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ACOUSTIC OBSERVATIONS OF JELLYFISH DISTRIBUTION IN MALO LAKE (MLJET IS., CROATIA)

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ABSTRACT

An acoustic survey covering Malo Lake (Mljet Is., Croatia) was performed to obtain a synoptic picture of the distribution of acoustically detectable jellyfish and other biota at 120 kHz. Acoustic records from 24 parallel transects were associated with fish schools and with the scyphomedusa Aurelia *sp. for which vertical and horizontal distributions were documented. Echointegration and in situ acoustic target strength measurements were employed to estimate medusae abundance, accounting for approximately 500,000 individuals for Malo Lake.*

Key words: Hydroacoustics, medusae, Scyphozoa, *Aurelia*, distribution, abundance

OSSERVAZIONI ACUSTICHE DELLA DISTRIBUZIONE DI MEDUSE NEL LAGO MINORE (ISOLA DI MLJET, CROAZIA)

SINTESI

Gli autori hanno portato a termine un'indagine acustica nel Lago Minore (isola di Mljet, Croazia) allo scopo di ottenere un'immagine sinottica della distribuzione di meduse e altri organismi acusticamente distinguibili a 120 kHz. Le misurazioni acustiche derivanti da 24 transetti paralleli sono state associate a banchi di pesci e alle scifomeduse Aurelia *sp., per le quali è stata documentata la distribuzione verticale ed orizzontale. Ecointegrazioni e misurazioni acustiche in situ sono state effettuate al fine di valutare l'abbondanza delle meduse, che si aggira intorno ai 500.000 individui per il Lago Minore.*

Parole chiave: idroacustica, meduse, Scyphozoa, *Aurelia*, distribuzione, abbondanza

INTRODUCTION

Recent worldwide increases in jellyfish abundances, blooms and related economical and societal problems (Graham, 2001; Hay, 2006; Lynam *et al.*, 2006; Attrill *et al.*, 2007; Purcell, *et al.*, 2007) have focused attention on finding ways to obtain accurate measures of jellyfish abundance, distribution and temporal variability (Brierley *et al.*, 2005; Alvarez Colombo *et al.*, 2009). Traditional surveys based on plankton net trawls, SCUBA diving and underwater videos provide only semi-quantitative estimates. Consequently, the spatial distribution of medusae is generally not well understood.

Recently, acoustics have been employed with increasing refinement for jellyfish population assessment (Brierley *et al.*, 2005; Lynam *et al.*, 2006; Alvarez Colombo *et al.*, 2009; Han & Uye, 2009), and for detailed individual behaviour studies (Alvarez Colombo *et al.*, 2003; Båmstedt *et al.*, 2003; Klevjer *et al.*, 2009). Acoustics has been used effectively also in a variety of different environments, such as deep sea fjords, small salt lakes, large upwelling systems and turbid coastal lagoons and estuaries (Mianzan *et al.*, 2001; Alvarez Colombo *et al.*, 2003, 2009; Båmstedt *et al.*, 2003; Brierley *et al.*, 2005; Lynam *et al.*, 2006; Han & Uye, 2009; Klevjer *et al.*, 2009).

On the north-western side of the offshore island of Mljet (Croatia, the southern Adriatic Sea), there is a system of small seawater lakes in a submerged karstic valley (Fig. 1). Veliko jezero (BL, Big Lake) is the biggest lake on which descriptions of some biotic components and their distributional patterns have been published (Benović *et al.*, 2000; Malej *et al.*, 2007; Alvarez Colombo *et al.*, 2009). Inland and adjacent to this lake, connected to it by a narrow passage, is another smaller lake, Malo jezero (SL, Small Lake), with a surface area of 0.24 km^2 and a maximum depth of 34 m. Information about biological components of this small lake is scarce but it is also characterized by the presence of medusa *Aurelia* sp. BL is an oligotrophic coastal lake, and the medusae therein persist in the lake throughout the year (Benović *et al.*, 2000). Although the scyphomedusa *Aurelia* is present in the shallow northern portion of the Adriatic Sea and in other semi-enclosed bays along the Adriatic coast, it is absent in open Adriatic waters offshore of Mljet Island (A. Benović, *unpubl. observ.*). The *Aurelia sp.* population in SL seems to wax and wane over the years, disappearing completely then re-populating the next year, perhaps due to influx of medusae from BL (Benović *et al.*, 2000).

