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Research Article

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An Experimental Trial on Biological Control of Zebra Mussel

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Abstract Zebra mussels are a preferred prey for most crayfish but this tendency of consumption has not been tested in lab and field experiments especially in Turkey. For this reason, 18 juvenile crayfish (*Astacus leptodactylus*) and 240 juvenile zebra mussels (*Dreissena polymorpha*) of 1.95 mm in mean length were used in the experiments. At the end of the second day, faeces of the crayfish were examined in all petri dishes, and a large proportion of the granular fish feed had not been consumed by the crayfish. These results show that crayfish were potentially significant predators and may be able to limit zebra mussel populations.

Keywords Freshwater, crayfish, zebra mussel, predation, consumption

1. Introduction

The zebra mussel (*Dreissena polymorpha*) is a small freshwater mussel. This species was originally native to the freshwaters of southern Russia, Ukraine [1] and Turkey [2-3]. However, the zebra mussel has been accidentally introduced to numerous other areas, and has become an invasive species in many different countries worldwide. It is commonly found on the bottom of ships and eat the algae that are food for fish. It is usually about the size of a fingernail, but can grow to a maximum length of nearly 5 cm [4]. Shells are D-shaped, and attached to the substrate with strong byssal threads, which come out of their umbo on the dorsal (hinged) side (Figure 1).

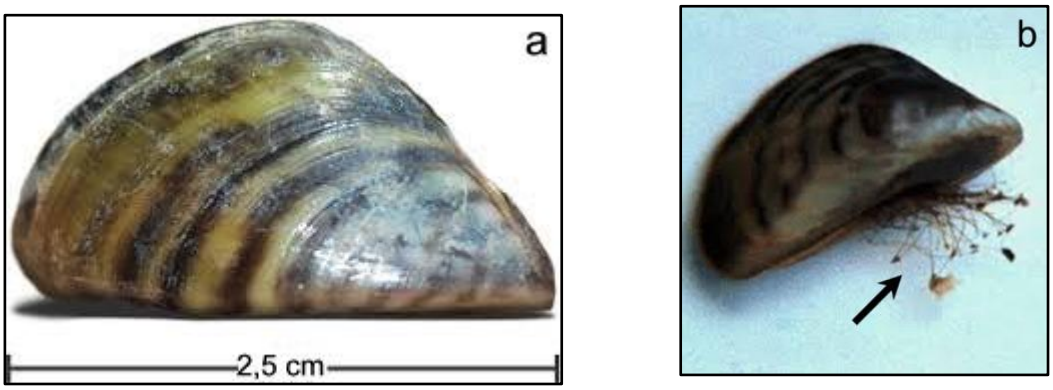

Figure 1: Zebra mussel (a) and byssal threads (b)

The species name "**polymorpha**" is very appropriate for this organism since the stripe pattern on the shells of the zebra mussel can be quite variable. "**Polymorpha**" in the Latin refers to the many colorations and patterns found in zebra mussel population. The zebra mussels collected from the Atatürk, Birecik and Karkamis dams and HEPPs appear cream-colored or completely black [5-7]. Zebra mussels in Egirdir Lake located in the southwestern Mediterranean region of Turkey can also range from cream to black [8]. However, the shells of mussels taken from Kesikköprü Dam Lake are brown (those collected from surface water) or black (those collected from deepwater) (Figure 2).

Zebra mussel is a filter-feeding organism. It removes particles from the water column. The zebra mussels process up to one liter of water per day, per mussel. Some particles are consumed as food, and faces are deposited on the lake floor. Non-food particles are combined with mucus and other matter and deposited on lake floors as pseudo-faces [9-10].

Figure 2: Zebra mussels collected from Birecik (a) and Kesikköprü Dam Lake (b)

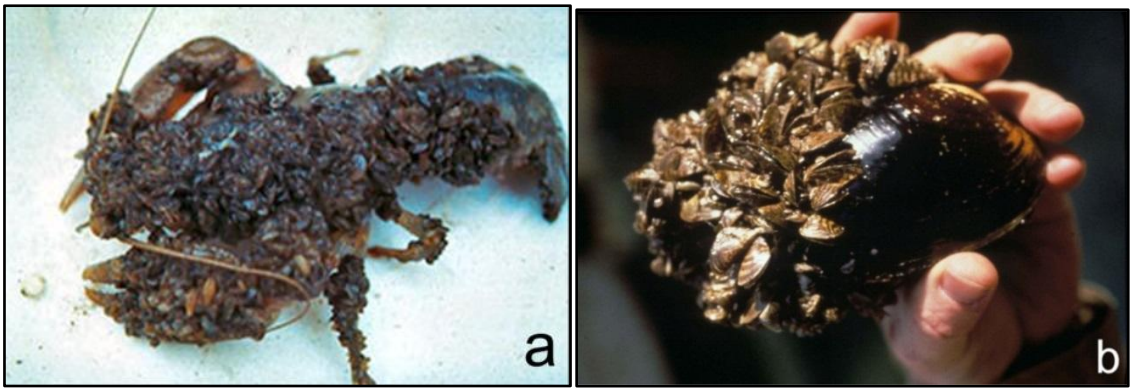

Figure 3: Bioaccumulation of zebra mussels on exoskeleton of crayfish (a) and unionid (b)

