ISSN: 0001-5113
AADRAY

ACTA ADRIAT.,
43 (1): 65-75, 2002

UDC: 594.1(497.5 Mljet)"1998/2001"
Original scientific paper

A visual census of bivalve distributions in the saltwater lake Malo jezero (Mljet National Park, South Adriatic Sea)

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A visual census of 3 epifaunal dwelling bivalve species was performed by SCUBA diving along four transect lines in a saltwater lake, Malo jezero (Mljet National Park), during the summer months (June to August), between 1998 and 2001. Significant differences in the distribution of Arca noae L. Pinna nobilis L., *and* Chlamys glabra (L.) *were found with respect to depth and diving transects.* Pinna nobilis *was absent from depths greater than 15 m, whilst* Chlamys glabra *has disappeared from all transects in 2001.* Pinna nobilis *and* Chlamys glabra *were measured* in situ *and size distribution changes were noted with respect to 2000 to 2001 and 1999 and 2000, respectively. The survey method employed in this study was non-destructive and relatively simple to perform and therefore it can be easily applied for monitoring long-term changes in epifaunal bivalve distributions.*

Key words: diving surveys, *Arca noae*, *Pinna nobilis*, *Chlamys glabra*, Mljet National Park

INTRODUCTION

The establishment of marine reserves is a recent development in the world in comparison to terrestrial reserves. Several hundred marine reserves already exist and their number is constantly growing (TISDELL and BROADUS, 1989). Their size, design and management vary dramatically (NORSE, 1993). Conservation, research and education are among the main purposes of marine reserves (KELLEHER and KENCHINGTON, 1981; SPOTO and FRANZOSINI, 1991). By comparison with other marine reserves, the saltwater lake Malo jezero was one of the first established reserves for its special natural beauty, relatively early - in 1960, as a part of the Mljet Island National Park (NN 49/60). The marine flora and fauna, including bivalve inhabitants of the National Park, have been protected since 1976 under the Law of nature protection (NN 54/76). Previous research (DRAGANOVIĆ, 1980; OREPIĆ *et al.*, 1997; ŽERLIĆ, 1999) conducted in the Malo jezero gave a comprehensive list of bivalve species present in the area and some qualitative data on their distribution which indicate relatively high abundance of a few edible species.

Some authors, such as HARMELIN (1987) and ROBERTS (1995), have used a visual census of fish assemblages to assess the effectiveness of marine reserves. According to EDGAR and BARRETT (1997), this method can reveal long-term changes in the distribution of some benthic invertebrates. Observations in protected areas can provide valuable data on populations that are undisturbed and are free from fishing pressure, and these populations can be studied to assess exploitation rates and population structures in non-protected regions. This paper presents the results of a four-year visual census of 3 commonly occurring bivalve species in Malo jezero.

MATERIALS AND METHODS

The Island of Mljet is an offshore south Adriatic Island extending in a NW-SE direction. A saltwater lake, Malo jezero, located on the western part of the island, is a natural phenomenon of karstic depressions filled by seawater about 5000 years ago (WUNSAM *et al.*, 1999). Malo jezero is connected to a saltwater lake Veliko jezero through a shallow and narrow channel, which in turn is connected to the surrounding open sea through a somewhat deeper and wider channel. Malo jezero has a maximum depth of 29.4 m and a total area of 241.320 m^2 (VULETIĆ, 1953) (see Fig. 1a). In shallow parts of a lake, down to approximately six meters, the seabed is composed of rocks and different types of sandy substrates often overgrown with seagrass *Cymodocea nodosa* (UCRIA) ASCHERS. Sandy substrate is dominant down to approximately 15 to 20 m depth, whilst at greater depths sediment is predominantly muddy (DRAGANOVIĆ, 1980; PEHARDA, 2000).