Throughout the Adriatic this species has been called *Aurelia aurita* (Linnaeus, 1758). Recent molecular investigations, however, have questioned the traditionally taxonomic designation (Schroth *et al.*, 2002) and now, provisionally, the species is simply called *Aurelia* sp. 5 (Dawson *et al.*, 2005). In the present study, therefore, it is referred to as *Aurelia*.

During October 2006, a field study was carried out at BL employing a scientific echosounder and video-recorder to determine synoptically the distribution, density and biomass of the *Aurelia* population and other biological scatterers like fish (Alvarez Colombo *et al.*, 2009). The *Aurelia* population consisted of approximately 4,200,000 individuals that were mostly aggregated in and below the thermocline during the day. The acoustic techniques used to characterize *Aurelia* in BL, therefore, were used also in the adjacent SL. The *Aurelia* population in SL has been reported to have distributions and behaviour somewhat different than BL population, with a more regular vertical distribution not associated with the thermocline and with the highest abundances in the deeper layers (17–25 m) at densities of 1 to 10 ind. per 100 m^{-3} (Benović *et al.*, 2000).

This paper presents field information on *Aurelia* in SL. The goals are to quantify the population of *Aurelia*, to describe the horizontal and vertical distribution patterns of its aggregations, and the distribution of other biotic components of the ecosystem.

MATERIALS AND METHODS

On October 6, 2006, a 4 m boat was used in SL to conduct an acoustic survey of the entire lake by dividing the surface into 24 parallel transects 20 m apart, perpendicular to the lake's main axis. Given that the complete area was covered in a period of 2 hours, it may be considered that the distributions of the entire *Aurelia* population and other biological scatterers like fish, were synoptically registered (Fig. 1). Acoustic recordings were obtained by means of a SIMRAD EY500 portable echosounder operating at 120 kHz, with a split-beam transducer. Angle and power sample data were recorded, providing simultaneous 20 log R and 40 log R time-varied-gain (TVG) functions for volume backscattering and target strength analysis, respectively. The echosounder was calibrated after sampling with a tungsten carbide calibration sphere following Foote *et al.* (1987). Post processing of echo-data was done with Echoview v. 4.1 software.

Aurelia acoustic target strength (TS) measurements were obtained *in situ*. The TS measurements were obtained while the boat stayed still at the point selected for the calibration process, following the methodology described in Alvarez Colombo *et al.* (2009). Following the same authors, those echotraces showing similar characteristics and individual acoustic signals as the medusae repeatedly sampled in BL in previous days, were then assigned as *Aurelia*. The abundance of *Aurelia* was estimated by echointegration (Foote *et al.*, 1991) for the water column from 2 m below the surface (beyond the transducer's acoustic near-field) to 1m above the bottom (in order to avoid the contribution of small demersal fish). The echograms were divided into intervals of 10