Zebra mussels settle on hard surfaces normally, including inorganic substrata and biological surfaces such as carapaces of crayfishes and a range of freshwater organisms. Because adult crayfish moult at longer intervals than do juveniles, the number of filter-feeding zebra mussel accumulates on adult crayfish, and their foraging is likely diminished [11]. Crayfish encrusted with mussels move more slowly and must spend more energy as a result of carrying this load of attached bivalves. It is unclear if these attached mussels increase or decrease risk of predation. Fishes that feed on zebra mussels would likely be able to consume the crayfish as well as the mussels. Crayfish derive energy from suspended particles by filter feeding [12] even though they also forage on a wide range of other foods that differ in size and type. Competition with zebra mussels for suspended organic material could have a negative effect on adult crayfish under some conditions [13] (Figure 3).

Zebra mussels cause ecologic, technic and economic damages where available. From ecologic standpoint an individual zebra mussel can filter one to two liters of water each day [14]; as a result high densities of zebra may cause major shifts in the plankton communities of lakes and rivers [15-16]. Reductions in phytoplankton numbers and biomass also limit food to fish larvae and other consumers further up the food chain [17]. Zebra mussels have the potential to severely impact other native animals such as unionids (other large mussels) and crayfish by interfering with their feeding, growth, locomotion, respiration and reproduction. Therefore, unionid bivalves and crayfish in aquatic environment can be killed by zebra mussels colonizing the shells of unionids and the exoskeletons of crayfish [18-21]. Habitat loss is another issue as zebra mussels invade space and dominate the shoreline ecosystems. Multiple technic and economic impacts include the negative effects such as the interference with fishing gear, prey for commercial fish, alteration of fish communities, fouling of cages,

clogging of water intake pipes, fouling of ship hulls and navigational constructions. Invasion of the zebra mussels to the North America is causing annual multimillion losses to the economy [22-24].

There have been miscellaneous methods in control of zebra mussels. But, every method has some its own advantages and disadvantages. Therefore, biological control can be regarded the one of the best ways from control methods. Although zebra mussels have both competitors and parasites [25-26], predators are a significant factor to be dominated or restricted zebra mussel population [27-28]. For instance, migratory waterfowls can decrease between 14 and 90 % of zebra mussel population in the aquatic environment of Europe while some fish can affect mussel population in the range of 1 or 2 % [29-30] and these species are essential for population dynamics of zebra mussels [31-32]. Furthermore, turtles [33], crayfish [34-37] and crabs [38] are admitted as a factor in restriction of zebra mussel population. Crayfish are one of the important predators and have an outstanding potential in control of zebra mussel population [39].

Crayfish are represented by six indigenous and five nonindigenous species in Europe and by two species (*Astacus leptodactylus* and *Austropotamobius torrentium*) in Turkey [40-41]. Crayfish species are naturally abundant in most of natural freshwater bodies of Turkey. Among these species, *A. leptodactylus* distributes in most of Turkish freshwater (Figure 4). It is well known that crayfish have been transferred between water bodies due to anthropogenic effects [42-43] such as introduction of crayfish into newly constructed dam lakes by fisherman or government fisheries officials. It has been of great profit to the economy of country, especially as the demands from Europeans countries and, domestic consumption is very little in Turkey.

Figure 4: The crayfish (Astacus leptodactylus) in Turkish freshwaters

Zebra mussel colonization of invertebrates, particularly unionid mussels [44] and larvae [45-46] has already been documented. Colonization or fouling of crayfish species has only occasionally been reported, e.g., *Astacus astacus* [47], *Astacus leptodactylus* [48], *Orconectus limosus* [49], *Orconectus rusticus* [50], *Orconectes luteus* [51] and in the last decade *Orconectes pardalotus* [52].

European workers have observed high rates of predation on zebra mussels by the crayfish *Orconectes limosus*, and have suggested that crayfish predation can greatly reduce the abundance of Dreissena populations [53-54]. Piesik [53] observed that *O. limosus* tended to prey selectively on small (1-7 mm) zebra mussels, and that predation rates by female crayfish were higher than those of males.

