SHORT COMMUNICATION

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TRANSFER OF *Arca noae* Linnaeus, 1758 FROM NATURAL TO DIFFERENT EXPERIMENTAL FARMING CONDITIONS

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ABSTRACT

Noah's ark shell *Arca noae* Linnaeus, 1758 is one of commercially important species in Croatia harvested from the wild. Its length/sex relationship, sex ratio and survival after transfer from natural habitat to different experimental farming conditions were examined. Statistically smaller lengths were detected for males (x=52.6±8.7 mm) than for females (x=60.2±9.5 mm). The overall sex ratio was 1.8 : 1.0 in favour of males. Survival after 17 months was only 20.5%. This study demonstrated that *A. noae* specimens can be transferred from the wild onto field experimental conditions, but high post transfer mortalities occurred. Gathered data about post transfer mortalities and relationship between the sexes and lengths could be useful when planning aquaculture/hatchery operations for this bivalve species. Furthermore, they will be of great help for the further development of farming technology of this species.

INTRODUCTION

Long history of harvesting and aquaculture of bivalves is present along the Eastern Adriatic coast (Benović, 1997; Zavodnik, 1997; Bratoš et al., 2004). Noah's Ark shell (*Arca noae* Linnaeus, 1758) is one of the most commercially important species in Croatia harvested from the wild (Benović, 1997). Until the end of the Second World War this species constituted an important part of the diet for local people with annual catch rate of >600 tonnes (Zavodnik, 1997). Due to catastrophic mortality caused by an unknown agent in the late 1940s, ark fishery in the Adriatic Sea collapsed and never fully recovered (Hrs-Brenko, 1980). Although present daily on Croatian fish markets, there are no reliable catch data for this species. For example, only a 5.5 tonne harvest was reported in 2006, while reports from the field indicate that illegal unreported catch could be significantly higher (Bavčević and Peharda, personal communication). Due to illegal SCUBA harvesting, high demand and price of 7 EUR/kg (personal information) on the tourist market, natural beds are in jeopardy of becoming overexploited. Currently the only protective measure for *A. noae* in Croatia is the minimal legal landing size of 50 mm (Official Gazette, 63/2010). Previous studies carried out on the reproductive cycle of *its* populations have suggested that the species may produce gametes continuously, with major spawning during June and July (Peharda et al., 2006; Bello et al., 2013). Since this coincides with the beginning of the tourist season, when demand for sea food is in increase, it is easy to conclude that large individuals are being harvested intensively just before or during spawning. Also, according to the regulations and market demands, divers are targeting larger specimens which may lead to a population being dominated by smaller individuals. Population of *A. noae* is additionally threatened due to its slow growth rate of 1.29±1.34 mm month-1, as noticed by Kožul et al. (2011).

In support of aquaculture and sustainable fisheries development for this species, a study on the length/sex relationship, sex ratio and survival of *A. noae* after transfer from the natural habitat to different experimental aquaculture conditions was initiated. Some implications for planning culture of broodstock for hatchery production or transfer to harvesting sites are also discussed.

MATERIAL AND METHODS

This study was carried out between October 2008 and March 2010 in the area surrounding Pašman Island (middle Adriatic Sea), as one of the major harvesting area for *Arca noae*. Site 1 was placed in the Pašman Channel where arks naturally occur, while other two sites were on the opposite side of the Pašman Channel. Site 2 was located next to sea bass *Dicentrarchus labrax* (Linnaeus, 1758) and sea bream *Sparus aurata* Linnaeus, 1758 fish cages, while Site 3 was 60 m away from the cages (Figure 1).

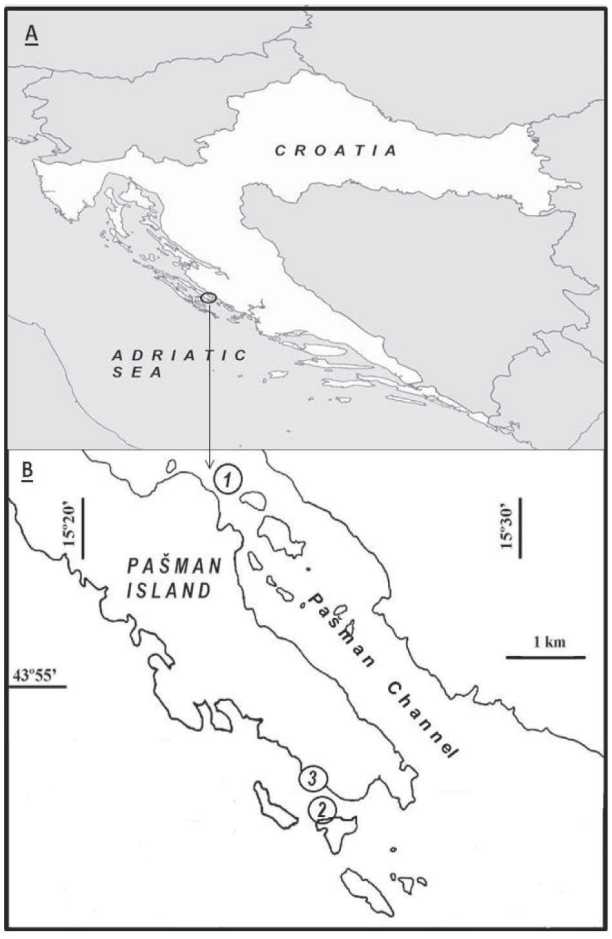

Fig 1. Map of the study area: a) Adriatic Sea; b) Pašman Island and Site 1 in the Pašman Channel and Sites 2 and 3 on the south side of Pašman Island