A visual census of several large visible bivalve species was performed by SCUBA diving along four approximately 100 m long transect lines, orientated perpendicular to the shore towards the deeper part of the lake during the summer months (June-August) between 1998 and 2001 (Fig. 1b). Bivalves were counted up to one meter distance from the transect line by one to three divers. Results were grouped by depth:

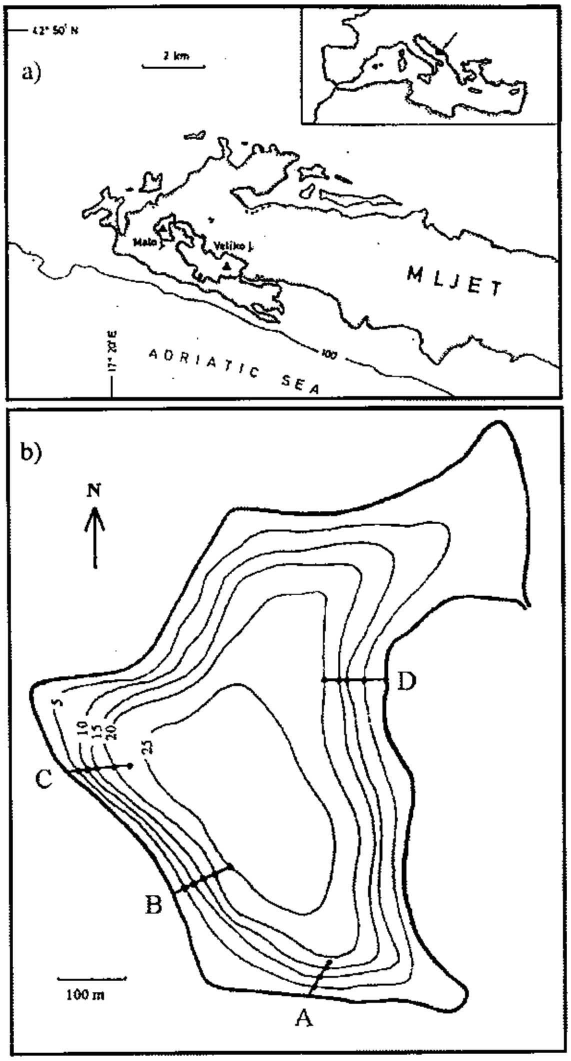

Fig. 1.A) Geographic location of island of Mljet and Malo jezero; B) Location of SCUBA transects in Malo jezero

0-5 m, 5-10 m, 10-15 m, 15-20 m, 20-25 m and average species density was calculated. Due to the dense *C. nodosa* meadows in the shallow water, it was hard to count bivalves between 0 and 5 m, and these data were not included in the analysis of the 1998 data. In the following years, careful counting was carried out in these shallow depths (0-5 m) and these data were included in the comparison of species numbers.

The total number of individuals of the following species were noted: *Arca noae* LINNAEUS, 1758 (Noah' Ark), *Pinna nobilis* LINNAEUS, 1758 (fan shell), and *Chlamys glabra* (LINNAEUS, 1758) (smooth scallop). Due to technical problems in the field, *A. noae* were not counted on the transects in 2000. Presence/absence data for *Modiolus barbatus* (LINNAEUS, 1758) (the bearded horse mussel), *Chlamys varia* (LINNAEUS, 1758) (variegated scallop), *Ostrea edulis* LINNAEUS, 1758 (European flat oyster), and *Gastrochaena dubia* (PENNANT, 1777) were noted between 1998 and 2001.

During the first preliminary surveys, the clump dwelling life style of *A. noae* was frequently observed in Malo jezero. Therefore, in 1998, the number of *A. noae* individuals in a clump was counted and analyzed. *P. nobilis* was measured in 2000 and 2001 using the technique described by MORETEAU and VINCENTE (1982) and GARCIA MARCH and FERRER FERRER (1995): the shell height above the sediment (*Hs*), maximum width of the shell (*A*) and width of the shell at sediment level (*a*) were measured *in situ*. From these data total shell height (*HT*) (apex to rim axis) was estimated using the following equation: $HT = (1.79\,a + 0.5 \pm 0.2) + Hs$ (GARCIA MARCH and FERRER FERRER, 1995). Length of *C. glabra* was measured *in situ* in 1999 and 2000.

A KRUSKAL-WALLIS test was used to analyze the distribution of bivalves. A non-parametric Mann Whitney U was used to examine differences in the shell height of the *P. nobilis* between 2000 and 2001, whilst a parametric two-way t-test was used to test differences between the length of *C. glabra* in 1999 and 2000. Any relationship between the height of *P. nobilis* and a change in water depth were investigated using a SPEARMAN rank-correlation test (AMBROSE and AMBROSE, 1987; DYTHAM, 1999).

