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Spreading of invasive bivalves *Anadara kagoshimensis* and *Anadara transversa* in the northern and central Adriatic Sea

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Two non-indigenous invasive bivalve species, Anadara kagoshimensis *(Tokunaga, 1906) and* Anadara transversa *(Say, 1822), were recorded for the first time in the open waters of the eastern Adriatic Sea trawling grounds. Samples of these species were collected in 2008–2011 with modified beam trawl (rapido) during the SoleMon project, a project aimed at investigating the northern and central Adriatic Sea. In the years following its first record in 2008, the abundance of* A. kagoshimensis *increased in the area of investigation off the Istrian coast. The highest recorded abundance index per station was 1089 N km^{-2} in 2011. Species was present at depths from 31 to 41.5 m. Presence of* Anadara transversa *was recorded only at one station in 2011, in the middle of the open Adriatic between 70 and 72.5 m depth. The possible vectors of invasion of these species, from the western Adriatic coast to the eastern, are discussed.*

Key words: *Anadara kagoshimensis*, *Anadara transversa*, invasive species, non-indigenous species, Adriatic Sea

INTRODUCTION

In the Mediterranean Sea, 558 metazoan species were identified as alien species that had invaded Basin *via* different pathways: through the Suez Canal, by shipping and by mariculture (GALIL, 2008). In the past few decades numerous non native algae, invertebrates and fishes have been recorded in the Adriatic Sea (DESPALATOVIĆ *et al.*, 2008; DRAGIČEVIĆ & DULČIĆ, 2010; OCCHIPINTI-AMBROGI, 2011). Among non-indigenous invasive bivalve species that have established populations along the western Adriatic coast but not along the eastern part of the Adriatic, in Croatian waters, are *Anadara kagoshimensis* (Tokunaga, 1906) and *Anadara transversa* (Say, 1822).

Anadara kagoshimensis originates from the temperate North Pacific and is present in the Adriatic Sea since 1970s, when it was observed for the first time near Ravenna (Italy), where it was accidentally introduced most likely by shipping (GHISOTTI, 1973; ZENETOS *et al.*, 2003; ZENETOS *et al.*, 2010). Due to its ecological virtues, this opportunistic invasive species rapidly spread along the western and northern Adriatic coast, where it lives from inshore brackish waters down to 30 m on sandy, muddy and rocky bottoms (ZENETOS *et al.*, 2003; CROCETTA, 2011). This species is also established in some areas

of the Western and Eastern Mediterranean Sea, and in the Black Sea (SAHIN *et al.*, 2006; ZENETOS *et al.*, 2010). Previously, it had been misidentified in the Mediterranean Sea and was recorded as *Anadara inaequivalvis* (Bruguière, 1789) and *Anadara cornea* (Reeve, 1844), two species that do not exist in the Mediterranean and Black Seas (HUBER, 2010; ZENETOS *et al.*, 2010).

The native distribution of *Anadara transversa* covers the northwestern Atlantic Ocean, from southern Massachusetts to Florida and Texas (REHDER, 1981). In the Mediterranean Sea the species was recorded for the first time as *Arca amygdalum* in Izmir (Turkey) in 1972 (DEMIR, 1977). Twenty years later, in 1992, it was found in the North Aegean Sea (ZENETOS, 1994). In the Adriatic Sea, this invasive species is present since 2000, occupying the coastal waters of the northern and western basin (MORELLO & SOLUSTRI, 2001; MORELLO *et al.*, 2004a,b; CROCETTA, 2011), but it was recorded as *Anadara demiri* (Piani, 1981). Molecular analysis revealed that this alien species known as *A. demiri*, is an allochthonous population of *A. transversa*, and morphological comparisons may suggest that it originated from the Gulf of Mexico coasts of Florida (ALBANO *et al.*, 2009). To date, only two empty shells of this species have been recorded in Croatian waters, at the Jadro river mouth in Kaštela Bay (PEHARDA *et al.*, 2010). In addition, 6 juvenile specimens, introduced either by shipping or by aquaculture, were recorded in Lim Bay on the eastern Istrian coast at a depth of 4.4 m, but without confirmation that the population had established in the area (NERLOVIĆ *et al.*, 2012).

