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AN ECOLOGICAL INVESTIGATION ON COLONIZATION OF FRESH WATER ARTIFICIAL REEFS

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Colonization of four different artificial reefs (cemented rope, brick, wood and ceramic) was studied during a six-month period.. The study was conducted in a fresh water pond filled with water from the Tajan River, a river in north Iran which flows into the Caspian Sea. A total of 2901 benthic individuals were collected in a biweekly sampling program. Eight species colonized the reefs including two bivalves, three gastropods, one prawn and two algae. The two algal species, Chara sp. and Nitella sp., were the first settlers on the freshwater artificial reefs in late April and May 2004. Within one month the gastropod Psuedomnicola sphaerion and the bivalves Dreissena polymorpha and Cerastoderma lamarckii were also settled. The gastropods Valvata piscinalis and Planorbis contortus appeared in July with two weeks difference. The prawn Palaemon elegans was found taking refuge in ceramic vase treatments in late August and early September. Biomass was assessed for wet weight and totalled 975 g/m^2. D. polymorpha at 593 g/m^2 was densest settler on reefs. Colonization was faster and denser on brick and ceramic. Cemented rope was next, and wood was last. Observation of fish (Carassius carassius) and frog (Rana rana) around artificial reefs provided evidence that these reefs are producing food, as benthic animals, for the predators of the pond. Water temperature was measured and its effect on colonization is discussed.

INTRODUCTION

Study on benthic settlement on artificial reefs in marine environments has a long background. McGurrin et al. (1989) stated that the oldest document is related to Southern California Ichthyology and was published in 1860. Japan was the first Asian country to use artificial reefs in 1950 (Rostamian, 1996). Numerous studies were done on artificial reefs aiming at increasing production of the sea (e.g. Bohnsack, 1987; Bougrova and Bugrovo, 1994; Oren and Benayahu, 1998; Golani and Diament, 1999; Chojnocki, 2000; Jensen et al., 2000; Spanier, 2000; Cripps and Aabel, 2002).

In Iran, fishermen traditionally have put stones, trees, ceramics, etc. in Persian Gulf waters to increase fish production from the sea (Azhdari, 2002). Rostamian in 1996 studied artificial reefs for the first time in the Persian Gulf, in Bushehr Province. He assessed its effects on fish restoration; however his study was left incomplete because he could not find his reefs, probably due to sedimentation.

Research on the effects of artificial reefs on freshwater benthos has little background. For the first time Stewart et al., (1998) studied artificial reefs in western Lake Erie, USA. Keltch et al. (1999) conducted research on artificial reefs to see if they improve sport fishing opportunities in near shore waters of Lake Erie. They evaluated the effectiveness of these structures as fish concentration devices and eventually assisted other coastal communities to develop artificial reef programs. Hanchine et al. (2003) showed the positive influence of tree trunks on increasing spawning of yellow perch in Lake Madison, South Dakota.

There has been no background study on fresh water artificial reefs in Iran and little is known about benthic habitats of fresh water. Benthic invertebrates play an important role in providing food for commercially important animals, including fish species. This paper aims to investigate colonization of artificial reefs in a fresh water environment filled with Tajan River water.

MATERIALS AND METHODS

Design of the experiment

Different structures were deployed as artificial reefs in a freshwater pond. The sedimentation pond is 60 m long, 12 m wide and has a depth of 4 m, It is located at the Ecology Institute of Caspian Sea, one of the fisheries research centers of the Iranian Fisheries Research Organization (IFRO), situated 25 km from Sari. The pond was filled with Tajan River water, which is one of the largest rivers of Mazandaran province (Figure 1).

Field work

Four different treatments of artificial reefs (cemented rope, brick, wood and ceramic) were placed in the pond and sampled from April thru September 2004 on a biweekly basis. Three replicate samples were collected from each treatment each time. Total samples of each reef were separated and preserved in buffered 4% formalin solution. Water temperature was measured by a thermometer during the sampling period.