In Turkey, it was investigated that whether crayfish consume zebra mussels or not, and which size of mussels was consumed by crayfish. Zebra mussels range from 5 to 23 mm total length were separated to 3 size classes. To determine food type preference of crayfish, individuals were fed with fresh mussels, steamed mussels and pellet food. The results indicated that crayfish consumed mostly on small mussels and steamed mussels were completely consumed by crayfish. In the presence of alternative prey, experienced crayfish consumed mussels and alternative foods in similar amounts while crayfish chose firstly encountered zebra mussels as alternative food. In conclusion, it was determined that zebra mussels (*Dreissena polymorpha*) could be use an alternative food in crayfish culture and could be effective on control of zebra mussels in an area by artificially introducing of crayfish [55].

This experimental study aims to reveal in which proportion of zebra mussels are fed by crayfish (*Astacus leptodactylus*) in Turkey.

2. Material and Method

The juvenile zebra mussels to be used in the experiments were collected from Birecik Dam on the Euphrates River and crayfish were supplied from Faculty of Aquaculture of Cukurova University. Trout pellet feed of Number 2 was bought from fish market.

Experiments were carried out at constant water temperature of 22°C and in the laboratory settings.

18 juvenile crayfish that their mean weights are 0.04 g, their mean total lengths 10.95 mm and their mean carapace lengths 6.13 mm were placed in 18 glass petri dishes (Table 1).

Table 1: Measurements of 5 Juvenile Crayfish Using by Olympus SD30 Model Stereo Microscope(x10)

No	Total Length (mm)	Carapace Length (mm)	Weight (g)
1	10.98	5.86	0.04
2	11.03	6.10	0.04
3	11.00	6.22	0.04
4	10.68	6.12	0.04
5	11.05	6.34	0.04

In the experiments, 240 juvenile zebra mussels (*Dreissena polymorpha*) of 1.95 mm in mean length were used. 1 juvenile crayfish and 10 juvenile zebra mussels were put into each of six petri dishes (first series); 1 juvenile crayfish, 10 juvenile zebra mussels and 0.01 g granular fish feed into each of other six petri dishes (second series); and 1 juvenile crayfish and 0.01 g granular fish feed into each of different petri dishes (third series as a control) (Figure 5 and 6).

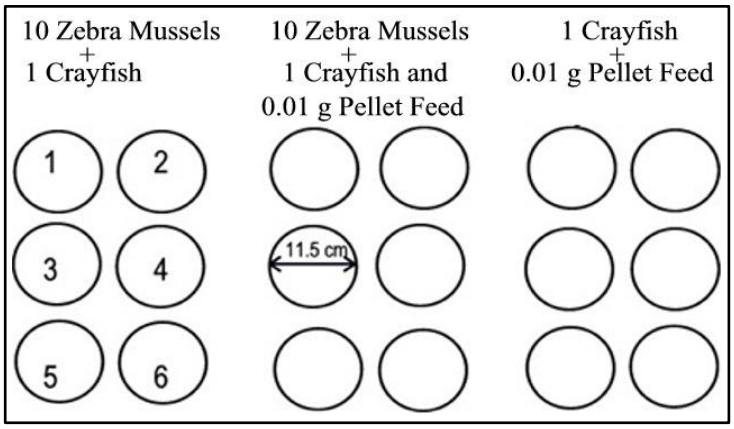

Figure 5: Experimental Setup

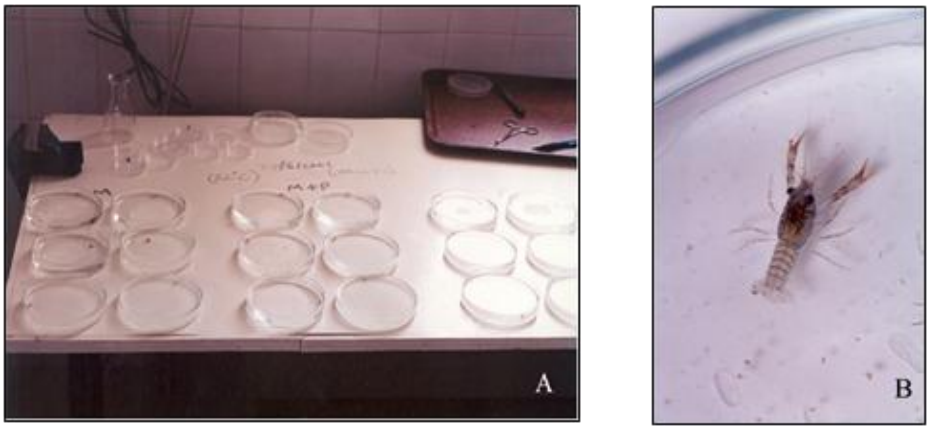

Figure 6: Experimental Setup in Lab and Juvenile Crayfish in Petri Dish

At the end of the second day, faeces of the crayfish were examined in all petri dishes, and a large proportion of the granular fish feed had not been consumed by the crayfish.

