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NOAH'S ARK SHELL (*Arca noae* LINNAEUS, 1758) – WHAT DO WE NEED TO KNOW FOR STARTING UP ITS AQUACULTURE?

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Summary

Noah's ark shell *Arca noae* Linnaeus, 1758 is one of the most important commercially exploited bivalve species in the eastern Adriatic Sea. High harvesting pressure, as a consequence of increasing market demands, could in the future result in its overexploitation in some areas. All mentioned above, together with a high market price, make *A. noae* a new species for introduction into aquaculture. Several studies have recently been conducted concerning biology and ecology of *A. noae* in the Adriatic, but there are still no studies dealing with possible introduction of *A. noae* into commercial aquaculture and there is limited and unreliable data on distribution and size of currently exploited stocks. The aim of this paper was to give a review of present knowledge on *A. noae,* particularly biological characteristics of this species related to aquaculture production.

Key words: *Arca noae*; Adriatic Sea, overexploitation; aquaculture; bivalve

INTRODUCTION

Along the eastern Adriatic coast 224 bivalve species were recorded out of which 66 are eatable and 16 species could be found on the market (Zavodnik, 1997; 1999). The most commercially important species are European flat oyster *Ostrea edulis* Linnaeus, 1758 and Mediterranean mussel *Mytilus galloprovincialis* Lamarck, 1819, which are aquacultured as well as harvested from natural populations. Other commercially important species include Mediterranean scallop *Pecten jacobaeus* (Linnaeus, 1758), warty venus *Venus verrucosa* Linnaeus, 1758, clam *Ruditapes decussatus* (Linnaeus, 1758) and Noah's ark *Arca noae* Linnaeus, 1758 and they are harvested from natural populations, mostly by SCUBA diving.

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Noah's ark belongs to the Arcidae family. In the 1940s, the annual catch of this species in Croatia was over 600MT and back then it was primarily harvested by dredge. However, due to unknown cause, its fishery collapsed and never fully recovered again (Hrs-Brenko, 1980; Hrs-Brenko et al., 1988). Today, *A. noae* is harvested mainly by SCUBA and skin divers, and as a by-catch in the rapido trawl. However, there are no reliable catch statistics data including catch quantities or number of people involved in exploitation of this species (Peharda et al., 2009). Majority of harvested *A. noae* is sold on the black market during the tourist season or is consumed by the local population. High harvesting pressure as consequence of increasing market demands, together with limitations of natural populations in future, could result in overexploitation of this species in some parts of the Adriatic (Bavčević, pers. comm; Peharda et al., 2009). All mentioned above, together with relatively high and stable price on the market (≈7€), make *A. noae* an interesting species for introduction into aquaculture.

However, before the start of the introduction of *A. noae* into commercial aquaculture it is necessary to review the existing knowledge about the biology and ecology of this species, evaluate the needs for additional studies as well as evaluate technological requirements for its aquaculture production. Data related to reproduction, larvae settlement and spat collection are especially important. Furthermore, in order to evaluate profitability of such investment, growth of this species in changed conditions needs to be investigated. The aim of this paper was to give a review of present knowledge on *A. noae,* particularly biological characteristics of this species related to aquaculture production.

BIOLOGY AND PRODUCTION OF OTHER ARCIDAE SPECIES

There are over 200 species of marine bivalve molluscs from the family *Arcidae* and many of them represent an important source of protein for human consumption (Broom, 1982). Majority of these species are harvested extensively from natural populations using different fishing methods and represent an important source of food for the local inhabitants. Most important targets of traditional fisheries are *Anadara tuberculosa, A. similis* and *Larkinia multicostata* on the Pacific coast of Columbia, *A. cornea* in Fiji, *Senilia senilis* in West Africa (Broom, 1982), *Lunarca ovalis, A. transversa* and *Noetia ponderosa* in coastal Georgia, USA (Walker, 1998) and *Arca noae* in the Mediterranean (Hrs-Benko, 1980). Species harvested on an intensive commercial basis with a high relevance to the industry are *Tegillarca granosa* in Malaysia and Thailand, *A. broughtonii* in South Korea and *A. sativa* in Japan (Broom, 1982). Also, *T. granosa* and *A. broughtonii* are produced in aquaculture activities throughout China, Malaysia, Thailand and Korea (Broom, 1982, 1983; Park et al., 2001). *A. broughtonii* is the most commercially important species in Korea and Japan with maximum production of 58.000MT reached in 1986 (Park et al., 2001) while *T. granosa* was third cultured bivalve species with production of 419.587MT in 2008 according to the FAO's Yearbook of Fishery Statistics (2010).