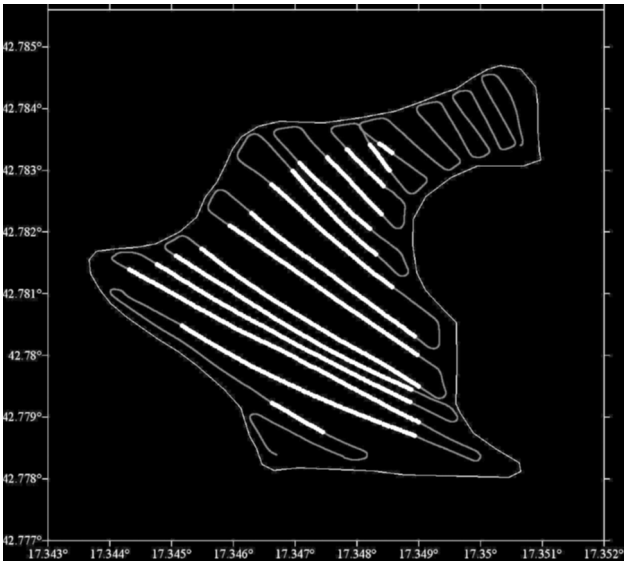

Fig. 1: Map of Malo Lake showing the acoustic track performed (grey line), the sections of the tracks considered for the assessment of* Aurelia *abundance (black lines), and the connection with Veliko Lake (upper right).
Sl. 1: Zemljevid Malega jezera s prikazom opravljenega sonarnega sledenja (siva črta), deli, obravnavani za oceno številčnosti* Aurelia *(črne črte) in povezava z Velikim jezerom (desno zgoraj).

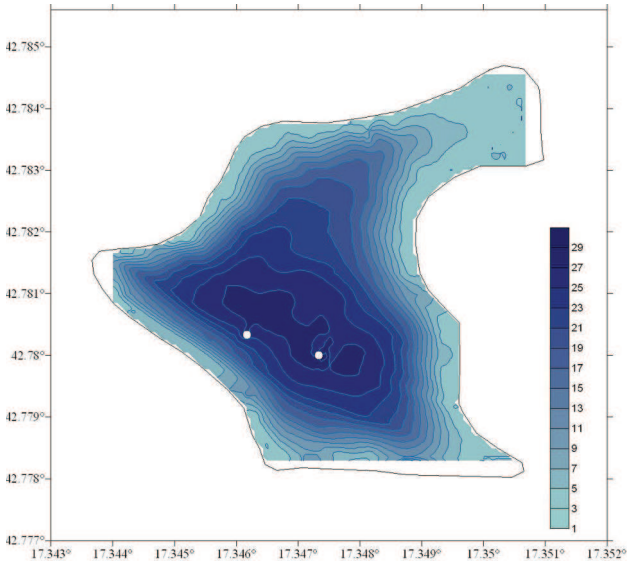

Fig. 2: Bathymetry of Malo Lake, showing the connection with Veliko Lake (upper right). The white circles represent the position of the deep hollows found. Scale in meters.
Sl. 2: Batimetrija Malega jezera z vidno povezavo z Velikim jezerom (desno zgoraj). Bela kroga označujeta položaj najdenih globeli. Legenda je v metrih.

pings, from where the coefficients of acoustic backscattering per unit area s_A (m^2 nmi^{-2}) and unit volume S_V (dB, re 1 m^2 m^{-3}) were obtained.

The near shore waters were excluded from the analysis of medusae distribution since these sectors contained mostly fish (Fig. 3). The abundance and concentration of individuals C (n m^{-3}) were derived from the echointegration data, using the average backscattering cross-section (σ_{bs}) obtained from *in situ* TS values, as described in Alvarez Colombo *et al.* (2009). An STO Hydrolab Surveyor 3 probe was employed to determine salinity (S), temperature (T), and dissolved oxygen (DO) structure at a station located at the deepest sector of the lake.

RESULTS

Bathymetry

SL has a maximum depth of 32 m in the southern part (Fig. 3) where two noticeable hollows were found. These depressions are 36 and 51 m deep, respectively, confirmed also by divers (O. Pelar, *pers. comm.*). The northern part of SL is shallower and with a more gentle slope.

In situ TS measurements

Behaviour of dispersed individual jellyfish in the upper part of the water column resembled that of individuals observed in BL during TS measurements (targets with steady echotrace positions relative to the speed of the drifting boat). Hence, these measurements are considered to reflect the behavioural component (*i.e.* medusa bell contractions/relaxation swimming pulsing and tilt-angle distribution) of the individuals at that moment. Mean medusae TS obtained was -76.69 dB (range= -84.87 to -66.03 dB) (Tab. 1).

