J. Mar. Biol. Ass. U.K. (2007), **87**, 789–796
Printed in the United Kingdom

doi: 10.1017/S0025315407053842

On the occurrence of ocean sunfish *Mola mola* and slender sunfish *Ranzania laevis* in the Adriatic Sea

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Presence and habitat preference of two pelagic fish species—*Mola mola* and *Ranzania laevis*—are investigated from all available records obtained in the Adriatic from 1781 up to today. Absence of systematic investigations is overcome by relating their occurrences to the long-term meteorological and oceanographic data sets representing local conditions and processes. Seasonal and interannual distributions of these two species are significantly different and point to a possible different causes of their appearance. On the seasonal scale almost all findings of *M. mola*, with only a few exceptions, are from the warm part of the year, whereas *R. laevis* is appearing throughout the year with the highest number of individuals in December. Analysis of the interannual meteorological and oceanographic conditions indicates that occurrence of *M. mola* coincides with the sea warming, whereas the oceanographic conditions favourable for appearance of *R. laevis* are more complex and could be related to the abrupt change in the large scale atmospheric conditions. Changeable atmospheric conditions coincided with increased productivity in the Adriatic and increased number of zooplankton and small pelagic fish, which are the main food for *R. laevis*.

INTRODUCTION

The Molidae family is represented in the Mediterranean by the two monotype genera: *Ranzania* and *Mola,* with the two species: *Ranzania laevis* (Pennant, 1776) and *Mola mola* (Linnaeus, 1758). The occurrences and habitat preference of large pelagic fish species as the sunfish, *M. mola* and *R. laevis*, are poorly understood because they are rarely encountered and hence have not been the object of systematic investigations. Knowledge of the natural history of Molidae is sparse, but they are recognized as the most fecundant extant vertebrate with a single female capable of producing as many as 3×10^6 eggs (Parenti, 2003). Ocean sunfish *M. mola* inhabit warm and temperate zones of all oceans (occasionally the western Baltic, Mediterranean), while slender sunfish *R. laevis* is a cosmopolitan species, inhabiting subtropical areas of the Atlantic and the eastern Pacific (Tortonese, 1990). These two species are rare in the Adriatic Sea (Jardas, 1985, 1996; Affronte et al., 2002), and there are only a few contradictory reports on their occurrence. The only published report on the ocean sunfish off the eastern Adriatic coast is given by Morović (1974), who claims that slender sunfish occurs more rarely than ocean sunfish, whereas on the other hand several other authors reported sparse data on slender sunfish only (Specchi & Bussani, 1973; Onofri, 1978; Jardas & Knežević, 1983). Slender sunfish has never been recorded in the Black Sea and it is rather rare in the Mediterranean and Adriatic Seas (Jardas & Knežević, 1983). In the year 2002, an unusual occurrence of ocean sunfish specimens have been recorded along the northern Adriatic coasts. Five specimens were found stranded on the Italian coast and an additional two specimens have been sighted in the period from April to June 2002 (Affronte et al., 2002). The same authors cited only five records of sunfish before that unusual occurrence in 2002 on the Italian coasts of the northern Adriatic.

Very little is known about the biology, ecology and behaviour of these two species. Myers & Wales (1930) presented the data on the occurrence and habits of ocean sunfish in Monterey Bay, California. Lee (1986) reported the data on seasonal, thermal and zonal distribution of ocean sunfish off the North Carolina coast. Sims & Southall (2002) reported the occurrence of ocean sunfish near the fronts in the western English Channel, while Castro & Ramos (2002) related the occurrence of slender sunfish to the sea warming off the island of Gran Canaria (Canary Islands), while Cartamil & Lowe (2004) described diurnal movement patterns of ocean sunfish off southern California. Houghton et al. (2006) presented data on the distribution, abundance and behaviour of the ocean sunfish in the Irish and Celtic Seas.

The present paper aims to assess the presence of the ocean and slender sunfish in the Adriatic Sea in relation to the basin-scale meteorological and oceanographic conditions and also to contribute to the knowledge of their populations in the area.