Laboratory work

In the laboratory, samples were sorted using a 1 mm meshed sieve and washed with water. Then they were identified using appropriate keys (Ahmadi and Nafisi, 2001; Birshtain et al., 2000). Biomass of the samples was measured as wet weight. Biometry of each specimen was done by a graded ruler during sampling.

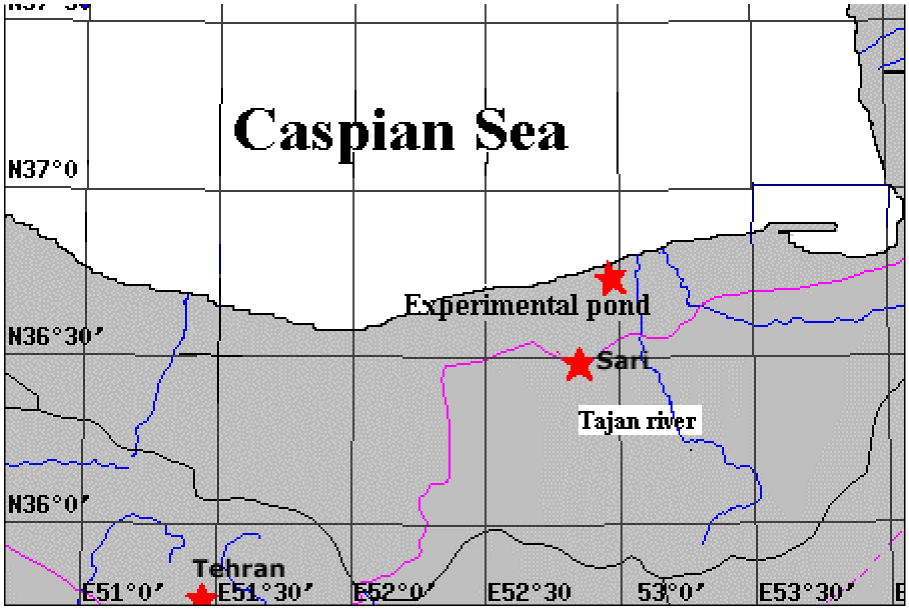

Figure 1. Study site and location of artificial reef experimental pond.

Statistical analysis

The differences between treatments in terms of density and biomass were tested using a one-way Analysis of Variance (Underwood, 1997). A post hoc analysis of LSD was carried out for comparing the differences between density and biomass on artificial reef treatments.

RESULTS

As Table 1 shows, eight species colonized the artificial reefs. They appeared gradually during the biweekly sampling period. A total of 2901 benthic individuals were collected. *Dreissena polymorpha* was the most dominant species and showed a significantly greater density compared to other species (Figure 2, $P<0.01$).

Water temperature fluctuated between 20 to 28°C during the experiment (Figure 3). Density was significantly different on artificial reef treatments (Figure 4, $P<0.01$). A total of 975 g/m^2

Table 1. Benthic species collected from the artificial reef treatments.

Artificial Reef Treatments				Family	Benthic Species
Ceramic	Wood	Brick	Cemented Rope		
+	+	+	+	Dreissenidae	*Dreissena polymorpha*
+	+	+	+	Cardiidae	*Cerastoderma lamarckii*
+	+	+	+	Lithoghyphidae	*Psuedomnicola sphaerion*
+	+	+	+	Valvatidae	*Valvata piscinalis*
+	+	+	-	Planorbiidae	*Planorbis contoratus*
+	-	-	-	Palaemonidae	*Palaemon elegans*
+	+	+	+	Characeae	*Nitella* sp.
+	+	+	+	Characeae	*Chara* sp.
8	7	7	6	Total species observed on each treatment	

