring, when sardine is still spawning and anchovy is migrating to the north and starting to spawn, areals of both species are not overlapping. This spatial separation in spring is visible also in distribution of their eggs (*Štirn et al.,* 1974). In winter, adult sardines migrate southwards from feeding areas such as Gulf of Trieste, Venice and Istrian coast, towards island Dugi Otok for spawning (Morello *et al.,* 2009; Škrivanič *et al.,* 1973). On the contrary, the main anchovy spawning activity takes place in warmer months in the offshore waters of island Dugi Otok towards the coastal Istrian waters (Morello *et al.,* 2009) and the coastal waters between the Gulf of Trieste and the Gargano peninsula, with the highest abundance of eggs in the Gulf of Trieste and off the mouth of the river Po (Morello *et al.,* 2009; Regner, 1996). Therefore, we expected Slovenian coastal territorial waters to be an important spawning ground for anchovy, but only of minor importance for sardine spawning.

Developmental time of anchovy and sardine eggs depends on temperature and is shortest during warmer water temperatures (Regner, 1987, 1996) minimizing exposure time of the most vulnerable, egg developmental stage. In such conditions egg sizes are smaller, since there is need to provide safety and nutrition to the embryo for much shorter time in such conditions (Riveiro *et al.,* 2004). In addition, smaller eggs have been observed later in the spawning season, when first year individuals tend to spawn (Regner, 1985). In view of this knowledge, we would expect sardine and anchovy eggs to be larger when their first spawning in the year occurs and when environmental conditions are not yet the most suitable. The eggs should be smallest during peak spawning and medium sized to large towards the end of the spawning period when environmental conditions are becoming less suitable.

In view of this knowledge, we would expect sardine and anchovy eggs to be larger when their first spawning in the year occurs and when environmental conditions are not yet the most suitable. The eggs should be smallest during peak spawning and medium sized to large towards the end of the spawning period when environmental conditions are becoming less suitable, which is also in line with results of anchovy egg developmental stage duration in Boka Kotarska Bay in Montenegro (Mandić. 2011).

As a partner of the AdriaMed project, Slovenia is contributing to development and application of the DEPM for the stock assessment of small pelagic fish in the Adriatic Sea (Pengal *et al.*, 2014). Therefore, the initial spatial study of egg distribution performed in August 2014 and supported by the AdriaMed project was extended by ZZRS (Fisheries Research Institute of Slovenia) to also gain insight into temporal distribution of spawning for both small pelagic species in Slovenian coastal territorial waters. Thus, this study provides results of the spatial and temporal distribution of spawning for sardine and anchovy in Slovenian territorial waters.

MATERIAL AND METHODS

Location and sampling

The studied area is situated in the southern part of the shallow Gulf of Trieste, which is the northernmost part of the Adriatic Sea (Fig. 1). Larger part of the gulf belongs

to the infralittoral zone with typical flat muddy bottom, composed of clayey silt (Ogorelec *et al.,* 1991), while other the rest of the habitat types are limited to small dispersed areas (Lipej *et al.,* 2006). Slovenian territorial waters (studied area) is extremely shallow, with mean depth of 18.7 m (Ogrin, 2012). Because of its shallow nature with a mean depth of 35 m, northern Adriatic is extremely productive, but becomes hydrographically unstable and subjected to environmental variability during winter (Štirn, 1968).

In all the seasons there is a general inflow into the Gulf of Trieste at its south-eastern, deeper part, while the outflow appears along the gulf's axis near the sea surface and is driven by the dominant "bora" wind during winter. The surface layer of the Gulf of Trieste is dominated by seasonal winds and typical (anti)cyclonic circulations formed in different seasons, suggesting lower current speeds in the central part of the Gulf (Zavatarelli *et al.,* 2003; Malačič *et al.,* 2009). Stronger currents are typical near the capes such as Cape Madona in Piran (Ogrin, 2012).

Sampling was performed for twelve months from August 2014 to July 2015 on ten sampling stations, positioned app. 3 nautical miles apart in the Slovenian territorial waters. Due to adverse weather conditions sampling was impossible to perform in October and in January on stations 6 to 10. Sampling stations were reached by a boat of ZZRS and exact locations found with a handheld GPS unit.

The Daily egg production method (DEPM) protocol (Mandić *et al.,* 2014; Pengal *et al.,* 2014) was followed and sampling was conducted using WP2 net with mesh size of 200 µm and mouth diameter of 0,264 m^2. The net was towed from 5 m above the bottom to the surface with a hauling speed of 1 m/s. The samples were immediately preserved in 3 % solution of buffered formaldehyde and analysed at the Department of Biology at the Biotechnical Faculty of University of Ljubljana.

At each sampling station water temperature [°C], salinity, oxygen levels [mg/L] and dissolved oxygen [%] for each meter of the water column were measured by means of a Hatch CTD probe (Horvat, 2017). In August, November and December, salinity measurements were not collected at all sampling stations due to probe failure. Therefore, salinity of peak spawning for anchovy (August) was estimated using July data.

Mean monthly air and water temperatures for each month were also collected from Slovenian Environmental Agency (ARSO; Strojan, 2014a, b, c; Strojan, 2015 a, b ,c, d, e). Speed and direction of currents were gained from the stainless–steel buoy "Vida" (45° 32′ 55,68″ N, 13° 33′ 1,89″ E), where an AWAC current meter from Nortek As is mounted at the seafloor, at the depth of 22 m. Additionally, the direction of wind was collected from Vida (NIB, 2017) during sampling of each station. For sampling stations 1, 5, 6, 7, and 8 Chlorophyll–a concentrations [µg/L] were obtained from the Slovenian Environmental Agency for months August (2014)–January (2015) and June–July (2015) (Sever, 2016).

Fig. 1: Geographic position of ten sampling stations (1 – 10) in Slovenian territorial waters inside the Gulf of Trieste.
Sl. 1: Enakomerna razporeditev desetih vzorčnih postaj (1 – 10) v teritorialnih vodah Slovenije (Tržaški zaliv).