MATERIALS AND METHODS

Data on the occasional surface appearances of the two sunfish species—*Mola mola* and *Ranzania laevis*—in the Adriatic for the period 1781 to 2006 were obtained from the published sources (Kolombatović, 1881, 1882; Faber, 1883; Katurić, 1892; Kosić, 1898, 1893; Langhoffer, 1905; Ninni, 1912; Parenzan, 1931, 1978; Morović, 1974; Onofri, 1978, 1983; Jardas, 1985; Mušin, 1989; Pallaoro & Jardas, 1996, Affronte et al., 2002) and interviews with fishermen (Table 1). Each record has the date and location of

Table 1. *Dates and locations of (A)* Mola mola *(A) and* Ranzania laevis *(B) occurrences.*

A.

Location	Month	Year
Castel di Mezzo (7 m. off Pesaro)	November	1781
Lido Venetto	September	1841
Bakarac	July	1893
Split	August	1898
Dubrovnik	June	1901*
Dubrovnik	April	1902
Rimini	April	1934
West of Dugi Otok	September	1958
Podvelebitski kanal	July	1960
Novigrad	July	1964
Foce del Bevano Ravenna	August	1966
Pelješki kanal	May	1973
Novigrad Zadarski	August	1973
Portorož	April	1975
Ratac	May	1977
Pelješac	May	1978
Rovinj	May	1978
Krk	July	1980
Podvelebitski kanal	August	1986
Podvelebitski kanal	August	1987
Šoltanski kanal	March	1987
Sveti Andrija	July	1993
Kopar	September	1998
Spiagge di Cervia	March	1999
Kupari	May	2001
Podvelebitski kanal	July	2001
Foce Fiume Musone, Numana (An)	April	2002
Lido degli Estensi (Fe)	April	2002
Trieste	April	2002
Porto Garibaldi (Ra)	April	2002
Riccione (Rn)	April	2002
Onde del Mare Riccione (Rn)	May	2002
Riccione (Rn)	June	2002
Porto Recanati (An)	June	2002
Podvelebitski kanal	July	2002
Lastovo	August	2002
Blitvenica	August	2003**
Novigrad	August	2005
Šibenski kanal	March	2006*

*, double occurrence; **, triple occurrence.

B.

Location	Month	Year
Split	January	1881
Split	March	1882
Dubrovnik	December	1884*
Dubrovnik	January	1892
Dubrovnik	March	1892
Novigradsko more	August	1892
Split	March	1898
Split	April	1898
Pelješki kanal	March	1903
Dubrovnik	April	1903
Pula	November	1931
Port of Trieste	July	1972
Marina	December	1973
Vela Luka	April	1975
Vrbovica	December	1977
Neretva	December	1977
Kotorska	December	1977
Pelješki kanal	December	1977
Boka Kotorska	December	1978
Drače Pelješac	October	1979
Kaprije	November	1979
Ulcinj	January	1980
Vela Luka	January	1980
Kaštela Bay	March	1980
Klek-Neum	March	1980
Bar	April	1980
Klek-Neum	April	1980
Gruž	December	1980
Punta Planka	May	1982
Vis	July	1990
Vis	July	1994
Pelješac	August	1998
Vela Luka	August	2002
Lastovo	August	2003

*, double occurrence.

occurrence. There is only rare evidence on the strandings of the sunfish in the whole eastern Mediterranean basin and Adriatic (Jardas, 1996). For that reason, each record of rare or little-known fish species has been always registered by scientists or by fishermen who always inform scientists about the record. There is a long tradition of monitoring of exotic, rare and little-known fish in the Adriatic (about 225 years) and cooperation between scientists and fishermen in tracking records of such fish.

We tried to overcome the absence of systematic investigations of the sunfish species in the Adriatic by relating their reported occurrences to the regularly measured oceanographic and meteorological parameters. Therefore, seasonal and interannual variability in the appearances of these two species is discussed in relation to the air and sea surface temperatures (SST). All available occurrences of *M. mola* and *R. laevis* were linked to the long-term air temperature data from the meteorological station Hvar (Figure 1). Hvar station is suitable for discussion since its long-term data series on the monthly and annual scale represents well atmospheric conditions along the Adriatic coast. The recent records (from 1986 up to today) for sea surface temperatures at the location closest to the occurrence spot were obtained from satellite measurements published in SATMER (1986–2002) and from NOAA/NASA AVHRR Oceans Pathfinder SST night-time data with 4 km resolution (http://podaac.jpl.nasa.gov; Vazquez et al., 1998). These values were compared to the climatological annual course of the *in-situ* SST from two permanent oceanographic stations in the northern (Maselli et al., 1990; Crisciani et al., 1995) and middle Adriatic: Trieste and Stončica (Figure 1). Salinity data from the intermediate layer of the Stončica station were also used in the discussion of the sunfish appearances, since it is well known that intermediate salinity is an indicator of the increased inflow of the warm and salty water from the Ionian Sea to the Adriatic (Buljan & Zore-Armanda, 1976).