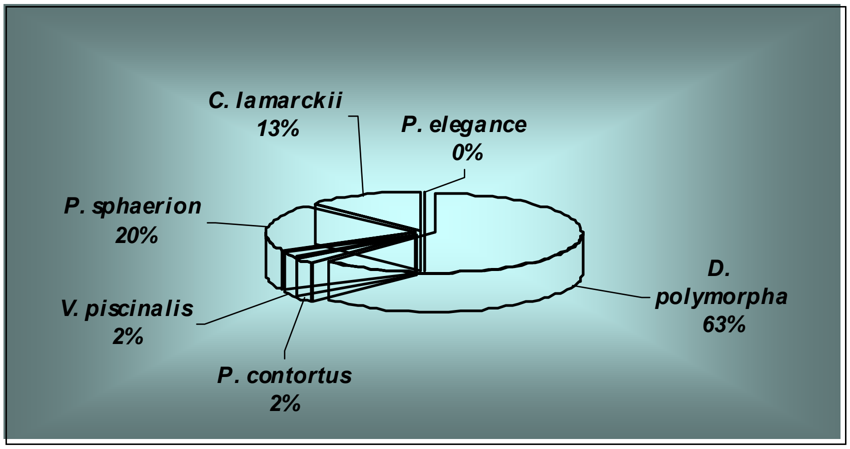

Figure 2. Density of benthic animals on artificial reefs.

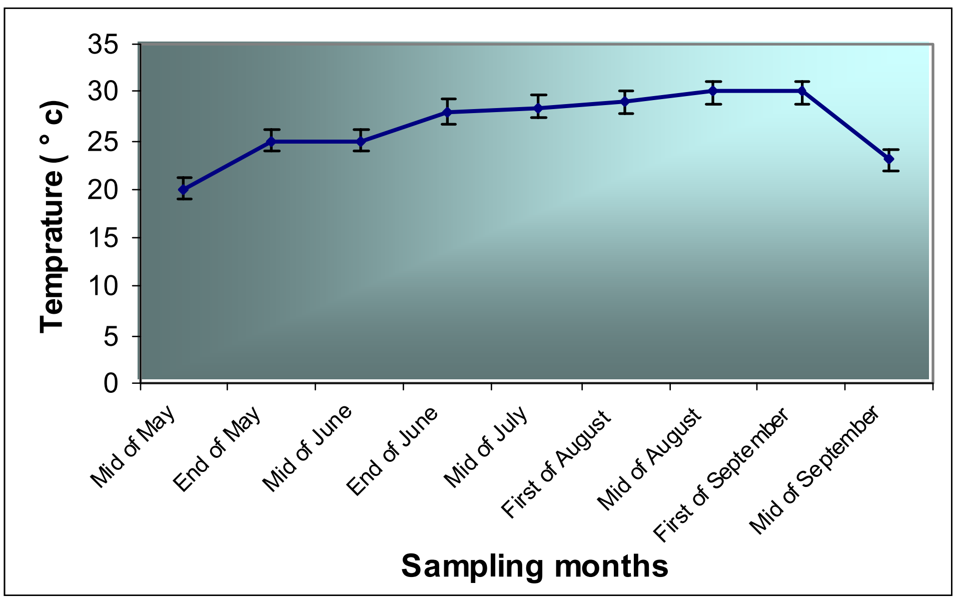

Figure 3. Water temperature during sampling, error bars are standard error.

biomass of benthos was measured, of which 593 g/m^2 was related to the most abundant species, *Dreissena polymorpha*. Treatments were also significantly different (P<0.01), so biomass was also significantly different on all treatments (P<0.01, Table 2).

The results indicated that the kind of artificial reef influences attraction of benthic animals. Density and biomass of the benthos on brick and ceramic were significantly greater than the other treatments (Figure 4, P<0.01).

Considering succession, at first *Nitella sp.* and *Chara sp.* were observed on the surface of artificial reefs in April and May. In June, in addition to these algae, *D. polymorpha, C. lamarckii* and *P. sphearion* had settled on the reefs. In July *V. piscinalis* and *P. contortus* appeared as well. During August there were no new species while in September *P. elegance* was added to other species on the ceramic reef.