RESULTS

Arca noae was the only bivalve of the 3 studied in detail which had a few live individuals at water depths >20 m (transect B, in 1998). Noah's Ark distributions with respect to years, transects and depths are shown in Figure 2.

The highest recorded density was 13.14 ind m^{-2}, whilst the average density was 2.82 ± 2.80 ind m^{-2}. Distribution significantly differed with water depth and transects (Table 1). Along transect C, *A. noae* appeared to be more abundant than on the other transects, espe-

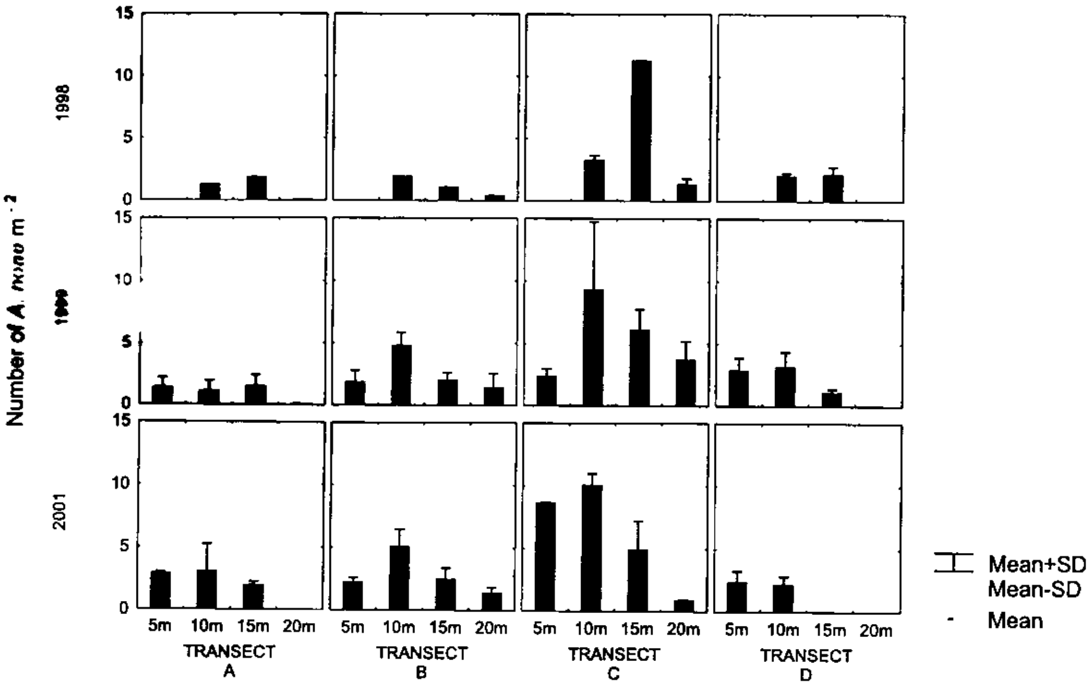

Fig. 2. Distribution of Arca noae *with respect to years, transects and depths of observation*

Table 1. Changes in density of Arca noae, Pinna nobilis *and* Chlamys glabra *with respect to depth, transects, and year*

	Depth	Transects (A-D)	Year
Arca noae	P<0.001 (0-20 m)	P<0.001	P=0.180 (1998, 1999, 2001)
Pinna nobilis	P<0.001 (0-15 m)	P=0.002	P=0.672 (1998, 1999, 2000, 2001)
Chlamys glabra	P<0.001 (0-20 m)	P=0.020	P=0.102 (1998, 1999, 2000)

cially at depths between 10 and 15 m. There was no significant change in *A. noae* distribution during the study. In 1998, a total of 259 Noah's Arks were counted along the transects, 82 individuals occurred as single individuals whilst others occurred in clumps. The largest *A. noae* clump consisted of 21 individuals with a mean group size of 3.68±3.31 individuals.

Pinna nobilis were not found at depths greater than 15 m. The average density of fan mussel shells was 0.17±0.17 ind m^{-2}, with a maximum recorded density of 0.90 ind m^{-2}. A significant difference in density of *P. nobilis* was found amongst samples in the shallow depth (15 m), with the highest density between 5 and 10 m (Table 1, Fig. 3). The density of *P. nobilis* also varied along the different transects, with more fan shells observed along transect A and D than along transects B and C. No significant differences were noted in the number of *P. nobilis* observed on the transects in different years.