Tab. 1: Results of the acoustic and physical parameters employed to estimate the total number of* Aurelia *in Malo Lake (SL).
Tab. 1: Rezultati akustičnih in fizičnih parametrov, uporabljenih za oceno skupnega števila primerkov* Aurelia *v Malem jezeru (SL).

Mean s_A (m^2 nmi^{-2})	3.86
SD	1.66
Mean S_V (dB re 1 m^2 m^{-3})	-83.03
N intervals	880
Area (nmi)	0.03485
σ_{bs} (m^2) (TS= -76.69 dB)	$2.14\ 10^{-8}$
Numerosity (n)	500,480

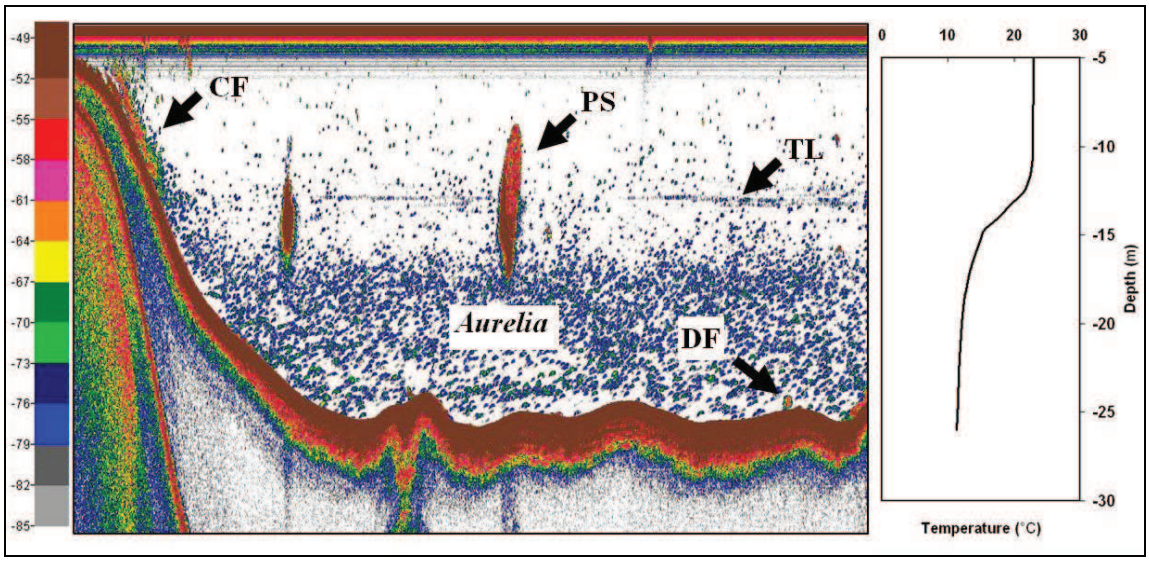

Fig. 3: Vertical distribution of the** Aurelia **population and the different groups recorded in Malo lake: CF = coastal fish; PS = pelagic schools; DF = demersal fish; TL = thermocline layer targets. The temperature vertical profile is presented, showing the thermocline between 12 to 15 meters (right). Scale represents mean volume backscattering strength in dB (left).
Sl. 3: Vertikalna distribucija populacije** Aurelia **in različnih skupin, zabeleženih v Malem jezeru: CF = obalne ribe; PS = pelagične ribje jate; DF = pridnene ribe; TL = skupina v sloju termokline. Prikazan vertikalni temperaturni profil z razvidno termoklino med 12 in 15 metri (desno). Merilo predstavlja povprečni volumen jakosti povratnega sipanja v dB (levo).