Although being very economically important, aquaculture implications and other related parameters for *T. granosa* and *A. broughtonii* are relatively poorly described. For example, Broom (1982; 1983) investigated growth in natural, artificially seeded and experimental populations and gonad development and spawning of *T. granosa.* Narasimham (1988) described some aspects of its biology, whereas Nakamura and Shinotsuka (2007) researched its growth and feeding habits in experimental conditions. Selin (2000) investigated shell form and growth of *A. broughtonii*, whereas Park et al. (2001) monitored its reproductive cycle and biochemical composition. Bivalves *T. granosa* and *A. broughtonii* are considered fast growing species with production period of up to two years achieved by very traditional culture methods (Broom, 1985).

Species *Lunarca ovalis* has recently been recognized as a potentially important species on the United States market with possibility for development of industrial fisheries and aquaculture. Walker (1998) described its growth and survival, McGraw et al. (2001) conducted field study in the oceanside lagoons and tidal creeks of Virginia, Power and Walker (2001; 2002) performed experimental aquaculture and growth and gametogenic cycle whereas Degner et al. (2005) investigated its marketing opportunities. *L. ovalis* is also considered a short living and fast growing species and its commercially feasible size of 45 mm is reached after two years (Power and Walker, 2001). The main obstacle in development of aquaculture and fisheries of this species is the lack of interest by the shellfish producers and the US market in general (Degner, 2005).

Furthermore, several publications described reproductive biology of various species of bivalves from the *Arcidae* family (Broom, 1983; MacKenzie, 2001; McGraw et al., 2001; Power and Walker, 2002; Afiati, 2007). Relatively a small number of studies dealing with population dynamics, age, growth and survival rates or other aspects that could lead to establishment of sustainable fisheries management or commercial aquaculture include those by Broom (1982; 1983) Mistri et al. (1988), Sahìn et al. (1999), Power and Walker (2001), Marin and Lopez Belluga (2005), and Stern-Pirlot and Wolff (2006).

BIOLOGY OF *Arca noae*

Bivalve *A. noae* is distributed in the eastern Atlantic Ocean, the Mediterranean and Black Seas and the West Indies (Nordsieck, 1969). This species inhabits areas from the low-tide level to depths of 119 m in the Mediterranean, whereas it was found up to the depths of 60m at the Croatian side of Adriatic (Hrs-Brenko and Legac, 1996). It lives attached with a solid byssus on rocks or shells and occurs either as solitary individual or in clumps with conspecifics such as mytilid species *Modiolus barbatus* (Linnaeus, 1758) (Hrs-Brenko, 1980; Hrs-Brenko and Legac, 1996). *A. noae* appeared to be more abundant in habitat characterized by lower salinities caused by terrestrial run-off, underwater springs or river inflows (Morton and Peharda, 2008). Although it is a widely distributed species, only few studies are dealing with its biology mainly based on populations from the Adriatic Sea. Recently, several studies have been conducted concerning biology and ecology of *A. noae* in the Adriatic including its population structure, growth and age, condition index, reproduction, predation and functional morphology (Bello and Paparella, 2001; Peharda et al., 2002, 2003A; Marin and Lopez Belluga, 2005; Peharda and Morton, 2006; Peharda et al., 2006, 2009; Morton and Peharda, 2008). *A. noae* can reach the age of over 15 years and sizes from 70 – 90mm (Hrs-Brenko and Legac, 1996; Peharda et al., 2002), although specimens of over 100mm were recorded in the Mljet National park in Croatia (Šiletić, 2006). Commercial size of over 50mm (Official Gazette 63/10) is reached between 3 and 7 years (Peharda et al., 2002). In Mali Ston Bay (the South Adriatic Sea), Peharda et al. (2006) recorded one spawning peak occurring between July and September, while according to Valli and Parovel (1981) *A. noae* from the North Adriatic Sea (the Gulf of Trieste) prolonged the spawning period with two peaks, one in March and another in September. During the study periods, both authors recorded hermaphrodite specimens which contributed maximally 2.2%. Peharda et al. (2006) found that really small specimens (only 12 mm in length) can be sexually mature and that majority of small specimens (less than 30 mm in length) are functional males, whereas number of females rises with increasing length. The study by Hrs – Brenko (1980) found relatively high percent of individuals longer than 50mm on the west coast of Istria in the Northern Adriatic Sea, indicating that *A. noae* populations are capable of recovering after large mortalities caused by unknown agent. However, more recent studies by Peharda et al. (2003A, 2009) indicate that population of *A. noae* in the Croatian Adriatic may be overexploited by SCUBA fishing. According to Peharda et al. (2009), share of specimens smaller than minimum market size of 50mm in Mali Ston Bay and the Pašman Channel were over 61% and 74%, respectively.