The size of the fan mussels ranged from 10.08 cm to 47.98 cm, while the mean height was 30.24±10.47 cm (n=84) in 2000 (Fig. 4). In 2001, the smallest *P. nobilis* measured was 17.73 cm, the largest one 60.56 cm, with a mean total height of 40.29±10.25 cm (n=89). There was a statistically significant difference in the size of *P. nobilis* between 2000 and 2001 (Mann Whitney U=5396.5, p<0.0001), *P. nobilis* measured in 2001 were significantly larger. A positive correlation was found between *P. nobilis* height and depth (n = 173, r = 0.417, p < 0.0001).

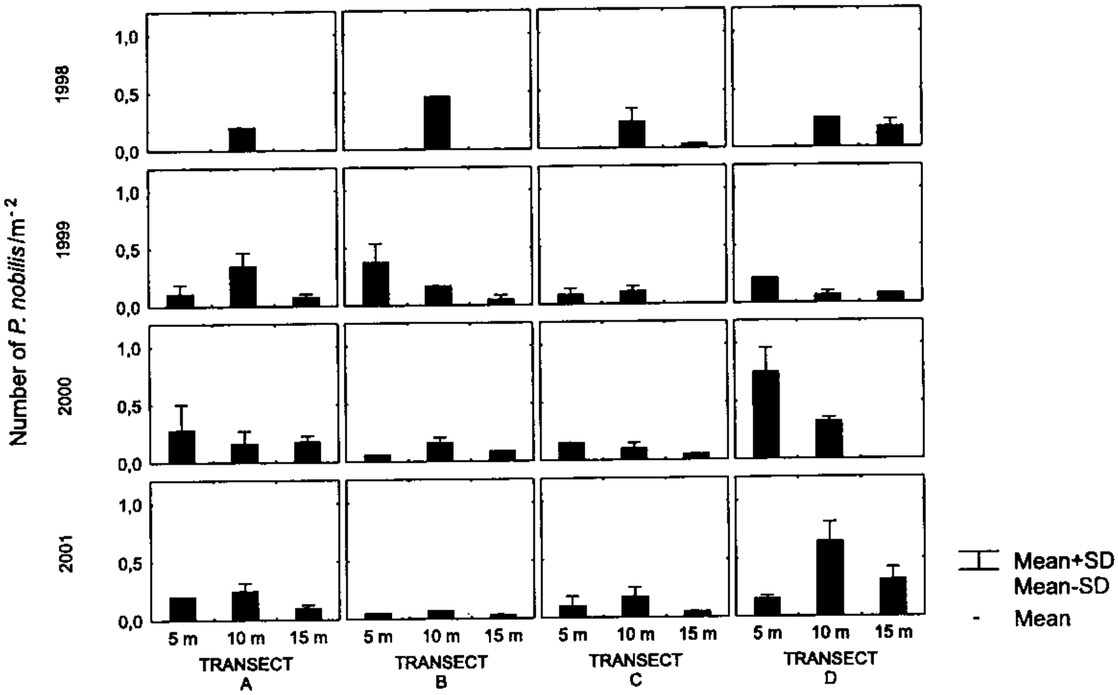

Fig. 3. Distribution of Pinna nobilis *with respect to years, transects and depths of observation*

