Main Introduction Way of Indo-Pacific and Red Sea Originated Benthic Foraminifers to the Eastern Mediterranean

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Abstract

Majority of the alien foraminifers recorded in the eastern Mediterranean are Indo-Pacific originated and entered the Mediterranean via Suez Canal. In this study, current literature on the alien benthic foraminiferal fauna of the eastern Mediterranean was reviewed and the main dispersal pathways are determined. Distribution patterns of the alien species suggests that most of the species are introduced via Suez Canal and expand their range of distributions in a counter-clockwise manner by the general surface currents of the eastern Mediterranean. However, not all, but some of the species have also been dispersed westwards along the North African coast and reached central Mediterranean. Locally abundant records of *Euthymonacha polita* (Chapman), *Coscinospira acicularis* (Batsch) and *Amphistegina lobifera* in the Aegean Sea indicates that Suez Canal may not be the only vector for the Indo-Pacific species to enter eastern Mediterranean and submarine springs help these thermophilic species to form establish populations in cool waters of the northern Aegean and the Sea of Marmara.

Keywords: Foraminifera, Eastern Mediterranean, Diversity, Indo-Pacific

Introduction

Mediterranean Sea is invaded by many alien marine organisms of, either Atlantic or Indo-Pacific origin (Galil et al., 2015). These alien species were likely transported via ballast waters or by attaching themselves onto vessels. In addition to that, some of the species were intentionally introduced to the Mediterranean for aquaculture purposes or inadvertently introduced from public aquariums. However, the most effective vector for the marine alien species invasion in the Mediterranean is the Suez Canal, which directly connects to different ecosystems that have been separated millions of years ago. Thus majority of the marine alien species recorded in the eastern Mediterranean are Red Sea originated (Zenetos et al., 2012).

Many alien benthic foraminifer species have also been recorded in the eastern Mediterranean (Zenetos et al., 2008; Meriç et al., 2008b, 2010a, b and 2011; Koukousioura, 2010). Since they are not active swimmers, these species can only be spread by currents or unintentional transportation by human activities after they are introduced to the Medit. The aim of this paper is to review the current literature on alien foraminifer in the Mediterranean and figure out the main dispersal pathways in the Mediterranean after they are introduced.

Findings

In a study which has been conducted on the coasts of Northern Red Sea 14 recent sediment samples have been collected from 7 locations