3. Results

The number of unconsumed zebra mussels was observed and recorded as three replicates 48 hours later (Table 2).

Table 2: The Number of Unconsumed Zebra Mussels after 48 hours

Petri No	1st Replicate		2nd Replicate		3rd Replicate	
	M*	M+P**	M	M+P	M	M+P
1	0	2	1	2	1	1
2	0	1	0	3	2	0
3	0	1	2	1	0	3
4	1	0	1	0	0	1
5	0	0	0	3	0	3
6	0	1	0	0	1	0

M : Mussel P : Pellet Feed M + P : Mussel and Pellet Feed

At the end of 48 hours the fine faeces and a large number of unconsumed granular pellet feed were observed in petri dishes. Furthermore zebra mussel and pellet feed (M+P) mostly were consumed (Figure 7).

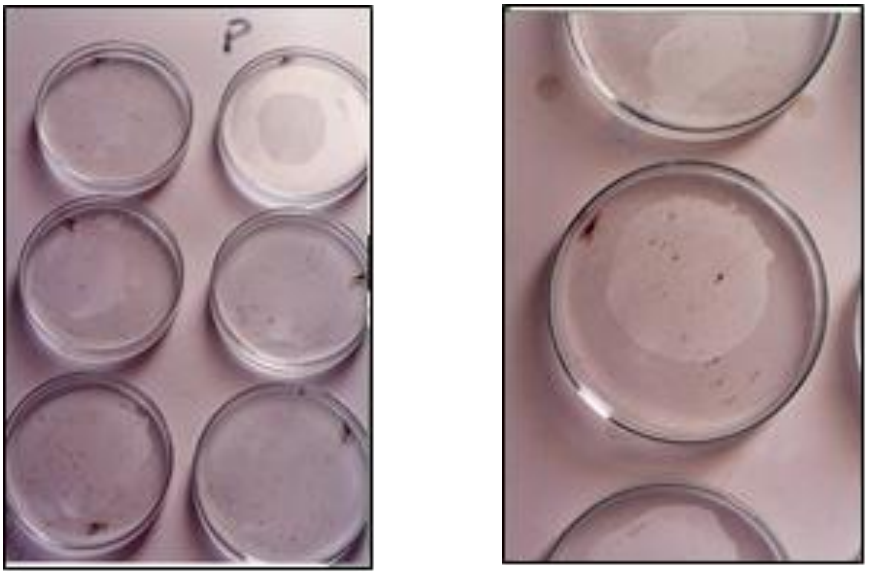

Figure 7: The Display of Petri Dishes 48 Hours Later

At the end of 3rd day it was recorded that all the zebra mussels in petri dishes were consumed. The consumption of pellet feed in control petri dishes was realized as 50 per cent.

4. Discussion

The propensity to consume of zebra mussels by crayfish as feed depends on the presence of other nutritional sources in aquatic environment [37], but it was determined that crayfish have been reduced zebra mussel population as far as 31 per cent in the experiments [36]. However there have been based on two factors in consumption of zebra mussels by crayfish: The short-term experiments and size of zebra mussels. These factors have been affected the experiments positively or negatively [34-35]. Zebra mussels in size of 5.5 mm have been consumed by crayfish as a whole while mussels bigger than 5.5. mm in size have been consumed by breaking their shells [36]. As the shell of mussels is bigger and bigger the balance of cost-benefit are destroyed and consumption of zebra mussels by crayfish has been become difficult. Also smaller mussels are hunted by crayfish easier and but they give less calorie. Moreover, an adult crayfish can consume 105 mussels in a day and 6000 in a season [56].

In addition to animal prey, crayfish consume detritus [57] and a variety of aquatic plants [58-62]. The impact of crayfish predation on zebra mussel populations in nature will depend on relative preferences for zebra mussels, other invertebrates, aquatic plants and detritus.

Crayfish and zebra mussel share the same aquatic environment and crayfish feed on molluscs, small fish, larvae, animal carcass, and vegetable substance [63-66]. At least, three species of crayfish (*Orconetes propinguus*, *O. virilise* and, *O. rusticus*) coincide with distribution of zebra mussels in North America.