Analysis

Sardine and anchovy eggs were sorted from the samples and counted in the laboratory. Eggs were then measured with the program CellSense Standard under the microscope (Olympus Cx41) with 10 X 4 magnification. Eleven egg developmental stages and 5 developmental classes (A–E) were determined for sardine eggs following the proposal of the General Fisheries Council for the Mediterranean (karlovac, 1967; GFCM, 1975). Ten developmental stages were determined for anchovy eggs according to Regner's templates from AdriaMed Training Course (REGNER, 1985). Additional literature Ré *et al.,* (2009) and Mandić (2011) was referenced to determine the ages of sardine eggs. Regner's (1985) formula for developmental time and mean correction time were used to calculate the spawning interval.

Monthly abundance of sardine or anchovy eggs per m^2 were calculated for each sampling station using Tanaka's formula (Regner, 1985; Regner *et al.*, 1987). Since sardine and anchovy eggs were only found at a small number of stations (less than 50 %) in most months, the empty stations were omitted from the calculation of mean monthly abundance of eggs per station (as per Karlovac (1964) and Mandić (2011)). Finally, categorization by Karlovac (1964) was used to determine the spawning intensity category for the survey area. Information on length of adult sardine and anchovy fish that were caught in Slovenian territorial waters during our survey were retrieved from the database of the Fisheries Research Institute of Slovenia (ZZRS).

RESULTS

In total, 1646 eggs were collected, of which 68 were sardine, 951 anchovy and 627 were unidentified eggs belonging to other species. Of those, 3 sardine and no anchovy eggs were found during the incomplete January sampling and these eggs were omitted from the analysis (Fig. 2). Moreover, 34 anchovy and 3 sardine eggs were damaged so that it was impossible to determine their developmental stage or measure them. These eggs were used for the calculations of abundance, but not for the other analysis.

Abiotic parameters

The water depth at sampling stations ranged from 18 to 25 m. With the exceptions of May and August, there was no clear stratification of the water column during our sampling, data is in more detail presented in Horvat (2017). Temperature in the water column was gradually decreasing towards the bottom in the summer months without a clear thermocline (Fig. 3). On the contrary, salinity was lowest on the surface and gradually increasing towards the bottom, with an exceptionally strong pycnocline with a pronounced low surface salinity layer in November, when the sampling was performed after a rainfall event and freshwater lingered on the surface for a few days. The only month with the mean water column salinity below 38 was May.

Persistence of low oxygen levels in the bottom layer was detected throughout the summer months, from July to the end of September at most sampling stations. Oxygen content was high throughout the water column during the winter months.

Sardine

The highest abundance of sardine eggs and persistence were detected at stations 6 and 7 located towards the central part of Gulf of Trieste and the Koper Bay (Tab. 1). No sardine egg was found in the samples from station 3 in this survey and only individual eggs were identified at the neighbouring stations 2 and 4, which are located off the Savudrija cape. Low presence of sardine eggs was also determined for stations closest to the shore. Higher abundances were calculated for station 10, just off the Cape Madona, the deepest part of the Slovenian territorial waters.

The eggs occurred in the sampling area from September to April with the first spawning peak in November and a second, lower spawning peak detected in February (Fig. 4a). Medium sardine spawning intensity was determined for the earliest occurrence of sardine eggs in Slovenian territorial waters in late September with a mean of 11 eggs/m^2. In November, mean abundance of 19 eggs/m^2 was found in the sampling area, which indicates Slovenian territorial waters as an area of strong spawning intensity for sardine. Mean water column temperature at peak spawning was 17.84 °C and salinity 37.97. During the second abundance peak in February sardine eggs were found at five sampling stations (6–10) with on average 8 eggs/m^2 which corresponds to a low intensity spawning event. The lowest mean water column temperature (9.76 °C) and the highest salinity (38.39) during the survey were recorded for this sampling. The latest occurrence of sardine eggs in Slovenian

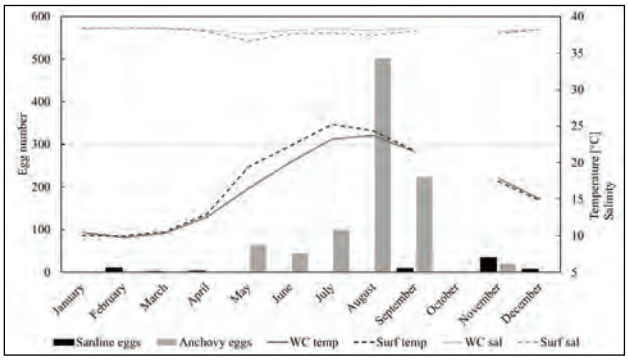

Fig. 2. Total number of sardine and anchovy eggs found in the samples from all stations by month with surface (Surf) and mean water column (WC) temperatures (temp) and salinities (sal).
Sl. 2: Skupno število iker sardele in sardona iz vseh vzorčnih postaj, predstavljeno po mesecih, vključno s temperaturo površinske vode (Surf) in povprečno temperaturo vodnega stolpca (WC) in slanostjo (sal).

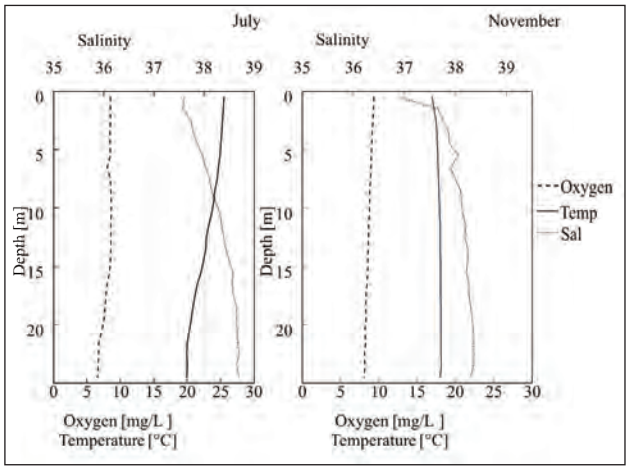

Fig. 3. Water temperature, salinity and oxygen profiles as a mean of all stations during peak spawning of anchovy (July; see Materials and methods) and sardine (November).
Sl. 3: Povprečne vrednosti vodnega stolpca vseh vzorčnih postaj za temperaturo, slanost in kisik tekom viška drsti sardona (julij; glej Material and methods) in sardele (november).

territorial waters was determined for April (on average 4 eggs/m^2).