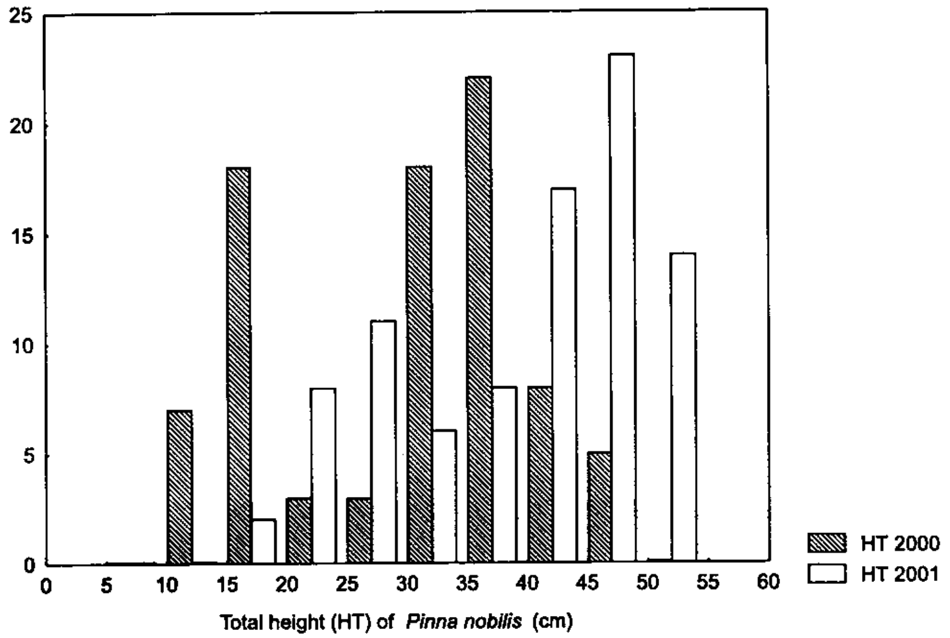

Fig. 4. Total height of Pinna nobilis *observed in years 2000 and 2001*

Chlamys glabra were not found on any transects in 2001. Empty shells, however, were observed on all transects, but covered with sedimentation. In previous years, a few individuals were recorded between 0 and 5 m depth. The highest density of this species was 2.86 ind m^{-2}, and were found on transect C from 5 to 10 m depth in 1999. There was a high variation in *C.*

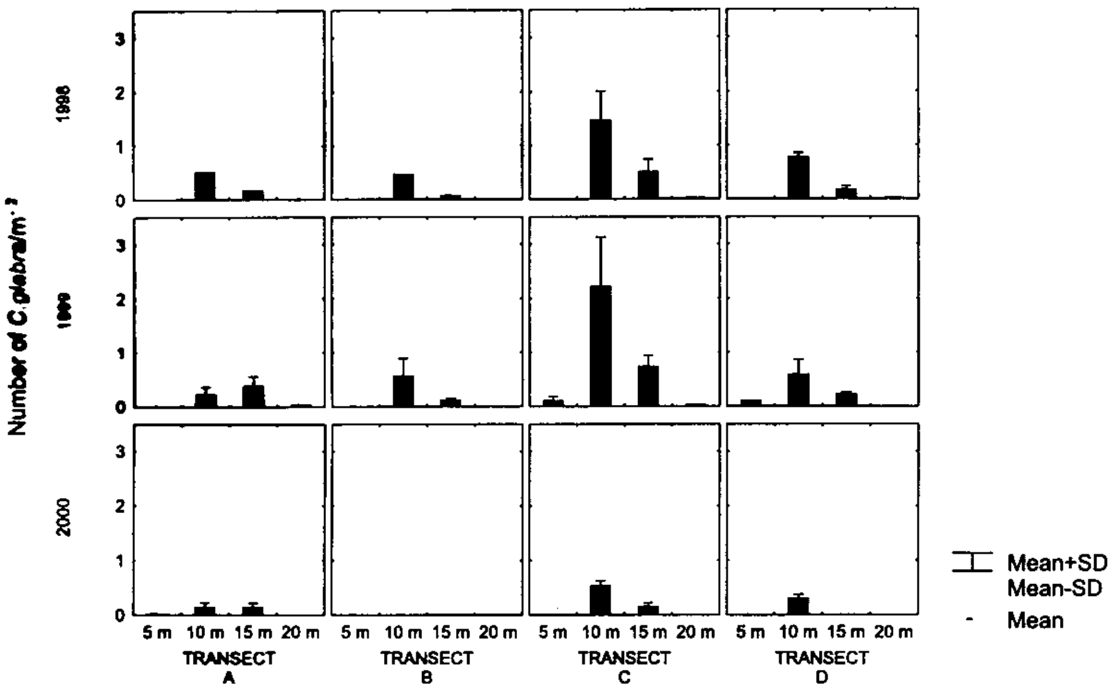

Fig. 5. Distribution of Chlamys glabra *with respect to years, transects and depths of observation*