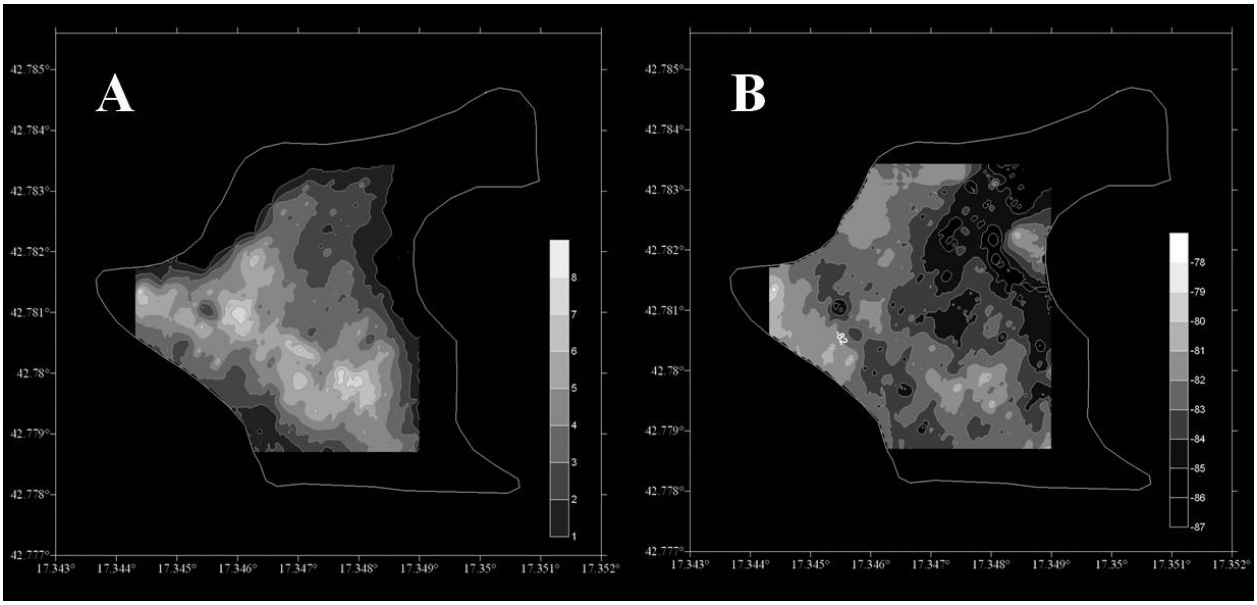

Fig. 4: Interpolation of density data of** Aurelia, **showing patterns of its horizontal distribution. A. Echointegration results in terms of the acoustic coefficient of backscattering strength per unit area (s_A). B. Values of mean volume backscattering strength per unit volume, in decibels (Sv).
Sl. 4: Interpolacija gostote osebkov** Aurelia, **s prikazano horizontalno distribucijo. A. Rezultati ehointegracije kot akustični koeficient jakosti povratnega sipanja na enoto površine (s_A). B. Vrednost povprečnega volumna jakosti povratnega sipanja na enoto prostornine, v decibelih (Sv).

Vertical distribution pattern

A strong thermocline (23 to 14° C) was present at 12 to 15 m. Most medusae were located a couple of meters below the thermocline but some individuals were observed dispersed to the surface (Fig. 3). A thin layer of weak echoes was clearly observed at the thermocline depth, possibly related to aggregations of small zooplankton, marine snow or even sound scattered from the physical interface between two water masses of different densities. Coastal fishes, small demersal fish aggregations and a school of pelagic fish were also observed at different depths along the acoustic track (Fig. 3).

Horizontal distribution patterns

Echo-integrated values of the water column (s_A) showed the largest medusae numbers in the deepest sector of the lake (Fig. 4a). This result was expected considering that the *Aurelia* population was mainly distributed below the thermocline, occupying greater water volumes with an increasing total depth. Also, backscattering values per unit volume showed that more medusae were present near the western margin of the lake (Fig. 4b), possibly related to advection (tidal and/or wind-related circulation). The horizontal distribution of different groups of fish was also recorded. While some schools of pelagic fish were detected in near-shore waters, most of the schools, mainly larger pelagic ones, were recorded in the deeper sector of the lake (Fig. 5).