Samples of arks were collected during October 2008 in the Pašman Channel on several locations: Babac, Komornik and Neviđane. Arks were sampled at depths from 3 to 10 m by SCUBA divers with the use of hand tool for detaching the byssal cord. The sea temperature in the Pašman Channel during collection and at all experimental sites was 19 °C. During collection, all arks encountered were sampled, except individuals that were observed attached in crevices of reefs. Upon collection, shells were carefully checked for damages and only undamaged shells were used in the experiment. A total of 873 arks were sampled, ranging from 11.3 to 83.8 mm in total length, measured with digital vernier calipers to the nearest 0.1 mm. Air exposure for all arks was between three and four hours. Arks were randomly divided into four samples, each consisting of three replicates, placed in nylon mesh nets, usually used for mussel farming (50 mm opening), and distributed to three sites. All samples were suspended at 3 m depth but there were differences in the total depth between sites. At Site 1, samples were placed on the sea bed (total depth of 3 m) inside protective iron cages with 50 mm net opening. At Sites 2 and 3, samples were suspended from mussel cultivation lines, hanging 15 m above the sea bed (total depth of 18 m). The temperature on all sites was similar during the entire duration of the experiment, ranging from 11.8 °C (March 2008) to 24 °C (August 2009). In March 2010, 17 months after sampling, sex was determined in all specimens that survived the period. Male gonads were white, while those of females had orange–red coloration (Peharda et al., 2006). A nonparametric Mann–Whitney U test was used for comparing male/female shell lengths, while the sex ratios were tested using a chi-square goodness of fit test (χ^2).

RESULTS AND DISCUSSION

A statistically significant difference was noticed in the mean lengths between males (x=52.6±8.6 mm) and females (x=60.1±9.5 mm) (Mann-Whitney test; P<0.001; Figure 2), suggesting that protandric development is occurring with increase in length, as previously recorded by Peharda et al. (2006) and Bello et al. (2013).

It is interesting that, although females had significantly higher average lengths, both the smallest (24.6 mm) and the largest ark detected were male (83.1 mm). Males dominating the smaller size classes were previously also found in Mali Ston Bay (Peharda et al., 2006), in the Pašman Channel (Peharda et al., 2009) and in the south-western Adriatic Sea (Bello et al., 2013) (Table 1).

Table 1. Mean lengths (x), standard deviations (st.dev), length range of *Arca noae* according to sex, from different investigated locations (n=number of specimens)

Location	Sex	N	L(mm) x±st.dev.	Min–Max (mm)	Source
Mali Ston	Males	236	45.8±14.0	12.3-75.9	Peharda et al. (2006)
	Females	308	55.8±9.4	15.9-80.8	
Pašman Channel	Males	311			Peharda et al. (2009)
	Females	142	43.7±12.83*	13.0-88.0*	
Bari - South-western Adriatic Sea	Males	80	41.6	17.0-61.0	Bello et al. (2013)
	Females	83	46.2	28.0-70.0	
Pašman Channel	Males	116	52.6±8.7	24.6-83.1	This study
	Females	63	60.2±9.5	42.9-81.1	

*not specified according to sex

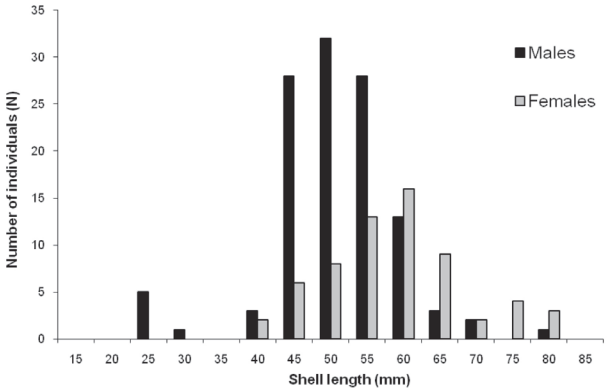

Fig 2. Lengths of *Arca noae* with respect to sex

All specimens were sexually mature at the end of experiment and the overall sex ratio was 1.8 : 1.0 in favour of males (χ^2=15.693; p<0.001) (Table 2).