The present paper discusses the distribution, abundance and vectors of spread of *Anadara* species in the eastern Adriatic Sea. In addition to natural expansion derived from larval transport, fishing activities, through their discarding practices, are discussed as possible vectors for the spread of these two species.

MATERIAL AND METHODS

Samples of *Anadara kagoshimensis* and *Anadara transversa* were collected during the SoleMon project surveys in November/December each year between 2008 and 2011. The main aim of the SoleMon project is to assess the state of the stock of sole (*Solea solea*) and other commercial benthic species in the northern and central Adriatic Sea (FAO GSA 17), but it is good opportunity for monitoring of other benthic species, as well as invasive species. For the purposes of this paper we only analysed stations located in the eastern part of the Adriatic, within the international waters of the Croatian Protected Ecological and Fishery Zone, that came into full effect in 2008 (Fig. 1).

The gear used in this investigation was a modified beam trawl (*rapido*) (width: 3.5 m; weight: 225 kg; four 120-mm wide skids; 40-mm codend diamond mesh size; towing speed: 5.5 knots; haul duration: 30 min) (GRATI *et al.*, 2013). DST Logic Temperature and Depth Recorders were mounted on the gear used in the surveys; this together with its fixed mouth, allowed an accurate calculation of the area explored by each *rapido* trawl.

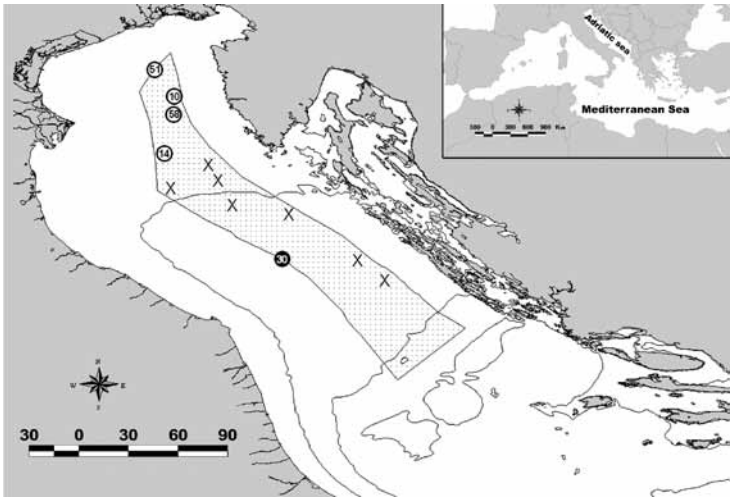
All specimens of *Anadara* collected from each haul (one haul per station) were separated, and the abundance of the species was calculated per square kilometer by station:

$$\textit{Abundance index in station X} = \frac{\textit{N. of spec.imens in station X}}{\textit{square km explored by gears in the station X}}$$

Length of all collected specimens at each station (2009–2011) was measured to the nearest mm.

RESULTS

In 2008 *Anadara kagoshimensis* was observed at Stations 10 and 58 within the Croatian Protected Ecological and Fishery Zone (Fig. 1; Table 1), but in small quantities (27 N km^{-2} and 57 N km^{-2} respectively) (Table 2). In subsequent years, between 2009 and 2011 the abundance of the species increased, with the highest abundance index recorded in 2011 (719 N km^{-2} at Station 10; 1089 N km^{-2} at Station 58). *Anadara kagoshimensis* was also sampled in significant quantities north and south of these stations (Stations 51 and 14, respectively; Fig. 1, Tables 1, 2).



The mean length of sampled *A. kagoshimensis* specimens ranged between 39 mm to 42 mm (Table 3) and the maximum measured length in the area of survey was 47 mm at stations 10 and 58.

Anadara transversa was recorded only at Station 30 in 2011 (Fig. 1; Table 1). Only one specimen was alive (24 mm length), and four empty shells, between 27 mm and 37 mm in length, were observed.