Although some populations from the Adriatic Sea are well investigated there are still no studies dealing with possible introduction of *A. noae* into commercial aquaculture and there is limited and unreliable data on distribution and size of currently exploited stocks.

POTENTIAL AND CONSTRAINTS REGARDING AQUACULTURE

Arca noae is considered a relatively slow growing species since it may take from 3 to 7 years to reach commercial length of over 50mm (Peharda et al., 2002; 2003A). Long production period could lead to lack of interest for investment in establishment of commercial aquaculture. For example, production period on the eastern Adriatic is around 15 and 24 months for *M. galloprovincialis* and *O. edulis,* respectively (Dujmušić, 2000). Similar growth rates were noticed in other ark species. Mistri et al. (1988) found that *Anadara inaequivalvis,* which was introduced in the Adriatic trough ballast water, has a slow growth rate and it takes over 10 years to reach its maximum theoretical size of over 100mm. Slow growth was also noticed for *N. ponderosa* which reaches its market size after 8 years (McGraw et al., 2001) and *A. tuberculosa*, which can live for 25 years before reaching its maximum size (Stern-Pirlot and Wolff, 2006). However, recent studies have indicated different growth rates of *A. noae*, mostly depending on location. For example, Peharda et al. (2002) noticed slower growth and smaller asymptotic shell lengths of *A. noae* population within the Mljet National Park in Croatia than it was recorded in Mali Ston Bay and Marina near Split. Differences in growth rates with respect to location were previously documented for other commercially important species such as mussels, oysters and scallops. For example, *Pecten jacobaeus,* a scallop species common in the Adriatic Sea, reaches its commercial size of over 100mm in range from 2 – 5 years, depending on the location and food availability (Peharda et al., 2003B).

Broom (1985) researched growth of several ark species and concluded that growth in sedentary and semi-sedentary bivalves is greatly influenced by environmental and biological factors and is known to vary widely from population to population and between individuals, even within the same species and population. Beside location and food availability, differences in growth of *A. noae* could be related to lifestyle – solitary individuals such as those found in Mali Ston Bay and Marina seem to grow faster than specimens which form clumps, like those found in the Mljet National Park (Peharda et al., 2002). Slower growth rates of shellfish living in higher abundance is probably related to food and life space competition (Peharda et al., 2003B; Lauzon-Guay et al., 2005). As previous researches only estimated growth of *A. noae* according to annual growth rings, an additional research of *in situ* growth of *A. noae* on different locations should be performed in order to determine the exact period of reaching the commercial size of over 50mm. If the results of such researches would confirm that this size is reached in 3 or 4 years, it would make this species interesting for commercial production.