Benthic animals were settled on artificial reefs in succession and their density was significantly

Table 2. Biomass and density of benthic species on the reefs.

Biomass percentage	Biomass (gr/m2)	Density percentage	Density (N/m2)	Benthos
60.79	593.108	62.60	1816	*D. polymorpha*
20.33	198.326	20.06	582	*P. sphaerion*
13.19	128.699	12.69	368	*C. lamarckii*
4.20	40.977	2.31	67	*V. piscinalis*
1.22	11.885	2.28	66	*P. contoratus*
0.27	2.641	0.07	2	*P. elegans*

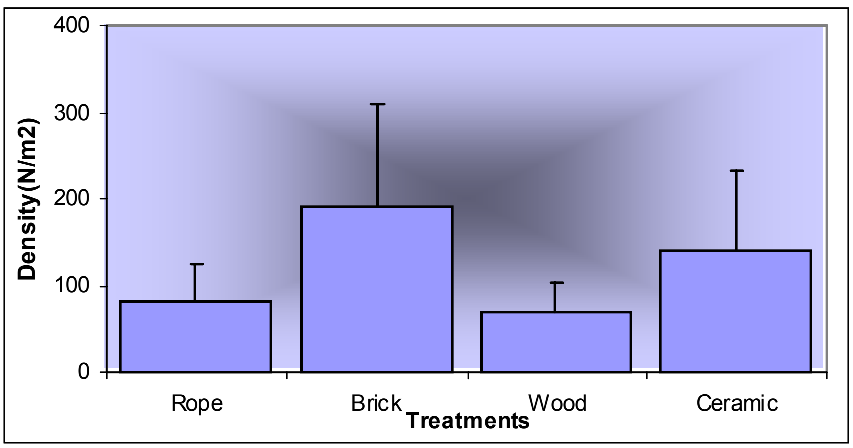

Figure 4. Mean density of benthos on artificial reefs, error bars are standard error.

different in sampling times (P<0.01). At the beginning in late April and during May only a few benthos were settled. In June and July, when natural recruitment stopped, no changes were observed. The biomass was also significantly different in sampling times (P<0.01). It was low at the beginning of sampling and increased gradually by warming water and decreased at the end of the sampling period (Figure 5).

DISCUSSION

The results indicated that the kind of artificial reef influences attraction of benthic animals. Density and biomass of the benthos on brick and ceramic were significantly more than the other treatments. One of the reasons which attract benthos to these artificial reefs may be their similarity to hard structures such as cliffs and stones which are the natural environment for their settlement (Turgeon, 1988).

D. polymorpha had the most density and biomass on all four artificial reefs. This species normally settles on cliffs and stones in the natural environment (Schloesser, 1995; Murphy, 1999), but it was able to settle on the four artificial reefs of the present experiment and increase in biomass. This bivalve is invasive in Europe and America, because in the early 19th century it was found just in the Black, Caspian and Azov Seas area (Stanczykowska, 1977). But somehow it spread

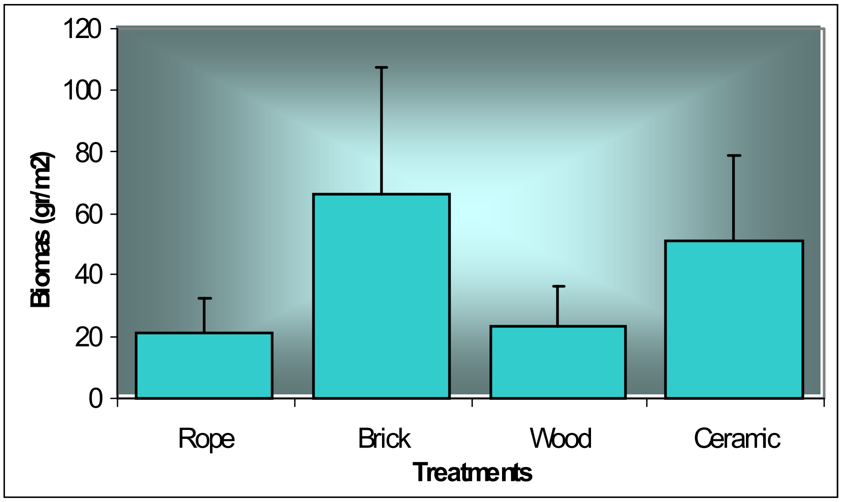

Figure 5. Mean biomass of benthos on artificial reefs, error bars are standard error.