The minimum egg developmental time (38.78 hours) for any station during our survey was calculated at station 8 in September and the maximum (137.01 hours) at station 6 in February. The shortest mean developmental time (39.21 hours) for sardine eggs was determined for September and the longest for February (128.25 hours; Fig. 4a), while in November it was the second shortest (51.80 hours).

Eggs stages B and C were detected in most samples, whereas stages A, D and E occurred only occasionally. Stage A was detected only in February, stages B and C from September to April and stage D in September and November. Stage E was never recorded.

Sardine eggs collected during this survey varied in size from 1.30 (in December) to 1.90 mm (in February; Fig. 4b). The smallest mean egg sizes were calculated for the autumn samples September (1.50 +/- 0.08 mm), November (1.55 +/- 0.09 mm) and December (1.54 +/- 0.02 mm). The largest mean egg sizes were detected in February (1.73 +/- 0.01 mm). Furthermore, the eggs containing the smallest oil drops were collected in September (mean of 0.15 +/- 0.03 mm) and the largest in February (mean 0.21 +/- 0.05 mm).

Anchovy

The highest abundance of anchovy eggs in the survey area were consistently detected at stations from 5 to 9, located towards the central part of the Gulf of Trieste and the Koper Bay (Tab. 1). The abundance decreased towards the mouth of the Gulf as well as towards the shore. Furthermore, stations 6–9 exhibited 100% persistence during the spawning season, with eggs being

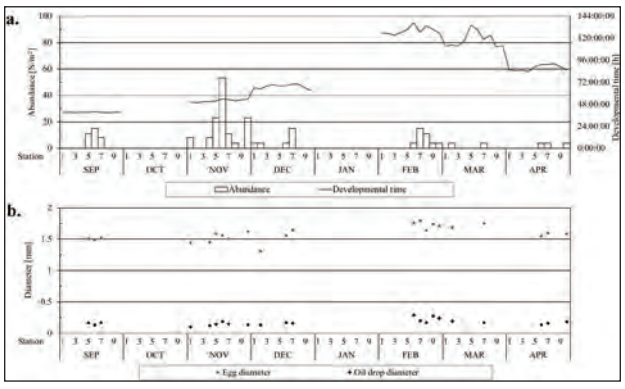

Fig. 4 Abundance of eggs, developmental time (a), mean egg diameter and mean oil drop diameter (b) by month and sampling station during the spawning period for sardine.
S. 4: Številčnost iker, razvojni čas (a), povprečni premer vseh iker in oljne kapljice (b) po vzorčnih postajah in mesecu drsti sardele.

Tab. 1: Mean abundance of sardine (Sar) and anchovy (Anc) eggs per station [N/m^2] during their presence in the survey area.
Tab. 1: Povprečna številčnost iker sardele (Sar) in sardona (Anc) na vzorčnih postajah [N/m^2] tekom njihove prisotnosti na območju raziskave.

Month/ Sampling station [N/m^2]	August		September		November		December		February		March		April		May		June		July		Mean abundance [N/m^2] on positive stations	
	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc	Sar	Anc
1	0	15	0	11	8	0	4	0	0	0	0	0	0	0	0	0	0	4	0	0	6	10
2	0	15	0	4	0	0	4	0	0	0	4	0	0	0	0	0	0	4	0	8	4	8
3	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	14
4	0	23	0	11	8	0	0	0	0	0	0	0	0	0	0	53	0	0	0	00	8	29
5	0	367	11	227	23	0	0	0	0	0	0	0	0	0	0	87	0	0	0	8	17	172
6	0	367	15	261	53	30	4	0	4	0	0	0	4	0	0	34	0	27	0	223	16	157
7	0	246	8	136	11	15	15	0	15	0	4	0	4	0	0	4	0	8	0	72	10	80
8	0	136	0	91	4	23	0	0	11	0	0	0	0	0	0	4	0	38	0	15	8	51
9	0	629	0	72	0	8	0	0	4	0	0	0	0	0	0	30	0	4	0	42	4	131
10	0	91	0	30	23	0	0	0	4	0	0	0	4	0	0	8	0	87	0	8	10	45

detected at these stations each month from May to November. We recorded the lowest abundances as well as persistency at station 3. Only during peak spawning in August anchovy eggs were present at all stations.

Anchovy eggs were detected in planktonic community of the Slovenian territorial waters between May and November, with the peak spawning recorded in August (Fig. 5a, Tab. 1). When the season's earliest anchovy eggs were identified in May at stations 3–10 (on average 30 eggs/m^2), mean water column temperature for these stations was 16.8 °C and salinity 37.57. The calculated abundance of anchovy eggs during peak spawning in August ranged from 8 eggs/m^2 at station 3 to 629 eggs/m^2 at station 9. However, the mean abundance of eggs for this period was 189.77 eggs/m^2. During peak spawning the mean water column temperature at positive stations was 23.75 °C and salinity around 38.09 (see Materials and Methods). Spawning intensity and persistence gradually decreased from September (94 eggs/m^2) to November, when the lowest egg abundances were detected (19 eggs/m^2) at stations 6–9.

Based on the temperature measurements, the mean developmental time for eggs was shortest in August (31 hours) and longest in May (72 hours). Most eggs from August samples were determined to be in stages IV and V (70.94 % of all eggs), which corresponds to highest spawning intensity between 1:00 and 2:30 o'clock in the night (Fig. 6). Furthermore, 93 % of eggs found in August samples were spawned between 21:00 in the evening and 8:00 in the morning.