An atmospheric index related to the Adriatic climate is defined and used in the analysis. It is defined following the

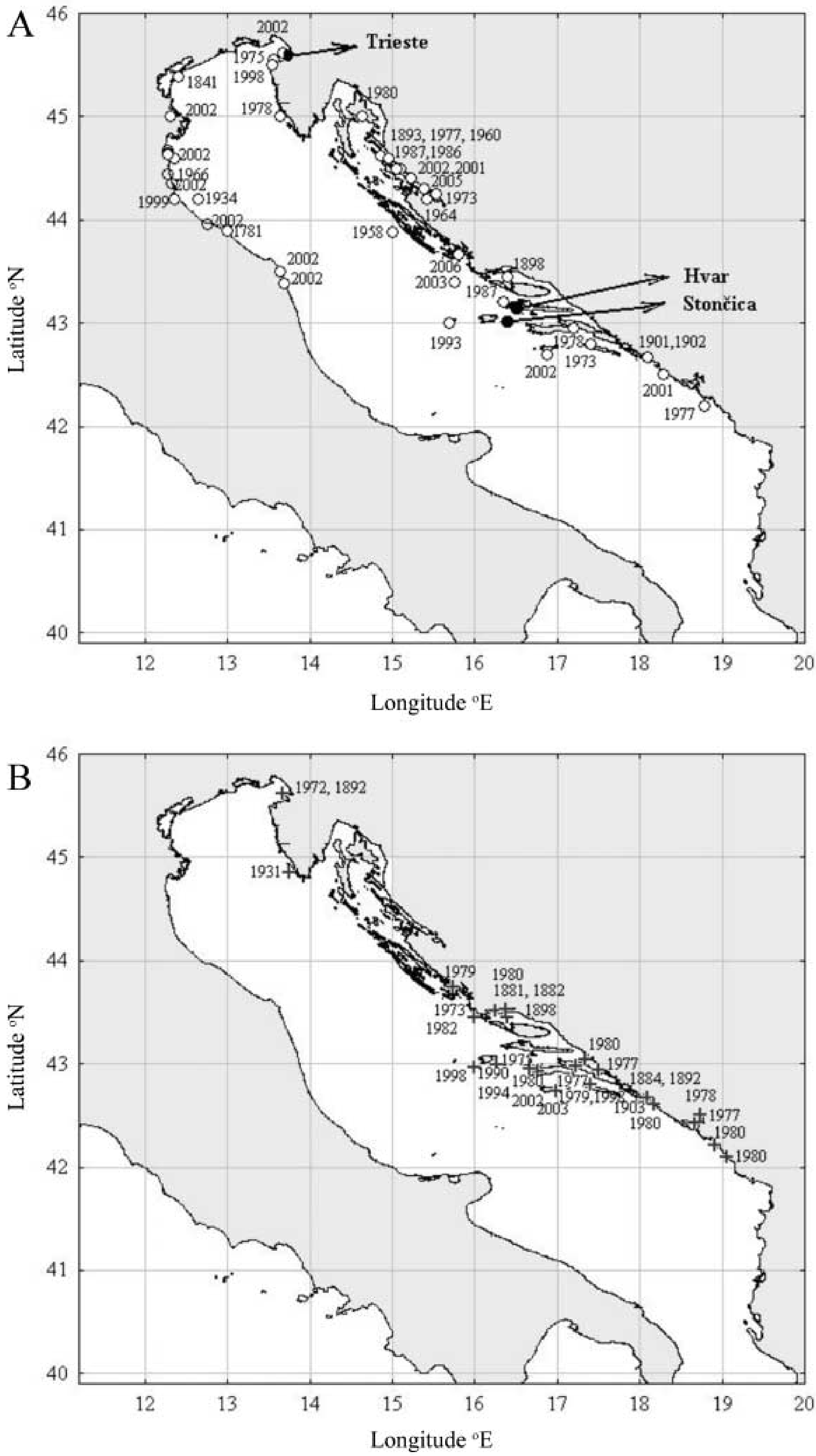

Figure 1. Adriatic Sea with (A) *Mola mola* (A) and (B) *Ranzania laevis* (B) occurrences. Locations of the meteorological station Hvar and oceanographic stations Stončica and Trieste are also denoted.

procedure from Grbec et al. (2002) as the first principal component of Principal Component Analysis (PCA) applied to the mean annual air pressure data over the northern hemisphere within the area 30°W–40°E and 30°–65°N for the period 1960–2003. The sea level pressure data are taken from the NCEP/NCAR re-analysis dataset (http://www.cdc.noaa.gov) and the obtained index describes mean annual pressure variability over the central part of the northern Atlantic, important for the Adriatic climate (Grbec et al., 2002, 2003).