to most of European and American waters (Mackie et al., 1989; Ram and McMahon, 1996; Griffiths et al., 1991; Ram et al., 1992; MacMahon, 1992). Today the zebra mussel lives in more than 230 lakes of the world (Mannien, 2005). This shows that this species has enormous ability to adapt itself to different environments. The result of the present study confirmed how strong this species is in colonizing any new habitat.

From a succession point of view when average water temperature was 20^{o}C, two algal species of *Nitella sp.* and *Chara sp.* appeared on the experimental artificial reefs (Figure 4). Temperature of water increased to 23^{o}C in June and the settled algae increased their biomass. In addition to algal growth, three mollusks including the two bivalves, *D. polymorpha* and *C. lamarckii,* and the gastropod *P. sphearion* were found on the reefs.

C. lamarckii is a cockle and reproduces in spring from May till July. The larvae have a pelagic life for 11 to 30 days. Then they search for a convenient substrate for settlement. Young cockles attach to these substrates temporarily by byssus threads (Holmes, 1979).

Spring and summer are the reproduction season for the zebra mussel (Murphy, 1999). Females spawn four times during the reproduction season and this can increase to more than four additional times in tropical regions. The larva has a pelagic life for 3-5 days and then they find a convenient substrate to attach by byssus threads (Nalepa and Schloesser, 1993; Schloesser, 1995).

In temperate species of *Psuedomnicola,* spawning takes place in spring and summer, and the other species that live in tropical regions reproduce in all seasons (Bureh, 1989). These snails have trochophore and veliger larval stages before settlement (Turgeon, 1988).

The present study showed recruitment of *D. polymorpha, C. lamarckii and P. sphearion* in June in the study area which is similar to recruitment of these molluscs in Michigan, New York and England (Murphy, 1999).

Gittenberger et al. (2004) showed that the eggs of *V. piscinalis*, which lives up to two years, are laid in March-July and hatched after 2-4 weeks. A high number of snails die after laying eggs. Snails born in summer reproduce the next summer, in the winter they hibernate in mud. Part of the adult snails survive the winter and reproduce in the summer. In the present study, in addition to the previous species, *V. piscinalis* and *P. contortus* were found in July on artificial reefs. This shows that *V. piscinalis* somehow reproduces earlier than those Gittengerger et al. (2004) examined, because they settled in July, when they are said to be reproducing. However *P. contortus* reproduced in our study similar to the specimens reported by Gittenberger et al. (2004).

P. contortus starts laying eggs in March. Snails born in the summer reproduce the next summer. They feed on bacteria in calm or streaming water with rich vegetation (Gittenberger et al., 2004).

The goldfish *Carassius carassius* and frog *Rana rana* were found around the artificial reefs. The reason for the presence of a high density of *C. carassius* around artificial reefs may be their feeding from invertebrates which were settled on the artificial reefs. *C. carassius* is omnivorous and eats zooplankton, water insects, crustaceans, molluscs, worms, algae, macropheata, small fish, etc (Penttinen and Hollopainen, 1992; Coad, 2002). The reason for the presence of *Rana rana* around the artificial reefs may be that tadpoles and little frog feed on the algae on artificial reefs. Tadpoles are herbivores and feed on algae, water plants, organic matter and microorganisms; though young frogs feed on insects and other microorganisms (Donegan, 1999; Mount, 1975). They may eat the invertebrates of the artificial reefs of this experiment.