around Sharm El Sheikh (Jackfish Alley, Ras Ghozlani, Ras Katy, Ras Umm Sid, Near Garden, Woodhouse Reef and Jackson Reef) at 10.00 m and 20.00 m of depths (Meriç et al., 2008a). Analysis of the samples has revealed the presence of a rich benthic foraminiferal fauna, including 50 genera and 84 species, such as, *Haddonia* sp., *Sahulia kerimbaensis* (Said), *Textularia foliacea* Heron-Allen and Earland T. occidentalis Cushman, *T. pseudorugosa* Lacroix, *T. rugulosa* (Cushman), *Siphoniferoides cf. balearicus* (Colom), *Clavulina angularis* d'Orbigny, *C. multicamerata* Chapman, *Vertebralina striata* d'Orbigny, *Spiroloculina angulata* d'Orbigny, *S. attenuata* Cushman and Todd, *S. antillarum* d'Orbigny, *S. communis* Cushman and Todd, *S. convexa* Said, *S. corrugata* Cushman and Todd, *Spiroloculina* sp. A, *Spiroloculina* sp. B, *Agglutinella robusta* El-Nakahal, *Schlumbergerina alveoliniformis* (Brady), *Affinetrina quadrilateralis* (d'Orbigny), *Hauerina diversa* Cushman, *Cycloforina carinata* (Albani), *C. collumnosa* (Cushman), *C. crenulata* (Cushman), *C. semiplicata* (McCulloch), *C. cf. semireticulosa* (Cushman), *Cycloforina* sp. A, *Cycloforina* sp. C, *Lachlanella corrugata* (Collins), *L. subpolygana* (Parr), *Lachlanella* sp. A, *Quinqueloculina mosharrafai* Said, *Q. multimarginata* (Said), *Quinqueloculina* sp. C, *Miliolinella hybrida* (Terquem), *M. webbiana* (d'Orbigny), *Miliolinella* sp. A, *Miliolinella* sp. D, *Pseudomassilina reticulata* (Heron-Allen and Earland), *Pseudomassilina* sp. A, *Pseudotriloculina subgranulata* (Cushman), *Pseudotriloculina* sp. B, *Pyrgo denticulata* (Brady), *P. yabei* Asano, *Triloculina assymetrica* Said, *T. fichteliana* d'Orbigny, *T. serrulata* McCulloch, *T. terquemiana* (Brady), *T. tricarinata* d'Orbigny, *Varidentella neostriatula* (Thalmann), *Articulina pacifica* Cushman, *Borelis schlumbergeri* (Reichel), *Coscinospira hemprichii* Ehrenberg, *Peneroplis pertusus* (Forskal), *P. planatus* (Fichtel and Moll), *Amphisorus hemprichii* Ehrenberg, *Sorites orbiculus* (Forskal), *S. variabilis* Lacroix, *Bolivina variabilis* (Williamson), *Brizalina simpsoni* Heron-Allen and Earland, *Floresina madagascariensis* (d'Orbigny) *spicata* (Cushman and Parker), *Loxostomina cf. africana* (Smitter), *Eponides concameratus* (Williamson), *Neoeponides bradyi* le Calvez, *Sphaeridia papillata* Heron-Allen and Earland, *Rosalina bradyi* Cushman, *R. orientalis* (Cushman), *Trethomphalus bulloides* (d'Orbigny), *Cibicides mayori* (Cushman), *Heterolepa cf. subhaidingeri* (Parr), *Planorbulinella elatensis* Thomas, *Cymbaloporetta tabellaeformis* (Brady), *Acervulina mahabeti* (Said), *Planogypsina acervalis* (Brady), *Sphaerogypsina globula* (Reuss), *Miniacina miniacea* (Pallas), *Epistomaroides punctatus* (Said), *Amphistegina lessonii* d'Orbigny, *A. lobifera* Larsen, *Neorotalia calcar* (d'Orbigny), *Ammonia convexa* Collins, *Elphidium craticulatum* (Fichtel and Moll), *Operculina ammonoides* (Gronovius) and *Heterostegina depressa* d'Orbigny (Meriç et al., 2008a).

Analysis of recent sediment samples from the Mediterranean coast of Israel has shown that *Amphistegina lobifera* Larsen, *Hauerina diversa* Cushman, *Coscinospira acicularis* (Batsch), *Amphisorus hemprichii* Ehrenberg, *Sorites orbiculus* Ehrenberg, *Pararotalia spinigera* (Le Calvez), *Operculina ammonoides* (Gronovius) and *Heterostegina depressa* have been widely distributed along this coastline (Meriç et al., unpublished data).

Rich benthic foraminiferal assemblages have been observed on the Levantine coast of Turkey, from Samandağ (Antakya), Gulf of İskenderun, Mersin, Antalya to Marmaris, including *Haddonia* spp., *Edenstostomina cultrata* (Brady), *Clavulina angularis* d'Orbigny, *C. cf. multicamerata* Chapman, *Nodopthalmidium antillarum* Cushman, *Spiroloculina angulata* Cushman, *S. antillarum* d'Orbigny, *Schlumbergerina alveoliniformis* (Brady), *Hauerina diversa* Cushman, *Quinqueloculina cf. mosharrafai* Said, *Miliolinella cf. hybrida* (Terquem), *Pseudomassilina reticulata* (Heron-Allen and Earland), *Pyrgo denticulata* (Brady), *Triloculina fichteliana* d'Orbigny, *Articulina alticostata* Cushman, *Peneroplis arietinus* (Batsch), *Cyclorbiculina compressa* (d'Orbigny), *Amphisorus hemprichii* Ehrenberg, *Sorites orbiculus* Ehrenberg, *S. variabilis* Lacroix, *Pyramidulina catesbyi* (d'Orbigny), *P. perversa* (Schwager), *Astacolus insolitus* (Schwager), *A. sublegumen* (Parr), *Entosigmomorphina* sp., *Cymbaloporetta plana*

(Cushman), *C. squammosa* (d'Orbigny), *Acervulina inhaerens* Schultze, *Planogypsina acervalis* (Brady), *P. squamiformis* (Chapman), *Amphistegina lobifera* Larsen, *Elphidium charlottense* (Vella), *E. striatopunctatum* (Fichtel and Moll) and *Heterostegina depressa* d'Orbigny (Avşar, 1997; Avşar et al., 2001 and 2009; Meriç et al., 2002 and 2008b, c, d).