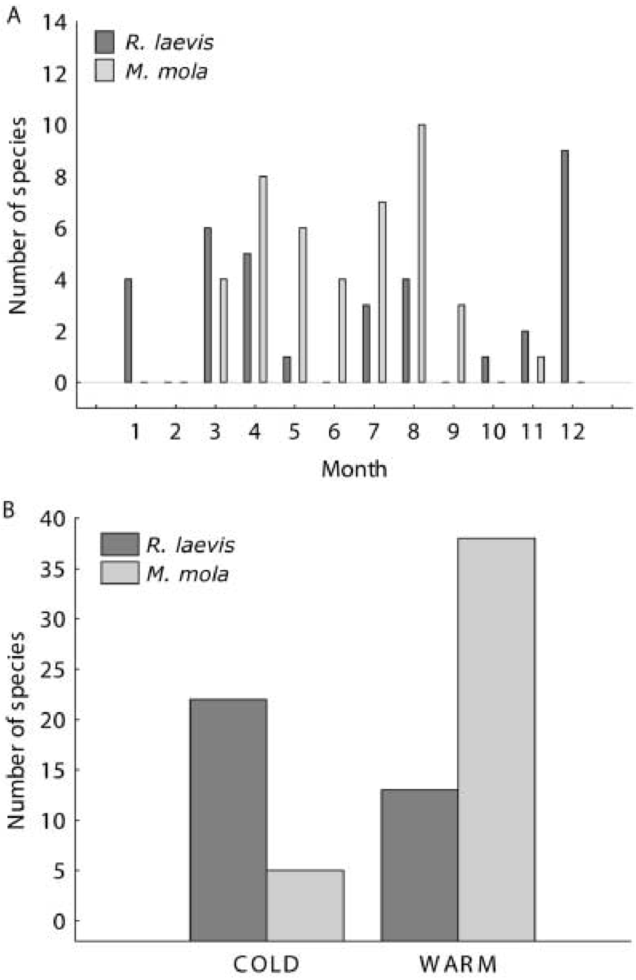

Figure 2. Monthly distributions of *Mola mola* and *Ranzania laevis* and their occurrences in (A) the warm (comprising October, November, December, January, February and March) and (B) the cold (comprising April, May, June, July, August and September) part of the year.