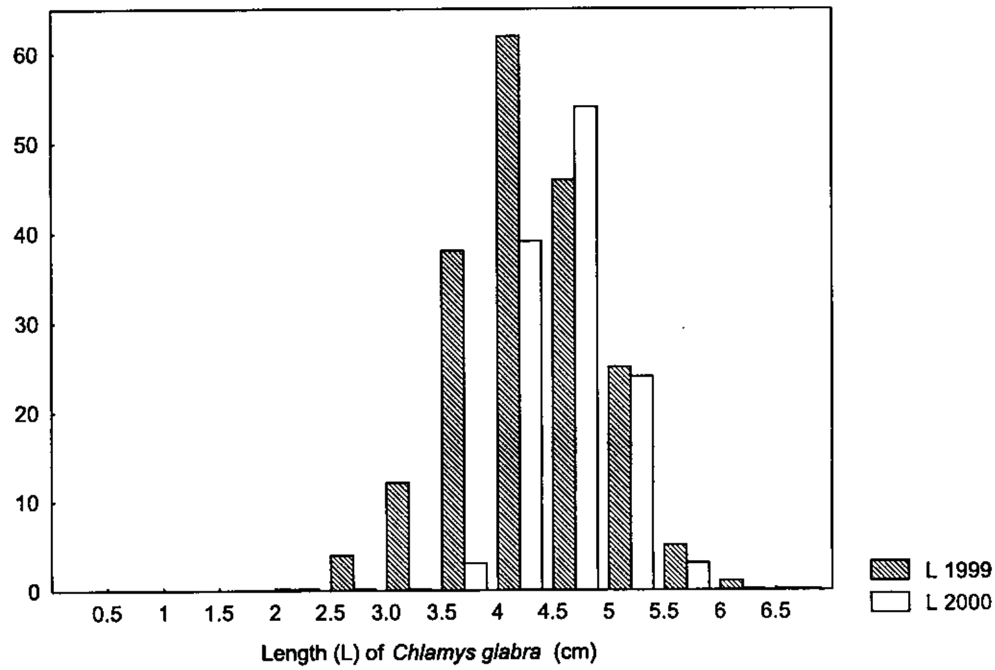

Fig. 6. Length of Chlamys glabra *observed in years 1999 and 2000*

glabra distribution with average density 0.27±0.46 ind m^{-2} recorded on transects at depths from 0 to 20 m. Distributions of *C. glabra* with respect to years, transects and depths are shown in Fig. 5.

Distribution significantly differed according to depth and diving transects (Table 1). No difference in the number of these scallops was noted between 1998, 1999 and 2000. There was a statistically significant difference in the shell length of *C. glabra* with respect to depth (KRUSKAL-WALLIS test, P=0.003). The median shell length was largest for individuals observed between 5 and 10 m depth, however, no difference was noted in the median length of *C. glabra* from the different transects (KRUSKAL-WALLIS test, P=0.237). Mean shell length of this species was higher in 2000 (4.74±0.40 cm, n = 123) than in 1999 (4.38±0.64 cm, n = 193) (t = - 6.16, P<0.001) (Fig. 6).

Other observed bivalve species such as *Gastrochaena dubia* and *Modiolus barbatus* were common in parts of the lake which were shallower than 20 m, similarly *Chlamys varia* and *Ostrea edulis* occurred in depths <20 m but were rare.

DISCUSSION

The non-destructive visual census carried out during this study has been found to be a useful method for investigating the distribution of bivalves, particularly in protected areas such as Malo jezero, where sampling impact needs to be reduced as much as possible. Due to their high abundance in Malo jezero, the epifaunal bivalves *Arca noae*, *Pinna nobilis* and *Chamys glabra* provided sufficient data for the analyses of their distribution with respect to depth. Further on, previous studies on distribution of substrate type and hydrographic conditions in Malo jezero (VULETIĆ, 1953; BULJAN, 1956; BULJAN and ŠPAN, 1976; BENOVIĆ *et al.*, 2000; PEHARDA, 2000) enabled the indirect analysis of environmental influences on the distribution of studied bivalves. These three species are subject to exploitation in other parts of the Adriatic Sea, even though *P. nobilis* has been protected as endangered species in Croatia since 1977 (NN, 23/77). Therefore, observations in protected areas provide valuable base-line data on bivalve populations that are not under fishing and human pressure. Such data is valuable and can be compared the assessment of population structures and exploitation rates in non-protected regions.