The minimum length of anchovy eggs in the samples from Slovenian territorial waters was 1.07 mm and the maximum was 1.52 mm (Fig. 5b). The smallest mean egg sizes (length: 1.20 +/- 0.02 mm; Fig. 5b) were calculated for samples collected during the abundance peak in August. On the contrary, eggs were largest (length: 1.40 +/- 0.02 mm) towards the beginning and end of the spawning season.

DISCUSSION

As suggested by Regner (1985) temperature and salinity seem to be the most important factors determining spawning period and limiting spawning area of the small pelagic species in the Adriatic.

No significant correlation was found between abiotic (temperature, salinity, chl-a, …) and biotic (egg abundance, size, occurrence,…) parameters, so the PCA

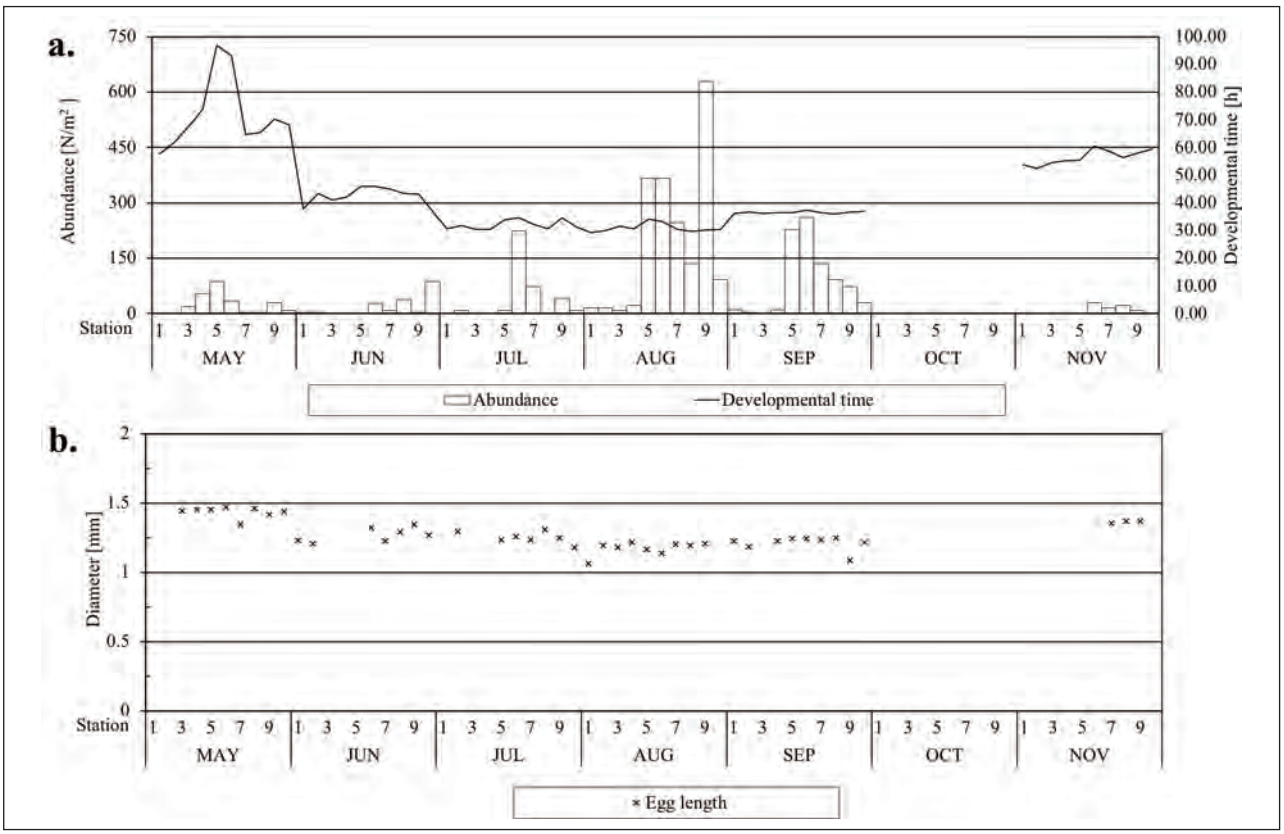

Fig. 5 Abundance of eggs, developmental time (a), mean egg length (b) by month for each sampling station during the spawning period for anchovy.
Sl. 5: Številčnost iker, razvojni čas (a), povprečna dolžina iker (b) po vzorčnih postajah in mesecu drsti sardona.

results are not presented in this article. The lack of correlation is attributable to the small surface, low depth and stable conditions of the Slovenian territorial waters, lacking the required diversity for such analysis.

Our findings confirm past findings (Štirn, 1968; Štirn *et al.,* 1974; Morello *et al.,* 2009) with anchovy spawning mainly during warmer months (Štirn, 1968; Štirn *et al.,* 1974; Morello *et al.,* 2009) in Slovenian territorial waters. In spring, the last sardine eggs were detected in April and the first anchovy eggs were found in May, completely separating spawning periods of the two species. In autumn, on the other hand, spawning periods were overlapping from September to November, when eggs of both species were found in the samples. The prolonged spawning of anchovy till November was recorded in 2014, which is a usual spawning period for central and southern Adriatic (Zavodnik, 1970; Regner, 1972; Morello *et al.,* 2009; Mandić, 2011) but not for the Northern Adriatic (Štirn, 1968; Štirn *et al.,* 1974; Morello *et al.,* 2009). We assume that one of the reasons might be the persistence of unusually high November mean sea water temperatures when comparing it to the mean November sea temperatures since 1981 at the Measurement station Koper (Strojan, 2014b). High abundances of anchovy eggs were still detected in the September samples, but low numbers collected in November were indicating the end of the spawning period. On the contrary, only individual sardine eggs were found in September samples and the first spawning peak was determined in November. The relatively low abundance of sardine eggs in September could be attributed to the numerous presence of anchovy who is more abundant and, thus, dominant in the area (Štirn, 1986). On the other hand, Slovenian territorial waters also represent the marginal area of sardine spawning range due to extreme environmental conditions during winter (Štirn, 1968, Gačić *et al.,* 1997; Shaltout *et al., 2014)*.