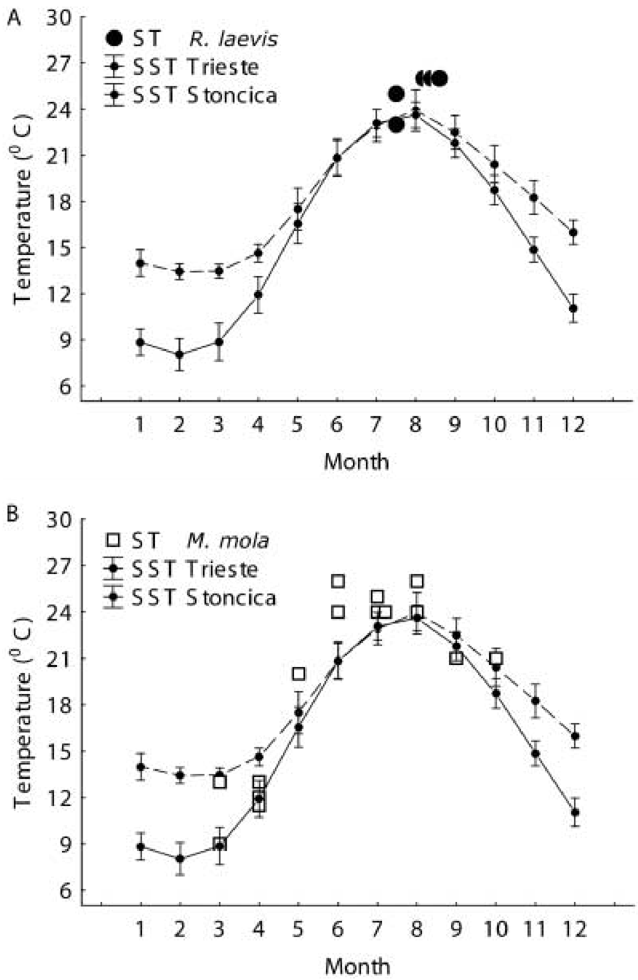

Figure 3. Mean annual sea surface temperatures (SST) from the permanent oceanographic stations Trieste and Stončica with satellite estimates of sea surface temperatures (ST) in relation to *Ranzania laevis* (A) and *Mola mola* (B) appearances.

RESULTS

A total of 43 and 35 reliable captures of ocean sunfish and slender sunfish were reported in the Adriatic, respectively (Table 1). Dates of recorded captures ranged between 1781 and 2006. Spatial distribution depicted on Figure 1 indicates that most of the occurrences of the two sunfish species are from the eastern coast, with only a few records of *Mola mola* along the western coast.

Seasonal distributions of the occurrence of the two sunfish species are different (Figure 2): *M. mola* is appearing in the warm season, with only four occurrences in March and one in November, whereas on the other hand *Ranzania laevis* is appearing almost throughout the year with the highest number of individuals in December. To test the differences in the seasonal cycles of the two sunfish species we calculated the significance level for the difference between proportions of small independent samples. *Mola mola and R. laevis* occurrences are independent since their correlation coefficient is not significant. The significance level for the differences is computed based on the t-values for the respective comparison. In the calculations we compared per cents of the occurrences for both species in the cold and warm seasons, with the cold season being October, November, December, January, February and March, and the warm season being April, May, June, July, August and September (Figure 2B). The first hypothesis that the occurrences of the two species are different in the cold part of the year is significant at the level of 99%. The same result is obtained for the warm part of the year, again the occurrences of the two species are significantly different with the same significance level. Hence, both hypotheses confirm significantly different seasonal occurrences for these two species.

Satellite estimates of SST at the positions of the sunfish occurrences were above 20°C, with the exception of the *M. mola* findings from March 1987 and 1999 and findings from April 2002 (Figure 3B). Comparison of the satellite SST at the location of the sunfish occurrences with the *in situ* climatological SST from the permanent oceanographic stations Stončica and Trieste showed that temperatures associated with *M. mola* and *R. laevis* appearances were below the climatological monthly values only in three cases and the differences were below half a degree (Figure 3). Although the satellite infrared sensor actually measures skin surface temperature, obtained estimates are calibrated with *in situ* temperatures and therefore satellite estimates follow better *in situ* than skin temperature (Schluessel et al., 1990). Moreover, skin temperatures,