Table 2. Analysis of the sex ratios of *Arca noae* according to shell length categories (χ^2 = chi-square goodness of fit test)

Length (mm)	Males	Females	χ^2	P
<30	5	0	5	0.025
30-39	1	0	1	0.317
40-49	31	8	13.564	<0.001
50-59	60	21	18.778	<0.001
>60	19	34	4.245	0.039
Total	116	63	15.693	<0.001

A total of 116 males (64.8%) and 63 females (35.2%) were determined and there were no differences in the sex ratio between any of sites. In Mali Ston Bay, females dominated the population with male to female ratio of 1.0 : 1.3 (Peharda et al., 2006), while in the Pašman Channel the ratio was significantly in favour of males and more similar to our results – 2.1 : 1.0 (Peharda et al., 2009). This sex ratio is somewhat different than found in our study, but if sex was determined before mortality occurred, it would be at least similar or even higher in favour of males. Significant dominance of males in ark population could indicate that larger individuals (mostly females) in the Pašman Channel are subjected to overexploitation. Since several studies described functional protandric development in *A. noae* with males dominating smaller size classes (Peharda et al., 2006; Bello et al., 2013), overfishing of large females could cause serious consequences for recruitment. Generally, if adult bivalve spawning stock biomass is reduced by harvest in a way that it results in lower recruitment, it could eventually lead to effective elimination of the commercial fishery in the area (Peterson, 2002). Absence of large females as the basis of reproductive stock, together with slow growth rates of this species, can have negative long-term effects on ark population in the Pašman Channel (Peharda et al., 2002; Peharda et al., 2009). Since the relationship between adult spawning stock and recruitment is imperative to achieve sustainable fisheries (Myers and Barrowman, 1996), better management over *A. noae* fisheries in the Adriatic Sea needs to be developed.

Highest mortality rates were recorded in the beginning of the experiment indicating that arks are extremely sensitive to manipulation and stress associated with removal from the natural substrate (Župan, 2012). Only 179 specimens from all sites survived the 17 months period (20.5%) – 25 shells in the Pašman Channel, 73 at Site 2 and 81 at Site 3. A total of 447 shells were found dead, while 247 shells disappeared during the experiment. High mortalities and disappearance of arks imply that technology of cultivation in nylon mesh nets which is suitable for mussels is not optimal for this species. Similar results with pronounced post-transfer mortality were noticed also by Peharda et al. (2013) in their study conducted in Mali Ston Bay during 2010, where 49% of survival was noticed when arks were kept in hanging baskets and only 21% when the samples were deployed on the sea bed. In con-

trast, only 9% mortality after arks were transferred along with the substrate they grew on (rock) was reported (Kožul et al., 2011). Thus, the main reason for high post transfer mortality is the physical damage formed after the byssus was discarded. Although arks are capable of secreting new byssus within few days after discarding the old one (Morton and Peharda, 2008), the mechanical stress caused to the tissue by detachment from the natural environment is probably too high and might cause practical problems during aquaculture operations (Peharda et al., 2013).

CONCLUSIONS

Results of male/female lengths, sex ratio and survival are similar to previously conducted studies in the Adriatic Sea. The sex ratio significantly in favour of males could point to unsustainable harvesting of this bivalve population in the Pašman Channel. Noah's ark specimens can be transferred from the natural habitat onto a new location, but high post transfer mortalities, probably caused by stress after detachment from the sea bed, are to be expected. Other methods for cultivation of arks should be considered since technology used in this research was not optimal. In addition to high mortalities, relation between the sexes and length, among other important factors, should be taken into account when planning culture of broodstock for aquaculture operations.

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Sažetak

PREBAČAJ KUNJKE *Arca noae* Linnaeus, 1758 IZ PRIRODNIH UVJETA U RAZLIČITE UVJETE EKSPERIMENTALNOG UZGOJA

Kunjka *Arca noae Linnaeus*, 1758 je jedna od komercijalno važnih vrsta školjkaša u Hrvatskoj koja se izlovljava iz prirodnih staništa. Istražen je odnos dužina prema spolu, udio spolova i preživljavanje nakon prebačaja iz prirodnog staništa u eksperimentalne uzgojne uvjete. Statistički značajno manje dužine uočene su kod mužjaka (x=52,6±8,7 mm) u odnosu na ženke (x=60,2±9,5 mm). Ukupni udio spolova bio je 1,8 : 1,0 u korist mužjaka. Preživljavanje nakon 17 mjeseci iznosilo je 20,5%. Istraživanje ukazuje na mogućnost prebačaja kunjke iz prirodnih staništa u nove uzgojne uvjete, ali uz posljedično visoku smrtnost. Dobiveni podatci o mortalitetu nakon prebačaja i odnosa između spola i dužine mogu biti korisni prilikom planiranja akvakulture/mrijesta za ovu vrstu. Nadalje, podatci će biti korisni za daljnji razvoj tehnologije uzgoja kunjke.

Ključne riječi: kunjka *Arca noae*, dužina, udio spolova, eksperimentalni uzgojni uvjeti

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