It has been suggested that SW coasts Turkey have special ecological conditions for some of the thermophilic alien foraminifer species, especially for *Amphistegina lobifera* Larsen and *Amphisorus hemprichii* Ehrenberg (Meriç et al., 2008b). About one meter thickness test deposits of *Amphistegina* have been observed around Kalkan-Kaş-Kekova-Beşadalar-Üçadalar coasts (Yokes and Meriç, 2009). *Amphisorus hemprichii* Ehrenberg has been first recorded in the few sites along the Kalkan-Kaş-Kekova coasts and within a short time it has expanded its range of distribution towards the Aegean Sea, up to Bodrum (Meriç et al., 2008c).

Besides the Levantine coastline, Indo-Pacific originated alien foraminifer species have also been recorded on the Aegean coasts of Turkey, such as, *İridia diaphana* Heron-Allen and Earland, *Haddonia* sp., *Nodopthalmidium antillarum* (Cushman), *Edentostomina cultrata* (Brady), *Spiroloculina angulata* Cushman, *S. antillarum* d'Orbigny, *Hauerina diversa* Cushman, *Quinqueloculina* sp. C, *Triloculina affinis* d'Orbigny, *T. fichteliana* d'Orbigny, *Triloculina* sp. A, *Articulina alticostata* Cushman, *Coscinospira acicularis* (Batsch), *Euthymonacha polita* (Chapaman), *Peneroplis arietinus* (Batsch), *Amphisorus hemprichii* Ehrenberg, *Sorites orbiculus* Ehrenberg, *S. variabilis* Lacroix, *Pyramidulina perversa* (Schwager), *Astaloculs insolitus* (Schwager) *A. sublegumen* (Parr), *Brizalina simpsoni* (Heron-Allen and Earland), *Euuvigerina* sp., *Cymbaloporetta plana* (Cushman), *C. squammosa* (d'Orbigny), *Acervulina inhaerens* Schultze, *Planogypsina acervalis* (Brady), *P. squamiformis* (Chapman), *Amphistegina lessonii* d'Orbigny and *A. lobifera* Larsen (Avşar et al., 2009; Meriç and Avşar, 2001; Meriç et al., 2008, 2009a,b,c, 2010a,b and 2011; Zenatos et al., 2008;).

Euthymonacha polita (Chapman) is known to inhabit Pacific Ocean (Loeblich and Tapan, 1994). However, it has been abundantly observed around Kuşadası (Aydın) and Ilıca (Çeşme-İzmir) Bays and NW of Karaburun Peninsula (Meriç et al., 2010a). This species has not yet been recorded elsewhere in the Mediterranean. Moreover, an other Pacific originated alien species *Coscinospira acicularis* (Batsch) has also been recorded only in Ilıca Bay in the Mediterranean (Hottinger et al., 1993; Loeblich and Tapan, 1994; Meriç et al., 2010b and 2011). The thermophilic species *Nodophthalmidium antillarum* (Cushman) has been rarely observed in Gulf of İskenderun. Its presence around the submarine springs in Kuşadası Bay and Ilıca Bay suggested that the submarine springs might have enhanced the spread and establishment of the thermophilic aliens in Aegean Sea.

Spiroloculina antillarum d'Orbigny, Sorites orbiculus Ehrenberg and *Cymbaloporetta plana* (Cushman) have also been observed in the sediments of Dardanelles, where *Cushmanina stritopunctata* (Parker and Jones) has only been found along the Turkish coastline (Meriç et al., 2009b). The presence of *Spiroloculina angulata* Cushman and *Amphistegina lobifera* Larsen in the Gulf of Erdek (Sea of Marmara) indicated special ecological conditions around this site (Meriç et al., 2004 and 2005; Avşar et al., 2006). However, the most interesting finding on our coastline was the record of *Sorites orbiculus* Ehrenberg from west of Şile, near to the exit of Bosphorus to Black Sea (Meriç et al., 2010b).