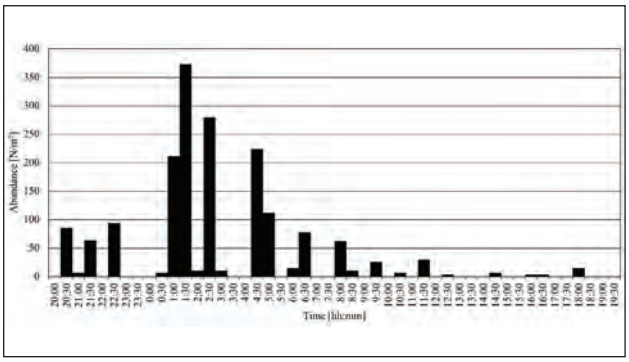

Fig. 6. Abundance of anchovy eggs (N/m²) by back-calculated spawning times during peak spawning in August.
Sl. 6: Številčnost iker sardona (N/m²) z "za nazaj" preračunanim časom drsti med viškom drsti v avgustu.

Sardine

The distribution of sardine eggs detected in this survey confirms the highest density of sardine eggs in the central open waters of the Gulf of Trieste. The abundance of eggs declines towards the entrance to the Gulf and towards the shores. Recent studies of currents in the Gulf of Trieste (Bogunović *et al.,* 2008) suggest that direction and speed of sea currents are the major reason for the described distribution of eggs. On the other hand, the average age for all sampled sardine eggs was approximately 16 hours at the time of sampling and considering the regular occurrence of strong winds and marine currents in the Gulf during winter time (Ogrin, 2012), the areas identified may not represent the actual spawning grounds.

The low absolute number of sardine eggs detected in this survey agree with other studies conducted in the northern Adriatic which found the spawning intensity in this area consistent with a periphery of the main sardine spawning grounds (Regner *et al.,* 1987; Štirn, 1968). Contrary to Štirn (1968), we can confirm sardine spawning in the Gulf of Trieste despite the low temperatures during winter. Sardine spawn with strong intensity in November as well as with medium intensity in September, December and February (Karlovac, 1964). Considering the trends observed, it is reasonable to conclude that spawning occurred also in October and January in Slovenian territorial waters. We predict that spawning intensity in October and January would also fall at least within the medium intensity category, if sampling was feasible during our survey.

Sardine eggs occurred in the survey area when mean water column temperature ranged from 9.20 to 22.00 °C and salinity range from 36.70 to 39.00. The first spawning peak in November was characterized by mean water column temperature of 17.77 °C and salinity around 37.80, calculated at stations where sardine eggs were found and salinity was around 37.80 (see Material and Methods).

According to previous research (Morello *et al.,* 2009; Regner *et al.,* 1987; Štirn, 1968), environmental conditions for peak spawning of sardine during this survey were the most suitable in January, when we also assumed the spawning peak would occur. Unfortunately, unsuitable weather conditions only allowed us to sample stations 1 to 5 and 10 in this month. Thus, the stations with otherwise highest abundances of eggs observed were not sampled and so the abundance is not comparable with other sampling months. Therefore, we allow the possibility that the highest sardine spawning peak in Slovenian territorial waters occurred in January.

The eggs recorded in this study were generally larger than those recorded by Mandić *et al.,* (2014) in Boka Kotorska Bay (Montenegro), suggesting that conditions for sardine spawning in the Gulf of Trieste are less suitable. Furthermore, the largest sardine eggs were found in

February and March, which can be partly explained by least favourable environmental conditions (low sea temperatures and salinity). Adults were not sampled during our survey and there is a lack of data from Data Collection Framework (DCF) for winter months, so we cannot confirm if length of fish also affected the size of eggs.

It was expected that egg stages D and E would be less frequent in all samples due to high mortality rates, since sampling was done in North Adriatic where, referring to Regner *et al.* (1987), mortality of sardine eggs and larvae is higher (coefficient of instantaneous mortality: 0.65) is higher than in the mean calculated on the entire Adriatic (coefficient of instantaneous mortality: 0.56). The exceptional occurrence of stage D eggs in November samples could indicate lower predator pressure during that time which is consistent with lower gelatinous plankton densities in northern Adriatic during autumn (Palmieri *et al.,* 2014; Malej *et al.,* 2004). Focused studies should be conducted to understand these dynamics.

Anchovy

The Gulf of Venice and the Gulf of Trieste are known to be the main spawning areas for anchovy in the Adriatic (Gamulin, 1983; Morello *et al.,* 2009). Similar to sardine, we found that anchovy eggs are the most abundant towards the central open waters of the Gulf of Trieste and decline in number towards the shores and entrance to the Gulf. On the contrary to what is shown by sardine, we can conclude and confirm (Štirn, 1968; Štirn *et al.,* 1974; Regner, 1985; Regner *et al.,* 1987; Dulčić, 1995) that these are the actual spawning grounds of anchovy, since the currents are very weak or absent during summer months (Malačić *et al.,* 2009) and the eggs are expected to linger where they were spawned.

During our survey anchovy spawned in Slovenian territorial waters between May and November. The first occurrence of eggs in May was characterized by the mean water column temperature of 16.44 °C and salinity 38.09. While exceptional presence of anchovy eggs until November has been reported in the central and southern Adriatic before (Regner, 1972), this study is the first to confirm occurrence of late, November spawning in the colder northern Adriatic. We assume the prolonged spawning coincided with higher water column temperatures (mean of 17.50 °C) in November during our survey, which were 2.6 °C higher than average (mean of 14.90 °C; Strojan, 2014b).