Arca noae lives attached by a solid green byssus plate to rocks or various molluscan shells. The species is distributed in the eastern Atlantic Ocean and the Mediterranean Sea where it occurs to depths of over 100 m (POPPE and GOTO, 2000). In the Adriatic Sea, *A. noae* lives down to 60 metres depth, is widely distributed, locally common, and shows temporal changes in population structure (HRS-BRENKO, 1980; VALLI and PAROVEL, 1981; ŠIMUNOVIĆ, 1992; HRS-BRENKO and LEGAC, 1996; ZAVODNIK, 1997). *A. noae* is one of the four commercially most important bivalves in the eastern Adriatic, where it is harvested year-round by boats using modified rakes, or by diving and hand collection (BENOVIĆ, 1997).

Arca noae has been noted in Malo jezero in previous studies (DRAGANOVIĆ, 1980; OREPIĆ *et al*., 1997; ŽERLIĆ, 1999), but no attempt has been made to estimate its population density. Maximal average density of *A. noae* recorded in the present study in Malo jezero at depths down to 20 meters (11 ind m^{-2}) agrees with ŠIMUNOVIĆ (1981) data for Mali Ston bay (10-12 ind m^{-2}) and MARGUŠ *et al.* (1991) for the estuary of the river Krka (11 ind m^{-2}). In the Krka estuary, *A. noae* was found between a depth of 4 to 10 m with maximum densities at 10 m depth (MARGUŠ *et al*., 1991). According to our results, Noah's Ark was most abundant on sandy substrates at depths between 5 and 15 meters, where it occurs in large clumps due to the limited availability of hard substrates for attachment.

Unlike *A. noae*, *Pinna nobilis* were found in Malo jezero only at depths down to 15 meters. In other parts of the Adriatic Sea, this species has been noted to occur down to depths of >30 meters (ZAVODNIK *et al*., 1991). Average densities recorded (0.17 ind m^{-2}) were high compared to studies conducted in other areas of the Mediterranean where typical population density is about 0.01 ind m^{-2} (COMBELLES *et al*., 1986; DE GAULEJAC and VINCENT, 1990; BUTLER *et al*., 1993). According to ZAVODNIK *et al.* (1991), *P. nobilis* density in sea grass meadows in the Adriatic Sea at depths between 10 and 20 m is approximately 0.10 ind m^{-2}.

It is interesting to note that *P. nobilis* was not present in Malo jezero in the late 1970's but was found in nearby Veliko jezero (DRAGANOVIĆ, 1980). Since it is the largest Mediterranean bivalve occasionally attaining heights of 120 cm (ZAVODNIK, 1991), it is highly unlikely that it was present in Malo jezero at that time but not recorded by DRAGANOVIĆ (1980). The absence of adult *P. nobilis* from Malo jezero in 1970's, and its later occurrence at the site, suggests out that larvae and have slowly emigrated and recruited from the surrounding areas, most probably Veliko jezero.

The largest size of *P. nobilis* recorded in Malo jezero was 48 cm in 2000, and 61 cm in 2001. At Carboneras (Spanish Mediterranean) a *P. nobilis* height of 50 cm corresponds to an age of five years, while individuals reaching size of over 60 cm are at least seven years old (RICHARDSON *et al*., 1999). Fan shells can, however, live for more that 15 years (MORETEAU and VINCENTE, 1980,1982), these findings suggest that the population in Malo jezero is probably young providing the shell growth rates are similar. This finding is further supported by the observed significant increase in shell height between the two years of observations. Conclusions on *P. nobilis* population age structure in Malo jezero are not possible at this point because it has been shown by RICHARDSON *et al.* (1999) that *P. nobilis* growth rates vary by location. Study of the growth rate of *P. nobilis* at this site is currently underway.

Chlamys glabra, a relatively abundant species in 1998, 1999 and 2000, was completely absent from all transects in 2001. Since Malo jezero is a relatively isolated area and thereby no migrations of *C. glabra* from this area are likely, the observed disappearance of these scallops is probably a consequence of mass mortality. According to ORENSANZ *et al.* (1991), Pectinid mass mortalities are widespread phenomena that result from episodic events such as storms, extreme temperatures, oxygen depletion, predator outbreaks, diseases and algae blooms. From this study, it is not possible to say which of this factors caused the mortalities but it is probable that the mortalities occurred in late fall or winter since empty shells observed on transects were covered by sedimentation. The length frequency distributions of *C. glabra* in years prior to the recorded absence show a distinct lack of smaller newly recruited individuals. This may suggest ageing of the population and a possible lack of recruitment. This may indicate problems in the years prior to the mortalities. However, it is interesting to note that there was no difference in distribution of this species between 1998, 1999 and 2000 indicating that there was no significant change in the scallop population between those years. Like *P. nobilis*, *C. glabra* was not recorded in Malo jezero in the late 1970's, but was present in Veliko jezero (DRAGANOVIĆ, 1980).