Indo-Pacific originated foraminifer species, such as, *Triloculina fichteliana* d'Orbigny, *Coscinospira hemprichii* Ehrenberg, *Sorites orbiculus* Ehrenberg, *Cymbaloporetta plana* (Cushman), *Planogypsina acervalis* (Brady) and *Amphistegina lobifera* Larsen have also been recorded on the NW and SE coasts of Crete, as well as in western Aegean Sea (Koukousioura et al., 2010). Some of these species are also known to inhabit Atlantic waters, suggesting that they might have been introduced to the Mediterranean not via Suez Canal, but Gibraltar (Koukousioura et al., 2010). Hovever *İridia diaphana* Heron-Allen and Earland and *Cushmanina stritopunctata*

(Parker and Jones) have not yet been recorded in the western Mediterranean. Besides, *Amphistegina lobifera* Larsen has shown a east to west expansion in time in the eastern Mediterranean and has reached Malta (Yokeş et al., 2007).

Besides the above data, Hyams et al., (2002) and Hyams-Kaphzan et al. (2008) have reported the presence of the aliens species, *Nodopthalmidium antillarum* (Cushman), *Agglutinella soriformis* El-Nakhal, *Hauerina diversa* Cushman, *Pyrgo denticulata* (Brady), *Triloculina affinis* d'Orbigny, *Sorites orbiculus* Ehrenberg, Borelis sp., *Pararotalia spinigera* (Le Calvez), *Amphistegina lessonii* d'Orbigny, *A. lobifera* Larsen, *Heterostegina depressa* d'Orbigny along the Mediterranean coast of Israel. Langer (2008) has also reported *Borelis* sp., *Pegidia lacunata* McCulloch, *Heterostegina depressa* d'Orbigny from Mediterranean coast of Israel; *Pseudolachlanella slitella* Langer from Egypt, Libya and Tunisia; *Coscinospira hemprichii* Ehrenberg and *Sorites orbiculus* Ehrenberg from eastern Mediterranean, Aegean Sea and Adriatic; *Amphistegina* spp. from eastern Mediterranean, Aegean Sea and north African coasts (Egypt, Libya and Tunisia).

Indo-Pacific originated foraminifer species have also been found to spread along the north African coasts. On the coasts of Alexandria alien benthic foraminifers such as, *Spiroloculina antillarum* d'Orbigny, *S. communis* Cushman and Todd, *S. corrugata* Cushman and Todd, *Aglutinella compressa* El-Nakhal, *A. robusta* El-Nakhal, *A. soriformis* El-Nakhal, *Pyrgo denticulata* (Brady), *P. oblonga* (d'Orbigny), *Triloculina affinis* d'Orbigny, *Pseudoschlumbergerina ovata* (Sidebottom), *Amphisorus hemprichii* Ehrenberg, *Sorites orbiculus* Ehrenberg, *Globulina gibba* d'Orbigny and *Amphistegina madagascariensis* (d'Orbigny) have been recorded (Samir et al., 2003).

Discussion and Conclusion

Recent sediment samples from Sharm El Sheikh and literature knowledge about Gulf of Aqabe indicate the presence of a rich benthic foraminiferal fauna on the northern coasts of the Red Sea and *Amphistegina lobifera* Larsen is found to be the most dominant species of the assemblages (Hottinger et al., 1993; Meriç et al., 2008a). If the foraminiferal assemblages of the northern Red Sea and the eastern Mediterranean are compared similarities in species composition and dominance are seen. According to the current knowledge on the benthic foraminiferal assemblages in the eastern Mediterranean and the dispersion patterns of the aliens, after entering the eastern Mediterranean via Suez Canal, majority of the alien species are dispersed northwards in the Levantine basin, establishing on the coasts of Israel, Lebanon, Syria and reach the Turkish coasts (Figure 1). Following the general surface currents of the eastern Mediterranean, the aliens expand their ranges of distribution westwards along the Levantine coasts of Turkey (Moncharmont-Zei, 1968; Cherif, 1970; Hottinger, 1977; Morariu and Hottinger, 1988; Hollaus and Hottinger, 1998; Hyams et al., 2002; Hyams-Kaphzan et al., 2008; Langer, 2008; Meriç et al., 2008b, c and d). Passing through the deep Aegean waters may take time, but recent literature about the alien foraminifer fauna of Greek waters (Koukousioura et al., 2010) and the records of *Sorites orbiculus* and *Amphistegina lobifera* Larsen from Malta and Sicily (Cimerman and Langer, 1991; Yokeş et al., 2007; Caruso and Consentino, 2014) proves that eastern Mediterranean populations of alien foraminifer species, with the help of global warming, eventually will expand towards the central Mediterranean.