From abundance of anchovy eggs peak spawning intensity was determined for August, with mean water column temperature 23.75 °C and salinity from 37,40–38, confirming previous findings for northern Adriatic (Štirn, 1968; Regner, 1985). The anchovy spawning intensity gradually increased during the 3 spring months (May–July), exploded in August and finally decreased during the autumn months (Sep–Nov). In line with Regner (1985), this pattern closely followed the observed water column temperature changes. Furthermore, salinity measured during peak spawning in the Slovenian territorial waters is at the higher end of the previously observed range (28–38.5; Morello *et al.,* 2009; Štirn, 1968).

Moreover, Regner (1985; Morello *et al.,* 2009) observed that anchovy eggs from the open sea are larger than those from the coastal areas such as Gulf of Trieste and Lugovaj (1964; *as cited in* Regner, 1985) found that salinity also affects egg sizes, which are smaller and more elongated in lower salinities. We can confirm these hypothesis, since the eggs collected during this survey are one of the smallest (0.49–0.56 x 1.17–1.43 mm) recorded in the Adriatic Sea (Lugovaj, 1964; Regner, 1985; Zorica *et al.,* 2014; Mandič, 2011). Length measurements refer to formalin-preserved eggs, no correction of size was performed. In addition, the smaller egg sizes can also be attributed to the smaller size of individuals representing the northern Adriatic anchovy stock (Levi *et al.,* 1994). Adults were not sampled during our survey and there is a lack of DCF data during winter months, so we cannot confirm these relationships for Slovenian territorial waters.

The anchovy daily spawning interval determined in this survey is wider compared to previous studies and shifted towards the early morning hours (peak from 0:30 – 5:00 am; Fig. 6b). In the area of Chioggia (Venice Bay) Varagnolo (1964) reported spawning of anchovy to occur between 18:00–20:00, while Somarakis (2004) assumed anchovy spawn between 22:00 and 2:00 in the Eastern Mediterranean.

For the future surveys, we recommend that since the DEPM application presumes the coverage of entire spawning area, Slovenian territorial waters should be included in the future samplings to avoid underestimation of the SSB. In addition, due to the opposing spawning periods of sardine and anchovy, separate surveys should be performed to collect data, and protection of the spawning grounds for these two species should be managed separately.

CONCLUSIONS

For anchovy the main spawning season occurred in autumn in northern Adriatic, confirming Štirn's findings (1968). However, since predicted climate change could shift the sardine spawning area further north, affecting the current equilibrium with potentially considerable effects on small pelagic fisheries of northern Adriatic, the spawning of these two species should be closely monitored. Future studies should try to predict the impact of climate change on the spawning areas, the consequent change in competitive interaction among these two species and the potential fisheries implications for the Adriatic. Future DEPM studies should also include chlorophyll-a, phytoplankton and zooplankton measurements, since data are not available and is not a good indicator of production in the Slovenian territorial waters, since heavy maritime traffic causes suspension of the mud throughout the year, distorting this correlation.

ACKNOWLEDGEMENTS

Research leading to this publication was made possible by the contribution of FAO AdriaMed project and ZZRS who also trusted us the field samples for further identification. Special thanks to Tomaž Modic, Aljaž Jenič and Blaž Cokan for their support and field work. Ron ten Boer identified the eggs in the first months of the survey. Our thanks to Milica Mandić for kindly helping us with the literature and the identification of eggs. Maja Sever (Slovenian Environment Agency) has generously provided data on chlorophyll-a from Slovenian territorial waters. Prof. Ingrid Čatić and prof. Anita Marušić from Institut za oceanografiju i ribarstvo, Split kindly provided the articles from Acta Adriatica. Roman Luštrik and Žan Kuralt kindly reviewed and added constructive comments on QGis figures.

PROSTORSKO IN ČASOVNO POJAVLJANJE IKER SARDELE IN SARDONA V SLOVENSKEM TERITORIALNEM MORJU

Polona PENGAL
REVIVO, Institute for ichthyological and ecological research PE Ljubljana, Staretova 1, 1233 Dob, Slovenia
e-mail: polona.pengal@ozivimo.si

Eva HORVAT
REVIVO, Institute for ichthyological and ecological research, Šmartno 172, 2383 Šmartno pri Slovenj Gradcu, Slovenia
e-mail: eva.horvat@ozivimo.si

Mihael J. TOMAN
Department of Biology, Biotechnical faculty of University of Ljubljana, Jamnikarjeva ulica 101, 1000 Ljubljana, Slovenia
e-mail: mihaeljozef.toman@bf.uni-lj.si

POVZETEK

Glavno obdobje drsti sardona v severnem Jadranu tekom naše raziskave je bilo jeseni, s čimer potrjujemo Štirnova (1968) odkritja. Zaradi pričakovanih klimatskih sprememb lahko pričakujemo, da se bo drst sardele pomaknila proti severnim območjem Jadrana, kar bi lahko vplivalo na trenutno ravnovesje staležev med malimi pelaškimi vrstami rib severnega Jadrana, zato predlagamo podrobnejše spremljanje drsti obeh vrst. V prihodnjih študijah bi bilo priporočljivo na podlagi različnih modelov predvideti kako se bodo spreminjala območja drsti, zaradi njunega kompetitivnega odnosa, in kakšen bo potencialni vpliv teh sprememb na njun ulov znotraj Jadrana. DEPM raziskave bi morale vključevati tudi beleženje zooplanktona, fitoplanktona in klorofila-a, saj se meritve s strani države ne opravljajo redno po celotnem območju teritorialnih voda Slovenije ter niso dober ali dovolj natančen pokazatelj primarne produkcije skozi leto, saj na meritve močno vpliva morski promet (tovorne ladje in križarke), ki povzroča dvig in mešanje sedimenta skozi vse leto.

Ključne besede: male pelaške ribe, sardon, sardela, drst, obdobje drsti, ikre, severno Jadransko morje

REFERENCES

ADRIAMED (2007): AdriaMed training course on daily egg production method for the appraisal of small pelagic fisheries resources in the Adriatic Sea. GCP/RER/010/ITA/OM-161. AdriaMed scientific cooperation to support responsible fisheries in the Adriatic Sea, Rome, Italy, 47 pp.