Acoustic estimation of *Aurelia* abundance

The total number of *Aurelia* inhabiting SL at the moment of the acoustic survey was estimated to 500,480 (Tab. 1). The layer of maximum concentration was recorded between 15 m and the bottom, with a mean density estimated as 0.43 ind. m^{-3}.

DISCUSSION

Acoustic techniques were employed to describe the *Aurelia* horizontal and vertical distributions, and estimate its numerical abundance in SL. In doing this, we employed the direct visual evidence and ground-truthing of the echorecordings of the *Aurelia* population in the neighbouring BL. In this sense, the information obtained for this species in SL was similar to the patterns found in the neighbouring BL during the same period (Alvarez Colombo *et al.*, 2009), including congruous vertical distribution of the population during the day. Moreover, behaviour of individual medusae (inferred from echotraces) and the average target strength measured in SL closely matched those of BL.

In addition, the echorecordings allowed us to distinguish medusae from other more actively swimming organisms during the echogram interpretation process. Medusa echoes were separated from the stronger echoes of fish with swimbladders, and from the weaker signals of small zooplankters, as expected from the output of reliable TS models (see Brierley *et al.* 2005).

Aurelia was found mostly below the thermocline, with most of the population concentrated at the deepest sections of the lake, as was also observed in BL. Mean density (0.43 ind. m^{-3}) estimated for the maximum concentration layer was close to that calculated for the neighbouring BL (0.52 ind. m^{-3}) within the main distribution layer between 15 to 30 m (Alvarez Colombo *et al.*, 2009).

The diurnal vertical distribution of *Aurelia* in SL also resembles that found in BL, with the bulk of the population within and below the thermocline (Malej *et al.*, 2007; Alvarez Colombo *et al.*, 2009). However, in BL the highest densities coincided with the thermocline (Alvarez Colombo *et al.*, 2009) while in SL the medusae layer was located a few meters below.

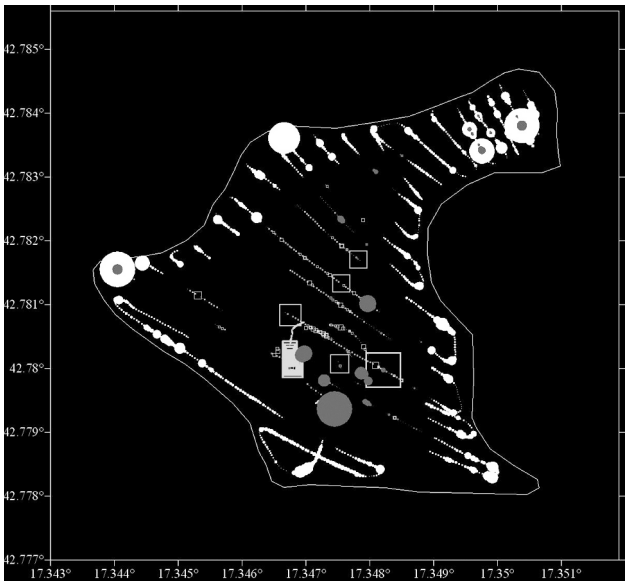

Fig. 5: Horizontal distribution patterns of fish aggregations: black circles = coastal fish; grey circles = pelagic schools; squares = demersal schools. Symbols are proportional to the acoustic coefficient of backscattering strength per unit area (s_A). Note that scales differ between the groups in order to compare distributions.
Sl. 5: Vzorci horizontalne distribucije skupin rib: črni krogi = obalne ribe; sivi krogi = pelagične ribje jate; kvadrati = pridnene ribje jate. Velikost krogov je proporcionalna akustičnemu koeficientu jakosti povratnega sipanja na enoto površine (s_A). Merilo se za različne skupine razlikuje zaradi primerjave distribucij.