In August with increased water temperature the reproduction and recruitment season ended and the benthic density and biomass remained approximately constant. At late August and early September *P. elegance* which is a fresh water shrimp was observed on ceramic treatments in low density. This shrimp naturally lives in cracks of stones in the intertidal zone to forty meters depth and is usually found in seagrass habitats in estuaries and the sea (Neal, 2004). This shrimp lives in dark places for hiding from predatory fishes which hunt them by using eye sight, so the ceramic vases provided suitable shelter for them.

The results indicated that the artificial reef structure influences benthos attraction. Forty percent of density and 41 percent of biomass was found on brick. 29 percent of density and 31 percent of biomass was on ceramic. Therefore colonization was faster and denser on brick and ceramic than other artificial reefs. Benthic invertebrates may prefer harder substrates which are to some extent similar to rocks, where they are naturally found.

D. polymorpha at 593 g/m^2 showed the densest population on reefs. Observation of fish (*Carassius carassius*) and frog (*Rana rana*) around artificial reefs provide evidence that these reefs are producing food, being benthic animals, for the predators of the pond. This paper showed clearly that artificial reefs can be deployed to increase the benthic animals which are in turn food for larger predatory fish.

Our study leads us to conclude that fresh water artificial reefs are suitable resources and can enhance production of fish food in fresh water, as is the case for marine environments.

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REFERENCES

Ahmadi, M.R., and Nafisi, M. 2001. Identification of bioindicator invertebrates in running waters (in Persian). Kheibar Publishing, Tehran, Iran.

Azhdari, H. 2002. Feasibility study of Marine artificial reefs for rehabilitation of demersal fish in the Persian Gulf, Iran (in Persian). Iranian Fisheries Co., Tehran, Iran.

Birshtain, Y.A., K.F. Kesler, and Y.N. Kodelina. 2000. Invertebrate Encyclopedia in Caspian Sea. (Translated to Persian by Delinad, L. and Nazari, F., 2001), IFRO, Tehran, Iran.

Bohnsack, J.A. 1987. The discovery of free lunch and spontaneous generation: Is artificial reef construction out of control? American Institute of Fishery Research Biology, April, 16)2:(2-3.

Bougrova, L.A. and L.Y. Bugrovo. 1994. Artificial reefs as fish–cage anchors. Bulletin of Marine Science, 55: 1122-1136.

Bureh, J.B. 1989. North American freshwater snails. Malacological publications, Ann Arbor, USA.

Chojnocki, J.C. 2000. Environmental effects of artificial reefs in the southern Baltic. In: Artificial reefs in European seas, Jensen, A.C., Collins, K.J. and Lockwood, A.P.M. (eds) Kluwer Publishers, UK, pp.307-317.

Coad, W.B. 2002. Freshwater fishes of Iran. Published by Throttle Technologies Inc, Ottawa, Ontario, Canada.

Cripps, S.J., and J.P. Aabel. 2002. Environmental and socio economic impact assessment of reef, a multiple platform rigs-to-reefs development. ICES Journal of Marine science, 59: 211-216.

Donegan, K. 1999. *Rana pipens*, Animal diversity. The Regent University of Michigan, Michigan, USA.

Gittenberger, E., A.W. Janssen, W.J. Kuijper, T. Meijer, G. Van der Veldeen, and J.N. de Vries. 2004. De Nederlandse zoetwatermollusken, recente en fossile weekdieren uit zoeten brak water. Naturalis publishing, Nederland.

Golani, D. and A. Diamant. 1999. Fish colonization of an artificial reef in the Gulf of Elat, northern Red Sea. Environmental Biology of Fisheries, 54: 275-282.

Griffiths, R.W., D.W. Schloesser, J.H. Leach, and W.P. Kovalak. 1991. Distribution and dispersal of the zebra mussel in the Great Lakes region. Can. J. Fish. Aq. Sci. 48: 1381-1388.

Hanchine, P.A., D.W. Willis, and T.R. Sauver. 2003. Influence of introduced spawning habitat on yellow perch reproduction in Lake Madison, South Dakota. J. Freshwat. Ecol., USA. 18 (2): 291-298.