All the observed bivalve species occurred at greater depths in other parts of the Adriatic Sea then they did at Malo jezero (LEGAC and HRS-BRENKO, 1982; ZAVODNIK *et al.*, 1991; ŽERLIĆ, 1999). Specific environmental factors at this latter site, such as water temperature, salinity, oxygen saturation, and sediment composition, can limit bivalve spatial distribution. Due to the relative isolation of Malo jezero, the surface layer of the lake is characterized by summer over-heating, with seawater temperatures exceeding 29°C (BENOVIĆ *et al.*, 2000). According to DAME (1996), temperature can limit the spatial distribution of bivalves and it represents a major controlling factor in many physiological rate processes. In Malo jezero, another important regulating factor can be oxygen saturation. For example, *A. noae* is known as an oxygen sensitive species that is among the first bivalves to die in the event of an oxygen crisis (HRS-BRENKO, 1988). Malo jezero is well saturated with oxygen only in the upper 15 m of the water column, below this depth there is an abrupt decrease somewhere between 20 and 25 m depth. Occasionally oxygen saturation falls to zero in the deepest parts of the lake (BULJAN, 1956; BULJAN and ŠPAN, 1976). Sometimes, during the summer, a layer of H_2S is present in parts of the lake deeper than 20 m (VULETIĆ, 1953; BULJAN, 1956; BULJAN and ŠPAN, 1976). This phenomenon can destroy almost all bivalve populations in deep layers and determine the lower depth limit of a bivalves population distribution.

The visual census method used in this study was suitable for obtaining some basic distribution data for *Arca noae*, *Pinna nobilis* and *Chlamys glabra*. In order to obtain data that can help explain the causes of temporal and spatial variations, future studies should include other bivalve species and be conducted throughout the year. Further more, the observations and any measurements of the bivalves should be accompanied by an analysis of hydrographic parameters, currents and by data on phytoplankton distribution. Previous oceanographic studies collected data only at one sampling station in Malo jezero, located above the maximal depth, and did not attempt to describe variations within the lake. Such data would aid in the interpretation of variations in bivalve distribution within Malo jezero that were noted in this study.

ACKNOWLEDGEMENT

The authors would like to thank the CROATIAN MINISTRY OF SCIENCE AND TECHNOLOGY for financial support and the employees of the NATIONAL PARK MLJET for logistic support. Special thanks to Tihana ŽERLIĆ, Marko SREČEC, Ognjen ULJEVIĆ and Antonija KINKELA for their help in the field. Two anonymous reviewers provided valuable comments on the manuscript.

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Received: 18 December 2001
Accepted: 8 May 2002

Istraživanje raspodjele školjkaša u Malom jezeru metodom popisivanja vrsta na profilima ronjenja (Nacionalni Park Mljet, južni Jadran)

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SAŽETAK

Lako uočljivi školjkaši popisani su na četiri profila autonomnog ronjenja u Malom jezeru (Nacionalni park Mljet) tijekom ljetnih mjeseci od 1998. do 2001. godine. Statistički značajna razlika zabilježena je u raspodjeli školjkaša *Arca noae* L., *Pinna nobilis* L. i *Chlamys glabra* (L.) s obzirom na dubinu i profil ronjenja. Vrsta *P. nobilis* nije nađena na dubinama većim od 15 m, a vrsta *C. glabra* nije zabilježena niti na jednom profilu u 2001. godini. Visina *P. nobilis* i dužina *C. glabra* su izmjerene *in situ* te su zabilježene promjene s obzirom na godinu istraživanja. Metoda upotrijebljena u ovom istraživanju nije destruktivna i relativno laka te se može uspješno primijeniti pri praćenju promjena u raspodjeli školjkaša.

Ključne riječi: prikaz ronjenja, *Arca noae*, *Pinna nobilis*, *Chlamys glabra*, Nacionalni Park Mljet