Fig. 1. Distribution of Anadara kagoshimensis *and* Anadara transversa *in Croatian Protected Ecological and Fishery Zone (shaded area) from 2008 to 2011, based on SoleMon project data. white circles –* Anadara kagoshimensis*, black circle –* Anadara transversa*, X – negative stations*

Table 1. Coordinates and depth ranges of investigated stations where bivalves from genus Anadara *were recorded during the SoleMon project from 2008 to 2011 in the northern and central Adriatic Sea*

Station / Year	Coordinate Start	Coordinate End	Depth Start (m)	Depth End (m)
10 / 2008	45°07.300 N 13°14.919 E	45°04.635 N 13°15.111 E	35.2	36.6
58 / 2008	45°01.397 N 13°14.611 E	44°58.811 N 13°14.559 E	37.8	38.7
10 / 2009	45°07.698 N 13°14.910 E	45°04.899 N 13°15.069 E	35.6	36.9
58 / 2009	45°03.364 N 13°14.610 E	45°00.489 N 13°14.630 E	37.2	38.9
10 / 2010	45°07.408 N 13°14.855 E	45°04.732 N 13°15.071 E	35.5	36.8
14 / 2010	44°45.181 N 13°10.539 E	44°42.872 N 13°08.552 E	41.5	40.4
58 / 2010	45°03.974 N 13°14.622 E	45°00.095 N 13°14.466 E	37.6	38.5
10 / 2011	45°08.980 N 13°14.754 E	45°05.232 N 13°15.012 E	34.8	36.6
30 / 2011	43°57.924 N 13°59.400 E	43°59.202 N 14°02.678 E	72.5	70
51 / 2011	45°19.923 N 13°03.879 E	45°20.447 N 13°05.730 E	32	31
58 / 2011	45°03.402 N 13°14.493 E	45°00.510 N 13°14.795 E	37	39.3

Table 2. Abundance index (N km^{-2}) of Anadara kagoshimensis *at the stations investigated within the SoleMon project from 2008 to 2011 in the northern and central Adriatic Sea*

Station	Abundance index (N km^{-2})			
	2008	2009	2010	2011
10	27	191	416	719
14	ns	ns	597	ns
51	ns	ns	ns	854
58	57	718	128	1089

ns - not sampled

Table 3. Mean length (mm), standard deviation and range of collected specimens of Anadara kagoshimensis *at the stations investigated within the SoleMon project from 2009 to 2011 in the northern and central Adriatic Sea*

Station	Length (mm)		
	2009 mean±SD (range)	2010 mean±SD (range)	2011 mean±SD (range)
10	42±3 (37-45)	41±3 (36-47)	41±3 (39-46)
14	ns	39±3 (36-43)	ns
51	ns	ns	42±2 (38-44)
58	42±3 (36-46)	41±3 (36-47)	41±2 (36-47)

ns - not sampled

DISCUSSION

Before the SoleMon survey in the Adriatic Sea, it was thought that *Anadara* species were only present along the northern and western coasts of the Adriatic Sea, where are very abundant in some areas (ZENETOS *et al.*, 2003). We believed that these species, due to the geomorphology of the Adriatic Sea and overall Adriatic cyclonic current system, would not spread their areal of distribution along the eastern coast without anthropogenic influence.

Anadara kagoshimensis was recorded for the first time in the eastern Adriatic during the SoleMon survey in 2008, in open waters off the Istrian coast within the Croatian Protected Ecological and Fishery Zone. Since only small numbers were sampled during the first observation, we doubted the presence of an established population. In subsequent years, the number of sampled individuals has significantly increased. It is still not clear how this species has spread its areal from the western coast so far to the eastern within short period of time. The data from 2011 showed that the bivalve was very abundant on the northernmost edge of the Protected Ecological and Fishery Zone, in the area where the sampling was not performed in previous years. It is possible that it has spread its areal naturally from the northern Adriatic due to increasing abundance. Larval transport by currents could also account for the south-easterly expansion of the distribution of this species. The prevailing Adriatic current system is cyclonic (BULJAN & ZORE-ARMANDA, 1971), but two current eddies exist in the northern area of the basin, one cyclonic, the other anticyclonic (ZORE-ARMANDA & VUČAK, 1984). The species distribution described herein coincides with the area of action of these two eddies advancing them as possible facilitators of larval transport in the wider area of the northern Adriatic. Finally, commercial fishing (*rapido* and otter trawls) is another possible vector that could be plausibly important in the spreading of the species. The northern Adriatic is a very important fishing ground (PICCINETTI *et al.*, 2012), with numerous fishing vessels that move across the basin from west to east. During that journey fishermen clean fishing gear and nets throwing discarded species on the surrounding areas. Discarded organisms are in different conditions, their survival differs between taxa and the injuries are related to fragility and physical characteristics of each species (KAISER & SPENCER, 1995). Morphology of *A. kagoshimensis* shell, which is solid and heavy, and its physiological characteristics allow it to survive the discarding practice.