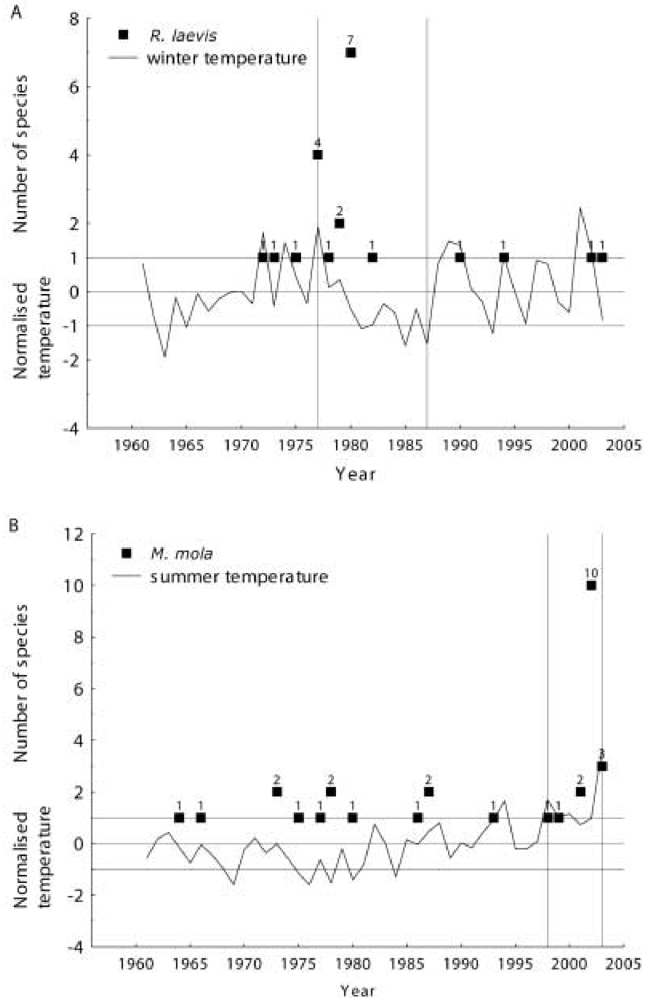

Figure 4. Normalized air temperature time-series from the meteorological station Hvar in (A) winter and (B) summer with *Ranzania laevis* and *Mola mola* occurrences.

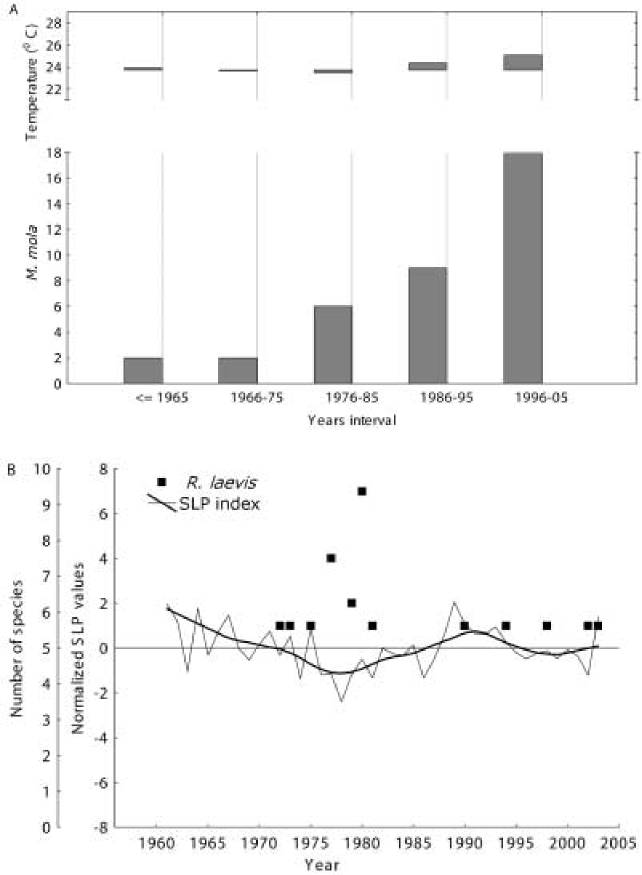

Figure 5. (A) Cumulative *Mola mola* occurrence and air temperature from the meteorological station Hvar; and (B) the sea level pressure (SLP) index over the central part of the northern Atlantic with *Ranzania laevis* occurrences.

especially the night ones which are used in our study, are due to the longwave radiation and evaporation below *in situ* values (Smith et al., 1996) and therefore we can accept the statement that SST values at the spots of the recent occurrences of both species are higher than climatological values. Unfortunately, during the period between 1977 and 1980 with the numerous occurrences of *R. laevis* satellite SST estimates are not available and the previous statement is questionable for this species.

Available satellite SST images from SATMER (1986–2002) publications and Pathfinder dataset (http://podaac.jpl.nasa.gov; Vazquez et al., 1998) coinciding with the sunfish occurrences showed no distinguishable patterns like filaments, fronts, eddies etc. It should be noted that almost all recent occurrences of *M. mola* were during the summer, as well as recent occurrences of *R. laevis*, when the Adriatic surface temperature field is characterized by weak thermal gradients (Artegiani et al., 1997; Gačić et al., 1997). Mesoscale circulation patterns are usually connected with strong wind and river influence, which are significant in the Adriatic during the other seasons.

To resolve a strong interannual variability in the occurrence, an attempt is made to connect it with the long-term atmospheric, and consequently oceanographic changes. The *M. mola* occurrences are related to the air temperature from the meteorological station Hvar (Figure 4A). The period with the most numerous *M. mola* occurrences from 1998 to 2006 has significantly higher summer temperatures than the period 1961–1997 with significance level of 99%, which confirms the statement that this species prefers warm summers. The most numerous occurrences of *R. laevis* were during winters in the period from 1977 to 1980 (Figure 4B). Comparison of the mean winter temperatures for the periods 1961–1976 and 1981–2003 with winters from 1977 to 1980 indicates that latter temperatures are significantly below the long-term average with significance level of 99%.