Basic condition for any aquaculture activity is continuous and sufficient supply of shellfish seed. Experiments with inducted spawning of *A. noae* have not yet been made so one option in case of aquaculture of *A. noae* is collection of seed from the natural populations and transfer to growing sites. This option also requires a serious research with aim to determine the most suitable locations for collection of seed, types of collectors that are to be used and the time and depths of their deployment. Successful seed collection from the wild requires knowledge of a species and the reproductive cycle and spawning patterns of its local population (Gosling, 2003). Previous research describing changes of condition index and reproduction cycle of *A. noae* (Peharda et al., 2003A, 2006) could be of great help while planning seed collection activities. Since the spawning period can vary between locations or seasons, it is necessary to track the gonad development of *A. noae* when planning these activities. Spawning of *A. noae* can easily be predicted by monitoring the condition index, since Peharda et al. (2006) found strong correlation between condition and development of gonads. This way a more expensive and complex histological analysis is avoided. With accurate prediction of the spawning period, results of seed collection could be improved since the efficiency of collectors is shown to decrease after only two weeks to one month period from immersion, mainly because of coverage with algae and untargeted species of shellfish (Brand et al., 1980).

Seasonal changes of environmental conditions, high pressure on natural stocks and conflicts over the use of the coastal zone are becoming more expressed and are increasing problems to producers who rely solely on recruitment of bivalve spat from nature (FAO, 2004). Insufficient supply of high quality seed is becoming a growing problem in aquaculture of some species and possible solution can be the production of spat in hatcheries and nurseries. According to FAO (2004), production in bivalve hatcheries will increase continuously in future, especially as a lot of work is invested to produce genetically selected strains with desirable characteristics suited to particular conditions. This is the potential area for series of investigation concerning inducted spawning of *A. noae*. Future research should focus on techniques of spawning, fertility, production of adequate food for larvae and juveniles, larvae settlement and growing in nurseries.

Next stage in development of technology for aquaculture of *A. noae* is to determine the most suitable way for growing juveniles on on-growing sites until they are ready for market. Experiments should focus on finding the best technique for growing of the arks (for example mesh bags, plastic boxes etc.), effects of seed size, densities and depths on growth and survival of *A. noae*. Technology should provide maximum survival, high growth rate and good condition as a main indicator of meat quality. Special attention should be focused on seeding densities and size of juvenile arks at transport at on-growing sites. Although Peharda et al. (2003A) did find slower growth rate for populations of *A. noae* living in higher abundance, for other species it was found that, in case of sufficient food availability, higher densities do not necessarily cause slower growth. For example, Lauzon-Guay et al. (2005) found for *Mytilus edulis* that higher seeding densities did not cause slower growth of the shell but did cause lower condition index and higher mortality. Since any kind of growing technique would be different to natural life style of *A. noae*, these experiments will show potential of *A. noae* in adaptingto changed conditions, which has not been investigated yet. Some biological aspects of this species indicate that it could have a potential for adaptation in aquaculture conditions. For example, *A. noae* is widely distributed along the Adriatic Sea, on locations with different environmental conditions, including different depths, salinity, temperature and food availability (Peharda et al. 2002, 2003A, 2006). Another characteristic that could be of great use in manipulation with arks, which is inevitable in aquaculture conditions, is renewal of byssus after the old one is damaged or discarded. Secretion of new byssus within few days in *A. noae* was noticed by Morton and Peharda (2006) and it could be important for readmission of juvenile arks after any kind of manipulation. Also, ability of *A. noae* to move by up to 20cm before byssally re-attaching, reported also by Morton and Peharda (2006), is important as arks can provide themselves with better feeding position. However, transfer of juveniles from collectors or natural habitats to growing sites could cause large stress with potential high mortalities of arks. Survival of *A. noae* after transfer is one of the most important factors for production results and future research should focus on determination of survival rates and the techniques to avoid large transfer related mortalities.

After the most appropriate methods for growing of *A. noae* are discovered, it is necessary to determine the most suitable areas for its commercial production. Various factors should be under consideration, such as distance from infrastructure (civilization), depths, variations of salinity and temperature, exposure to waves and tides, food availability, hygienic quality of the water, environmental impact and integration into existing activities of the area. It can be assumed that the most suitable areas would be the ones where the natural populations of this species are most abundant or where there is a long tradition in its harvesting. However, besides biological and traditional conditions, other factors like legislative and administrative constrains should also be taken into account. For example, the Pašman Channel, which is an important production area for harvesting of *A. noae*, is not classified as a shellfish farming area and there are currently no commercial shellfish farms. For this reason, attempt of commercial aquaculture of *A. noae* in this area would be very difficult, due to many legislative issues and user conflicts. However, it can be assumed that establishment of *A. noae* aquaculture will be easier in the areas with long aquaculture tradition in Croatia, such as Mali Ston Bay, the Krka estuary or the Lim Channel. In these areas polyculture of *A. noae* with traditional species such as *M. galloprovincialis* and *O. edulis* could be achieved.