All specimens collected during four year sampling period were sexually mature adult individuals, since the species reaches maturity at length of about 20 mm (SAHIN *et al.*, 2006). Additionally, during our investigation we recorded species deeper, from depths of 40.4 - 41.5 m, than previously recorded in the Adriatic Sea (30 m) (ZENETOS *et al.*, 2003). The significant increase in abundance of the species in the area of the Croatian Protected Ecological and Fishery Zone during the four-year period of monitoring

indicate that it has likely settled on a favourable substrate and, in accordance to its invasive ecology, it will likely spread its areal further.

Anadara kagoshimensis is listed among the hundred worst invasive species in the Mediterranean Sea, and the same is true for the other non-indigenous invasive bivalve recorded in area of investigation, *Anadara transversa* (STREFTARIS & ZENETOS, 2006). This species is abundant too along the western Adriatic coast (MORELLO *et al.*, 2004a,b), but it was surprising to find it in deeper waters (70-72.5 m) far from the coast, while in previous studies it was recorded shallower, at depths up to 16 m (MORELLO & SOLUSTRI, 2001; MORELLO *et al.*, 2004a). In the Aegean Sea species is recorded up to 22 m (DEMIR, 1977; ZENETOS, 1994). As this area is a very important trawling ground, as entire area of the northern and central Adriatic (MANNINI *et al.*, 2004), it is possible that fishing vessels enable dispersal of this bivalve in the same way as is explained for *A. kagoshimensis*. The presence of *Anadara* species in the area where was noted in 2011 was already recorded in data collected from SoleMon survey in 2006, but without confirmation of correct identification of the species at that time. After confirmation of new record in 2011, it is possible to expect that *A. transversa* exists in the deeper parts of the Adriatic.

It appears to be only a matter of time before *Anadara* species will colonise the eastern Adriatic coast, in areas with substrata and depths favourable for their establishment. Up until now only empty shells of *A. transversa* of unknown origin have appeared in coastal areas of the eastern Adriatic (Kaštela Bay) (PEHARDA *et al.*, 2010) and juvenile specimens in Lim Bay (Northern Adriatic Sea), but without any proof of established populations (NERLOVIĆ *et al.*, 2012). Within framework of projects that sample on the same stations over longer period of time, it will be possible to follow the spreading of these invasive species, monitor their impact on biodiversity of autochthonous benthic communities and understand the mechanisms of spread.

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Širenje invazivnih školjkaša *Anadara kagoshimensis* i *Anadara transversa* u sjevernom i srednjem Jadranu

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SAŽETAK

Dvije strane invazivne vrste školjkaša, *Anadara kagoshimensis* (Tokunaga, 1906) i *Anadara transversa* (Say, 1822), su po prvi put zabilježene u otvorenim vodama na koćarskim dnima u istočnom dijelu Jadranskoga mora. Uzorci ovih vrsta su sakupljeni za vrijeme SoleMon porojekta kojim je istraživano područje sjevernog i srednjeg Jadrana, u razdoblju od 2008. do 2011., a korišten je modificirani rampon (rapido). U godinama koje su slijedile nakon prve zabilješke 2008., abundancija vrste *A. kagoshimensis* se povećala na području istraživanja otvorenih voda uz obalu Istre. Najveća zabilježena vrijednost indeksa abundancije po postaji je bila 1089 N km^{-2}, a zabilježena je 2011. godine. Vrsta je bila prisutna na dubinama od 31 do 41,5 m. Prisutnost vrste *Anadara transversa* je zabilježena samo na jednoj postaji 2011., u otvorenom Jadranu, na dubinama od 70 do 72,5 m. Analizirani su mogući vektori širenja ovih invazivnih vrsta sa zapadne obale Jadrana na istočnu.

Ključne riječi: *Anadara kagoshimensis*, *Anadara transversa*, invazivne vrste, strane vrste, Jadransko more