Based on the absence of ephyrae and because the medusae appear to exhibit a random temporal distribution, it was proposed that the *Aurelia* population in SL originated from BL and was not permanent (Benović *et al.*, 2000). High sedimentation rates observed and the occasional presence of H_2S (Buljan & Špan, 1976; Juračić *et al.*, 1995) in SL was suggested to inhibit planula settlement and the establishment of a permanent local population (Benović *et al.*, 2000). The "stock" of SL coincides with that observed in BL in several features. In both lakes the animals were aggregated mostly in the deepest part of the lake and a similar vertical distribution during daylight was observed, with the same main upper limit of distribution (about 15 m depth), even with a shallower thermocline at SL. The behaviour of individual medusae inferred from echotraces and the average target strength measured (indicative of animal sizes) also closely matched the BL data. In May 2009, an additional survey was performed to check these results using the same boat and gear, but including observations with a ROV. On this occasion, we found no traces of *Aurelia* at all (W. Graham, *pers. comm.*) and the resulting echogram had a completely different signal pattern. All this evidence supports the hypothesis that SL *Aurelia* individuals are advected from BL.

We also obtained information about demersal and pelagic fish distributions and thus our acoustic information provides the basis for future species interactions investigations. In this sense, the acoustic survey of the lake community facilitates the monitoring of the total area synoptically, reduces sampling costs, and dramatically reduces avoidance of the active pelagic organisms such as adult fish and larvae, as expected from the use of sampling devices such as nets (Medwin, 2005).

CONCLUSIONS

The use of bioacoustic techniques allowed us to present for the first time a synoptic picture of the horizontal and vertical distribution of biological components such as different types of fish schools and the scyphomedusa *Aurelia* sp that inhabit Malo Lake. Acoustic signatures allowed us to assign individual echotraces to *Aurelia* sp and a population of 500,480 medusae was estimated for Malo Lake. However, as previously suggested, similarities in medusae distribution between the two connected lakes, and recent observations of the total absence of medusae in Malo Lake in particular years, while still present in Veliko Lake, indicate that the medusae in Malo Lake are not a population unit, but instead advected individuals from Veliko Lake.

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AKUSTIČNA OPAZOVANJA DISTRIBUCIJE MEDUZ V MALEM JEZERU (OTOK MLJET, HRVAŠKA)

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POVZETEK

Informacije o bioloških komponentah Mljetskih jezer so skope. Oligotrofni okolji jezer zaznamuje prisotnost izolirane populacije scifomeduz Aurelia *sp, v večjem Velikem jezeru potrjeno prisotne skozi vse leto. Za populacijo* Aurelia *sp. v manjšem Malem jezeru, ki pa je z Velikim jezerom povezano, se zdi, da skozi leta raste in se manjša, popolnoma izgine in se naslednje leto obnovi. Z akustičnim vzorčenjem, ki je bilo v Malem jezeru izvedeno tekom dneva 16. oktobra 2006, smo dobili splošno sinoptično sliko distribucije živih organizmov, zaznanih s frekvenco 120 kHz. Ugotovljena je bila vertikalna in horizontalna distribucija organizmov. Pridobljeni podatki o distribuciji različnih ribjih vrst so bili sortirani v obalno, demersalno in pelagično skupino.*

Kot je bilo potrjeno že pri pregledu Velikega jezera, akustični zapis ustreza vrsti Aurelia *sp. Ehointegracijske podatke smo analizirali skupaj z in situ akustičnimi meritvami velikosti ciljne skupine in ocenili, da gre v Malem jezeru za skupaj 500.000 meduz. Splošni dnevni vzorec vertikalne distribucije in velikost ciljne skupine* Aurelia *se ujemata s predhodno pridobljenimi podatki za Veliko jezero. Te ugotovitve, skupaj z odsotnostjo efir in občasno popolno odsotnostjo meduz v Malem jezeru kažejo na možnost, da so primerki* Aurelia *v Malem jezeru pravzaprav z vodnimi tokovi prinešeni posamezni primerki iz Velikega jezera.*

Ključne besede: hidroakustika, meduze**,** Scyphozoa, *Aurelia,* distribucija, številčnost

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