Holmes, S. 1979. Henderson's dictionary of biological terms, 9th ed. Longman Group, London, UK.

Jensen, A.C., K.J. Collins, and A.P.M. Lockwood. 2000. Artificial reefs in European seas. Kluwer Publishers, UK.

Keltch, D.O., F.L. Schneider, and J.F. Reutter. 1999. Evaluation of artificial reefs as fish concentration devices in Lake Erie: Case studies of the Lorian and Lakewood, Ohio artificial reefs. Ohio State University Extension, Ohio, USA.

Mackie, G.L., W.N. Gibbons, B.W. Muncaster, and I.M. Gray. 1989. The zebra mussel: A synthesis of European experiences and a preview for North American Great lakes section, Water resources branch, Ontario Ministry of Environment, London, Ontario, Canada.

Manninen, C.H. 2005. Great Lakes information. Milwaukee Journal Sentinel, 711-720.

McGurrin, J.M., R.B. Stone, and R.J. Sousa. 1989. Profiling United States' artificial reef development. Bull. Mar. Sci. 44: 1004-1013.

MacMahon, R.F. 1992. The zebra mussel. The biological basis of its macro fouling and potential for distribution in North America. Proceedings of Corrosion 92: 342.

Mount, R.H. 1975. The Reptiles and Amphibians of Alabama. Auburn University, Agricultural Experiment Station, Auburn, Alabama, USA.

Murphy, T. 1999. *Dreissena polymorpha*. University of Michigan. Michigan, USA.

Nalepa, T., and D. Schloesser. 1993. Zebra mussels Biology, Impact and control. Lewis Publisher, USA.

Neal, K.J. 2004. *Palaemon elegans*. Marine Biological Association of the United Kingdom, London, UK.

Oren, U., and Y. Benayahu. 1998. Didemind ascidians: rapid colonizers of artificial reefs in Eilat (Red Sea). Bulletin of Marine Science, 63: 199-206.

Penttinen, O.P., and I.J. Hollopainen. 1992. Seasonal feeding activity and ontogenetic dietary shifts in Crucian Carp. Env. Biol. Fishes, 33: 215-218.

Ram, J.L., P.P. Fong, R.P. Croll, J.S. Nichols, and D.A. Wall. 1992. The zebra mussel, a new pest in North America: reproductive mechanism as possible targets of control strategies. Invert. Rept. Dev. 22: 77-86.

Ram, J.L., and R.F. McMahon. 1996. Introduction: biology, ecology and physiology of zebra mussel. America Zoologist 36(3): 239-243.

Rostamian, H. 1996. A study on use of artificial reef in Persian Gulf (In Persian). Iranian Fisheries Research Organization (IFRO), Tehr Bougrova an, Iran.

Schloesser, D.W. 1995. Zebra mussel infestation of unionid bivalves (unionidae) in north America. Amer. Zool. 36: 300-310.

Spanier, E. 2000. Artificial reef of the Mediterranean coast of Israel. In: artificial reefs in European seas. Jensen, A. C., Collins, K. J. and Lockwood, A. P. M. (eds), Kluwer Publishers, UK, pp. 1-19.

Stanczykowska, A. 1977. Ecology of *Dreissena polymorpha* in Lakes. Pol. Arch. Hydrobiol. 24: 461-530.

Stewart, T.W., J.G. Miner, and R.L. Lower. 1998. Macroinvertebrate communities on hard substrates in western Lake Erie: structuring effect of *Dreissena*. Journal of Great Lakes Research, 24 (4): 868-879.

Turgeon, D.D. 1988. Common and scientific names of aquatic invertebrates from United States and Canada mollusks. American fisheries society, special publication. pp.17-19.

Underwood, A.J. 1997. Experiments in ecology, their natural design and interpretation using Analysis of Variance. Cambridge University Press, Cambridge, UK.

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