Alheit, J. (1993): Use of the Daily egg production method for estimating biomass of clupeid fishes: A review and evaluation. Bulletin of marine science, 53, 750–67.

Bogunović, B. & V. Malačič (2008): Circulation in the Gulf of Trieste: Measurements and model results. Nuovo Cimento, 31(3), 301–326.

COM (2017): Commission Staff Working Document Impact Assessment (COM) – Accompanying the document: Proposal for a Regulation of the European Parliament and of the Council Establishing a Multi-annual Plan for Small Pelagic Stocks in the Adriatic Sea and the Fisheries Exploiting those Stocks. Brussels, 47 pp.

Dulčić, J. (1995): Spawning of the anchovy, *Engraulis encrasicolus* (L), in the Northern Adriatic Sea in 1989, the year of intensive blooms. Annales, 7, 51–54.

Gačić, M., S. Marullo, R. Santoleri & A. Bergamasco (1997): Analysis of the seasonal and interannual variability of the sea surface temperature field in the Adriatic Sea from AVHRR data (1984-1922). Journal of Geophysical Research Atmospheres 1022(C10):22937-22946. Doi: 10.1029/97JC1720.

Gamulin, T. & J. Hure (1983): The spawning and spawning areas of pelagic fishes. Acta adriatica, 24, 97–131.

GFCM (1975): General fisheries commission for the mediterranean (GFCM) - studies and reviews. No 1, 47 pp.

Horvat, E. (2017): Časovno in prostorsko pojavljanje iker sardele (*Sardina pilchardus*) in sardona (*Engraulis encrasicolus*) v slovenskem morju. https://repozitorij.uni-lj.si/IzpisGradiva.php?lang=slv&id=94337 (2. 5. 2018).

Karlovac, J. (1964): Mriješćenje srdele (*Sardina pilchardus* Walb.) u srednjem jadranu u sezoni 1956-1957 (Spawning of (*Sardina pilchardus* Walb.) in middle Adriatic in season 1956-1957). Acta Adriatica, 10, 8, 3–40.

Karlovac, J. (1967): Etude de l'ecologie de la sardine, *Sardina pilchardus* Walb., dans la phase planctonique de sa vie en Adriatique moyenne (Ecological study of sardine, *Sardina pilchardus* Walb., in plankton phase in middle Adriatic). Acta Adriatica, 2, 1–109.

Lipej, L., R. Turk & T. Makovec (2006): Ogrožene vrste in habitatni tipi v slovenskem morju (Endangered species and habitat types in the Slovenian sea). Ljubljana, Zavod RS za varstvo narave, 264 pp.

Malačič, V. & B. Petelin (2009): Climatic circulation in the Gulf of Trieste (northern Adriatic). Journal of Geophysical Research, 114, C07002, doi:10.1029/2008JC004904.

Malej, A. & A. Malej Jr. (2004): Invasion of the Jellyfish *Pelagia noctiluca* in the Northern Adriatic: non-success story. In: H. Dumont, T.A. Shiganova & U. Niermann (Editor). Aquatic invasion in the Black, Caspian, and Mediterranean Seas: in the Ctenophores *Mnemiopsis leidyi* and *Beroe* in the Ponto-Caspian and other aquatic invasions. NATO Science Series 4: Earth and Environmental Sciences. Netherlands, Springer, 273–285.

Mandić, M. (2011): Sezonski aspekti diverziteta ihtioplanktona u Bokakotrskom zalivu (Seasonal aspects of ichthyoplankton diversity in the Boka Kotorska Bay). Thesis. University of Beograd, 169 pp.

Mandić, M. & A. Pešić (2014): Protocol for application of the daily egg production method (DEPM) in the Adriatic Sea. Kotor, Institute of marine biology, 31 pp.

Mandić, M. & S. Regner (2014): Variation in fish egg size in several pelagic fish species. Studia Marina, 27(1), 31–46.

Mandić, M., S. Regner, J. Krpo-Ćetković & A. Joksimović (2012): Unusual occurrence of anchovy (*Engraulis encrasicolus*, Linnaeus 1758) eggs in December 2006 in Boka Kotorska Bay (Adriatic Sea). Acta Adriatica, 53(1), 133–137.

Mandić, M., S. Regner, M. Đurović**, A. Joksimović & J. Krpo-Ćetkovič (2015):** Distribution and abundance of eggs and estimation of spawning stock biomass of anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), in the south-eastern Adriatic Sea. Journal of Marine Biological Association of the United Kingdom, 95(5), 1051–1059.

Morello, E.B. & E. Arneri (2009): Anchovy and sardine in the Adriatic Sea - an ecological review. Oceanography and Marine Biology: An Annual Review, 47, 209–226.

NIB (2017): A brief description of the coastal oceanographic buoy "Vida". Nacionalni Inštitut za biologijo (NIB), www.nib.si/mbp/sl/oceanografski-podatki/buoy-2 (3. 3. 2017).

NUMO (2013): Začetna presoja morskih voda v pristojnosti Republike Slovenije (Marine Environment Management Plan. Initial assessment of marine waters undert the jurisdiction of Republic of Slovenia). Načrt upravljanja morskega okolja (NUMO). Ljubljana, Inštitut za vode Republike Slovenije, 59 pp.

Ogorelec, V., M. Mišič & J. Faganeli (1991): Marine Geology of the Gulf of Trieste (northern Adriatic): Sedimentological aspects. Marine Geology, 99, 79–92.

Ogrin, M. (2012): Uvod v oceanografske razmere Tržaškega zaliva (Introduction to the oceanographic situation of the Gulf of Trieste). In: D. Ogrin (Editor). GeograFF 12. Ljubljana, Znanstvena založba Filozofske fakultete Univerze v Ljubljani, 107–111.