If the controlled spawning is proven to be successful, production enhancement and sustainable exploitation of *A. noae* could be achieved through a combination of aquaculture and fisheries, the so called sea ranching. Aquaculture could help develop sustainable fisheries of *A. noae* by producing high quality seed. Produced seed can be deployed on the sea bed of chosen production areas and harvested by the concessions owners by diving or dredging after reaching the market size. Sea ranching projects seem promising and good results with the development of industry employing thousands of people are underway in China and Japan with production of scallops, sea cucumber, abalone and shrimp (Bell et al., 2008). Advantages of this kind of production are lower cost (compared to hanging culture), repopulation of natural stocks, control of catch quantities with following statistics and sustainable fisheries in production areas. For sea ranching of *A. noae* on the Adriatic coast to occur, certain constrains must be taken care of. Besides stimulated spawning, the main problems could be complicated procedures over concessions in production areas, conflicts with other activities in the area (tourism) and the fact that this kind of production is still unknown on the Eastern Adriatic coast.

CONCLUSION

The opening of the large EU shellfish market for Croatian producers could increase the harvesting intensity of species from natural populations, including *A. noae.* This can lead into overexploitation with possible significant negative influence on natural stocks. Although there are still no reliable catch statistics for *A. noae*, some indications on field point out that natural populations are already reducing due to the overexploitation (Bavčević, pers. comm; Peharda et al. 2009). Present state where there are no valid data of harvesting intensity, population structure and production capacity is certainly not sustainable in long term. It is necessary to conduct a series of scientific researches in order to help develop sustainable exploitation of natural stocks and to investigate possibilities for introduction of new shellfish species into aquaculture. Noah's Ark *A. noae,* as one of the most economically important species in the eastern Adriatic, is certainly an eligible candidate for such interest. Potentials of this species are growing demand on the market, high and stable price and limitation of natural populations. Recent papers (Peharda et al., 2002, 2003, 2006; Morton and Peharda 2008; Peharda et al., 2009) give good view into biological characteristics regarding possible experimental aquaculture. Yet, almost nothing is still known about culture of *A. noae* in aquaculture conditions, availability of spat from natural populations as well from controlled spawning in hatcheries. These are all potential fields for future research.

Sažetak

KUNJKA (*Arca noae* LINNAEUS, 1758) – ŠTO MORAMO ZNATI PRIJE UVOĐENJA OVE VRSTE U AKVAKULTURU?

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Kunjka *Arca noae* Linnaeus, 1758 jedna je od najvažnijih komercijalno iskorištavanih vrsta školjkaša na istočnoj obali Jadrana. Visoki intenzitet ribolova, kao posljedica rastuće potražnje na tržištu, u budućnosti bi mogao dovesti do pretjerane eksploatacije prirodnih populacija u pojedinim područjima. Kada se navedenim činjenicama pridoda i visoka cijena na tržištu, kunjka *A. noae* se nameće kao moguća nova vrsta u akvakulturu. Nedavno je provedeno nekoliko istraživanja o biologiji i ekologiji kunjke u Jadranu, ali za sad nisu provedena istraživanja o mogućnostima uvođenja u komercijalnu akvakulturu. Također, malo je relavantnih podataka o distribuciji i prosječnoj veličini iskorištavanih populacija. Cilj ovog rada je pregled dosadašnjih saznanja o kunjki *A. noae*, sa posebnim osvrtom na biološke karakteristike vrste povezane s mogućnostima uzgoja, odnosno uvođenja u akvakulturu.

Ključne riječi: *Arca noae*; Jadransko more; prekomjerna eksploatacija; akvakultura; školjkaši

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