Comparing environmental conditions with occurrences of both species, additional analyses were made. Since most of the *M. mola* occurrences were from the warm part of the year and from the years with warm summers we compared its cumulative occurrence with the cumulative records of air temperature (Figure 5A). As the curves correspond very closely, we believe that the occurrences of *M. mola* are connected to the air, and consequently sea warming. The period with the most numerous occurrences of *R. laevis* (1977–1980) is significantly connected with low winter temperatures, and this period also seems to be linked to the shift in climatic regime. Namely, the analysis of the mean annual pressure index over the middle Atlantic (Figure 5B) reveals the marked decrease in the period 1975–1978, which precedes the years with the

https://doi.org/10.1017/S0025315407053842 Published online by Cambridge University Press

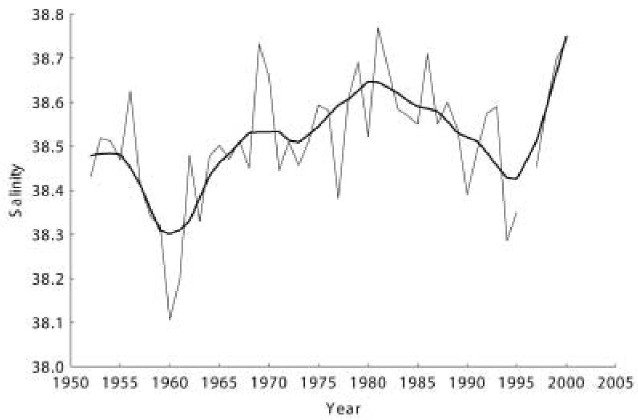

Figure 6. Mean annual salinity in the intermediate layer of the middle Adriatic Sea. Solid line displays values smoothed by LOWESS analysis (Cleveland, 1979).

highest number of *R. laevis* captures. The observed shift in the pressure regime is probably similarly linked with the changes in the Adriatic ecosystem that followed couple of years later and were reported by several authors. Pucher-Petković et al. (1987) reported an abrupt increase in the Adriatic primary production, whereas Marasović et al. (1988) found the correlation between increased productivity and catch of small pelagic fish in the middle Adriatic with a lag of two years.

DISCUSSION

The frequency rate of the two sunfish species in the Adriatic is different according to different authors. Morović (1974) stated that the slender sunfish occur more rarely than ocean sunfish, while according to other authors ocean sunfish is particularly rare (Specchi & Bussani, 1973; Onofri, 1978; Jardas & Knežević, 1983). Irrespective of these contradictory reports, both species are rare in the Adriatic Sea. In the period from 1781 to 2006 we found 43 and 35 records of ocean and slender sunfish, respectively.

Records on sunfish captures are coming mostly from the eastern Adriatic shore (Figure 1). There are several records of *Mola mola* from the western shore, but no records of *Ranzania laevis* there. The surface circulation in the Adriatic is cyclonic (Buljan & Zore-Armanda, 1976) with incoming flow along the eastern coast. These species, probably coming from the Mediterranean, enter the Adriatic following the north-westward current on their way from the Otranto Strait toward the northern Adriatic.

The question is what is the reason for different occurrence frequency of these two species in different years and why are the records of *R. laevis* randomly distributed throughout the year (although the highest number of individuals were observed in December), whereas *M. mola* appears mostly in the warmer part of the year? This cannot be easily answered since, on the one hand the records of these species are still very rare, even in the years of their increased occurrence, and on the other hand knowledge on ecology and biology of the two species is rather poor.

Most of the findings of the ocean sunfish around the world originate from the warm part of the year, similarly as in the Adriatic. Ocean sunfish observed in the western Atlantic off North Carolina were not randomly distributed by season or location and were most frequently encountered in spring (mid-April to mid-May) and occasionally in summer and autumn, but were absent in winter (Lee, 1986). Sims & Southall (2002) reported that ocean sunfish were not seen in May in any year in the western English Channel, but occurred almost entirely during June and July, although an individual was sighted in early September 1995.

There are some indications that slender sunfish are spawning in the Adriatic Sea, as Jardas & Knežević (1983) reported a caught male with fully ripe testicles ready for spawning. The same authors concluded that this species spawn probably at the end of the year and have connected such behaviour with their more frequent records in the colder part of the year, when they appear closer to the coast.