Palmieri, M. G., A. Barausse, T. Luisetti & R. K. Turner (2014): Jellyfish blooms in the Norther Adriatic Sea: Fishermen's perceptions and economic impacts on fisheries. Fisheries Research, 155:51–58. doi:10.1016/j.fishres.2014.02.021 (5. 3. 2018).

Pengal, P., T. Modic & B. Cokan (2014): Pilot action to perform the appraisal of small pelagic fish resources in

the waters in front of Slovenia through eggs and larvae surveys: Final Report. Ljubljana, Zavod za ribištvo, 29 pp.

Peterlin, M., E. Gabrijelčič, M. Orlando-Bonaca, L. Lipej, A. Malej, J. Francé, B. Čermelj, O. Bajt, N. Kovač, B. Mavrič, V. Turk, P. Mozetič, A. Ramšak, T. Kogovšek, M. Šiško, V. Flander-Putrle, M. Grego, T. Tinta, B. Petelin, V. Vodopivec, M. Jeromel, U. Martinčič, V. Malačič, B. Marčeta, P. Pengal & I. Strojan (2013): Načrt upravljanja morskega okolja. Začetna presoja morskih voda v pristojnosti Republike Slovenije: Bistvene lastnosti in značilnosti morskih voda (Management plan of marine environment. Initial assessment of marine waters under the jurisdicition of the Republic of Slovenia: Essential characteristics and characteristics of marine waters). Ljubljana, Ministrstvo za kmetijstvo in okolje, 59 pp.

Ré, P. & I. Meneses (2009): Early stages of marine fishes occurring in the Iberian Peninsula. Lisbon, IPIMAR in IMAR, 238 pp.

Regner, S. (1985): Ecology of planktonic stages of the anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), in the Central Adriatic. Acta Adriatica, 26(1), 5–113.

Regner, S. (1996): Effects of environmental changes on early stages and reproduction of anchovy in the Adriatic Sea. Scientia Marina, 60, 167–177.

Regner, S., F. Kršinić, I. Marasović & D. Regner (1987): Spawning of sardine (*Sardina pilchardus* (Walbaum, 1792)), in the Adriatic under upwelling condition. Acta Adriatica, 28, 12, 161–189.

Riveiro, I., C. Guisande, I. Maneiro & A.R. Vergara (2004): Parental effect in the European sardine *Sardina pilchardus*. Marine Ecology Progress Series, 274, 225–234.

Sever, M. (2016): Koncentracije klorofila–a za slovensko morje 2014/2015 (Concentrations of chlorophyll-a in the Slovenian Sea in 2014/2015). Ljubljana, Agencija Republike Slovenije za okolje, Sektor za kakovost voda, Oddelek za ekološko stanje (ARSO database display, January 2016).

Shaltout, M. & A. Omstedt (2014): Recent sea surface temperature trends and future scenarios for the Mediterranean Sea. Oceanologia, 56(3), 441-443.

Somarakis, S., I. Palomera, A. Garcia, L. Quintanilla, C. Koutsikopoulos, A. Uriarte & L. Motos (2004): Daily egg production of anchovy in European waters. e ICES Journal of Marine Science, 61, 944–958.

Strojan, I. (2014a): Dinamika in temperatura morja v avgustu 2014 (Sea dynamic and temperature in August 2014). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 78–83.

Strojan, I. (2014b): Dinamika in temperatura morja v septembru - novembru 2014 (Sea dynamic and temperature in September – November 2014). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 74–91.

Strojan, I. (2014c): Dinamika in temperatura morja v decembru 2014 (Sea dynamic and temperature in December 2014). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 88–93.

Strojan, I. (2015a): Dinamika in temperatura morja v februarju 2015 (Sea dynamic and temperature in February 2015). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 74–79.

Strojan, I. (2015b): Dinamika in temperatura morja v marcu 2015 (Dynamic and sea temperature in March 2015). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 52–57.

Strojan, I. (2015c): Dinamika in temperatura morja v aprilu 2015 (Dynamic and sea temperature in April 2015). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 50–55.

Strojan, I. (2015d): Dinamika in temperatura morja v maju 2015 (Dynamic and sea temperature in May 2015). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 60–65.

Strojan, I. (2015e): Dinamika in temperatura morja v juniju - juliju 2015 (Dynamic and sea temperature in June - July 2015). In: T. Cegnar (Editor). Naše okolje – Bilten RS agencije za okolje. Agencija Republike Slovenije za okolje, Ljubljana, Slovenia, 48–57.

Štirn, J. (1968): Pelagial Severnega Jadrana: Njegove oceanološke razmere, sestav in razporeditev biomase tekom leta 1965 (The North Adriatic pelagial: its oceanological characteristics, structure and distribution of the biomass during the year 1965). Thesis. Ljubljana, Slovenska akademija znanosti in umetnosti, 92 pp.

Štirn, J. & L. Kubik (1974): Prispevek k poznavanju migracij in obsega populacij sardele in inčuna v Severnem Jadranu (Contributions to the knowledge of migrations and the volume of the pilchard and anchovy populations in the northern Adriatic). Acta Adriatica, 16, 24, 401–422.

Škrivanič, A. & d. Zavodnik (1973): Migrations of the sardine (*Sardina pilchardus*) in relation to hydrographical conditions of the Adriatic Sea. Netherlands Journal of Sea Research, 7, 7–18.

WGSASP (2017): Working Group on Stock Assessment of Small Pelagic Species. Report. Rome, FAO HQ, 66 pp.

Varagnolo, S. (1964): Calendario di compares di uova pelagiche dei teleostei marini nel plankton di Chioggia. Archive Oceanographic Limnological, 13(2), 249–279.

Zavatarelli, M. & N. Pinardi (2003): The Adriatic Sea modelling system: a nested approach. Annales Geophysicae, 21, 345–364.

Zorica, B., V. Čikeš Keč, G. Brzulja & V. Kraljević (2014): Presence of anchovy eggs in the eastern Adriatic Sea during the winter, coincidence or not? Acta Adriatica, 55(1), 107–112.