Since majority of the Indo-Pacific originated foraminifer species are thermophilic, the low water temperature of the Aegean Sea may be the key element limiting their northward expansion in the Aegean Sea. However, dense populations of *Euthymonacha polita* (Chapman), *Coscinospira acicularis* (Batsch) and *Amphistegina lobifera* Larsen around the submarine springs in Kuşadası and Ilıca Bays suggest that the invasive aliens take the advantage of geological characteristics of Aegean Sea and find a way to establish populations (Meriç et al., 2009c; 2010a; 2011). It seems that the submarine springs around the fault lines on the sea bottom enhances the dispersion of the alien species. Thus, using these fault lines the alien species may enter the

Sea of Marmara via Dardanelles and expand their range of distributions up to the Black Sea. This scenario may explain the presence of *Amphistegina lobifera* Larsen in the eastern Sea of Marmara and the record of *Sorites orbiculus* Ehrenberg in the Black Sea (Meriç et al., 2005, 2009b and 2010c).

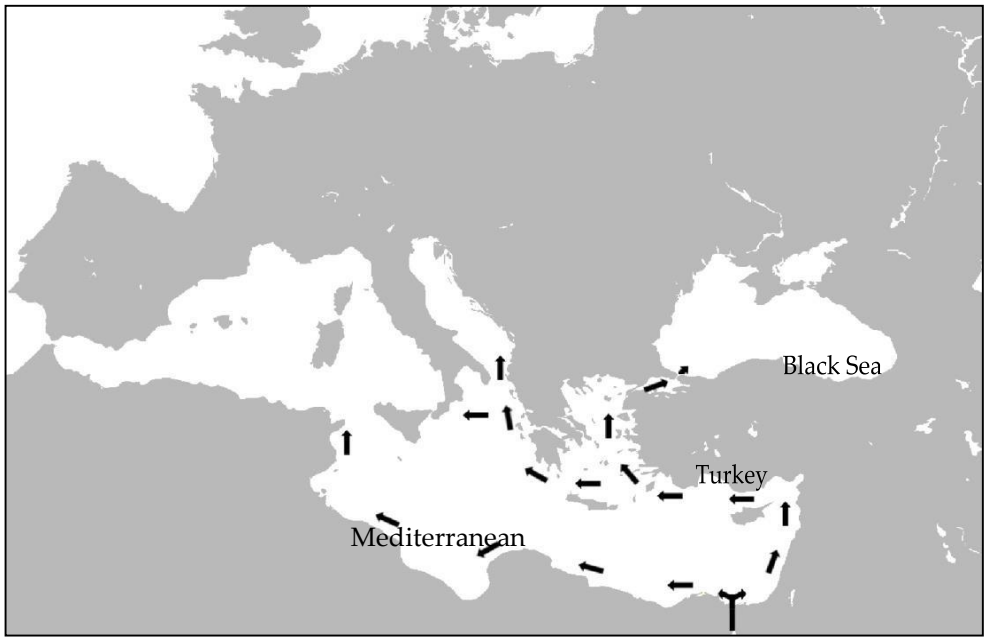

Fig 1. Study area

Alien species do not always expand their populations counter-clockwise in the eastern Mediterranean, some of these species have also been dispersed westwards along the north African coast after entering the eastern Mediterranean (Blanc Vernet et al., 1979; Crapon-de Caprona and Benier, 1985; Langer, 1989; Cimerman and Langer, 1991; Samir et al., 2003). The source of the alien foraminifer fauna observed in Malta and Sicily might have been the north African populations (Yokeş et al., 2007; Caruso and Consentino, 2014).

According to the dispersal pathways explained above, in the very near future, new records of *Borelis* sp., *Pegidia lacunata* McCulloch and *Operculina ammonoides* (Gronovius) around Gulf of Iskenderun is expected, which will be followed by new introductions. Global warming, submarine springs, human activities and biological adaptations will enhance the invasion of central and western Mediterranean, as well as the Black Sea, by Indo-Pacific originated alien foraminifers.

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