The presence of slender sunfish, as reported also for other Molidae, is normally associated with the seasonal warming process (Quero et al., 1983). Castro & Ramos (2002) also reported the occurrence of slender sunfish off the island of Gran Canaria (Canary Islands) in relation to the sea warming. Generally for the Adriatic, Dulčić et al. (2004) reported that the fish species richness correlates significantly with the temperature data, and that variations in temperature conditions correlate well with the North Atlantic Oscillation index. Although the increased number of ocean sunfish in the Adriatic during the last decade seems to be related to the increased summer temperatures, a similar conclusion cannot be reached for slender sunfish. On the contrary, our records on slender sunfish are correlated with winters having air temperatures below the long-term average. Around the coasts of Britain and Ireland *M. mola* is the most frequently reported member of the Molidae with *R. laevis* sighted only very rarely (Wheeler, 1969).

Numerous *R. laevis* winter occurrences during the period 1977–1980 are intriguing and we assume that they could be related to the abrupt increase of the primary productivity observed in the Adriatic Sea by the end of 1970s (Pucher-Petković et al., 1987). Changes in the primary production are coinciding with changeable atmospheric conditions on the hemispheric-scale, represented by air pressure index (Figure 5B). Increased productivity was beneficial for the fisheries of the small pelagic fish: e.g. in the middle Adriatic the connection between increased productivity and sardine catch has been found with a lag of approximately two years (Marasović et al., 1988). In this period huge quantities of jellyfish (especially *Pelagia noctiluca*) were also recorded in the Adriatic Sea (Purcell et al., 1999). Generally molids are reported to feed primarily on planktonic organisms and small pelagic fish, although a variety of prey such as brittlestars, flounders, and leptocephalus larvae have been found in their guts (Norman & Fraser, 1949; Sommer et al., 1989). Therefore we believe that *R. laevis* increased in number in the Adriatic as a result of food foraging.

Specchi & Bussani (1973) held that a slender sunfish individual caught from the Port of Trieste was associated with the currents which carried water masses from the southern Adriatic and Ionian Sea, and that it was in pursuit of small pelagic fish on which it probably fed.

Increased inflow of the warm and salty Ionian water mass into the Adriatic assumed by Specchi & Bussani (1973) can be confirmed by the corresponding intermediate salinity increase in the middle Adriatic (Figure 6). The highest frequency of slender sunfish records during the period 1977 and 1980 reported by Jardas & Knežević (1983) could be attributed to the same cause since this period was also characterized by the salinity increase (Figure 6) and by the increased productivity as already discussed.

CONCLUDING REMARKS

Although spatial and temporal distributions of two sunfish species do not arise from systematic investigations, their relation to the regularly measured meteorological and oceanographic parameters allowed us to bring the following conclusions.

All captures of *Mola mola* in the Adriatic, with a few exceptions, are from the warm part of the year, which is in agreement with the published findings for other areas. *Ranzania laevis* captures are distributed throughout the year, with the highest number of individuals in December, which can be connected with their spawning period. Inter-annual distribution of *M. mola* is correlated with the increased summer temperatures during the last decade, whereas *R. laevis* appearance seems to be connected with the increased productivity in the Adriatic and accompanied increased number of zooplankton and small pelagic fish, their main food.

Even though our results highlight some aspects of the population dynamics and distribution of two sunfish species in the Adriatic Sea, their status needs to be evaluated on a continuous basis, as it is becoming increasingly apparent that uncommon species, and particularly those on the edge of their distribution, can be essential indicators of environmental changes (Swaby & Potts, 1990; Dulčić & Pallaoro, 2002). There is also a need for satellite-tracking studies to determine the movements and habitat preferences of these two species over diel and seasonal scale.

AVHRR SST data were obtained from the NASA Physical Oceanography Distributed Active Archive Center at the Jet Propulsion Laboratory, California Institute of Technology, USA. NCEP air pressure re-analysis data were provided by the NOAA-CIRES ESRL/PSD Climate Diagnostics branch, Boulder, Colorado, USA, (http://www.cdc.noaa.gov/). Meteorological data from Hvar Station are kindly provided by the Meteorological and Hydrological Service of the Republic of Croatia.

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Submitted 21 March 2006. Accepted 27 March 2007.