Since crayfish have been observed to feed on zebra mussels [34, 36, 53, 67] in size ranges overlapping, it is difficult to understand why many of the mussels were attached in places (e.g., chelae) that were accessible to the crayfish. It may be that *Orconectes rusticus* is not well-adapted for removing attached organisms, but grooming morphology and behaviour have not been studied in this species. Many decapods have specialized structures for keeping the body free of epizoic growth, but grooming behaviours and time spent grooming vary considerably among species [68-69]. Lamanova [48] felt the small size (mostly <10 mm) of infesting zebra mussels and the presence of chitinous ulcers up to 1 cm indicated that the European crayfish, *Astacus leptodactylus cubanicus*, actively removed the mussels from its shell with the associated cost of breached integument and increased potential for infection. However, frequent molting probably also contributed to the small size Lamanova observed. In *Procambarus clarkia* grooming is relatively infrequent compared to marine decapods, and grooming morphology and behaviour do not appear to be efficient enough to prevent fouling by a tenacious colonizing exotic species [70].

Since the juvenile zebra mussels used in this experiment are in the same size nearly and the predator crayfish used are in the same length, this study has not been shown the relations between hunt and hunter. But the consumption of zebra mussels in the petri dishes by crayfish completely has realized in a short time(48 hours only) and at high rates such between 95 and 98 %. Mussel consumption in the petri dishes used M+P has been remained between 85 and 92 %. These consumption rates show that crayfish have preferred zebra mussels to pellet feed by far at least.

The trials implemented in cages show that crayfish have consumed zebra mussel population at the rate of 50 per cent in five weeks [58]. For this reason it can be readily said that crayfish will be able to use effectively in biological control of zebra mussel population in freshwaters or to suppress zebra mussels at least. But, in fact that crayfish were used in control of zebra mussel population for every aquatic ecosystem can create important problems in terms of ecosystem balance and population dynamics. Some crayfish diseases such as crayfish plague specially can affect other aquatic species negatively in fresh water environment.

5. Conclusion and Recommendations

To forecast ecosystems that can cause important problems generally in terms of both zebra mussel population and ecosystem dynamics is essential in management of natural resources. Forecasting and taking measure is an approach to forestall the resulting problems in a sense. If it is an aquatic ecosystem in question, the problem has been got bigger.

Many methods of zebra mussel control and eradication are now being used and tested. Manual scraping and abrasive blast cleaning has been successful, but are expensive and time-consuming. Oxidizing and non-oxidizing biocides have been used as well as ultraviolet radiation, with mixed results. Large-bodied molluscivores such as common carp, freshwater drum, and channel catfish can limit zebra mussel numbers in coastal wetlands. Densities of other molluscs were not affected, suggesting that fish can have a greater impact on numbers of attached zebra mussels than other benthic molluscs. Known predators also include roach, eel, sturgeon, diving ducks, crayfish and muskrats. Since every method has its own advantages and disadvantages, every method or measure could not use everywhere in control of zebra mussel population. For this reason, struggle against mussels have to be gone on by using multiple methods. However biological control methods seem promising among control methods.

Crayfish are common inhabitants of fresh waters in Turkey. Zebra mussel is a bivalvemollusc that is indigenous to Turkish fresh waters, and reproduction and adaptability to ambient conditions pretty much. So zebra mussel has been populated in all fresh waters of Turkey more or less. Where ecological conditions are appropriate zebra mussel can cause technical problems in artificial systems and ecological problems in natural ecosystems by overbreeding.

The biological control of zebra mussels by crayfish has some advantages such as (i) reducing decapod population, (ii) presence of crayfish abundant in lakes and running waters that are sensitive to zebra mussel

invasion, (iii) sharing the same environment of crayfish and zebra mussel, (iv) existence of crayfish in aquatic system all year round, (v) living in deep waters of crayfish.

In conclusion, the results obtained both field and lab experiments show that adult and juvenile crayfish can use affectively to suppress zebra mussel population or to mitigate its damages. However, the researches must be focused on zebra mussels in environment where other invertebrates will naturally become and the decision must be made whether crayfish will be commonly used in control of zebra mussel population or not.

References

1. WoRMS (2013). *Dreissena polymorpha* (Pallas, 1771), World Register of Marine Species, http://www.marinespecies.org/aphia.php?p=taxdetails&id=181566, Retrieved June 12, 2017
2. Altınayar, G., Ertem, B., Aydoğan, F. (2001). Hidroelektriksantrallardavesuarıtmatesislerindesorunyaratan zebra midye [*Dreissena polymorpha* (Pallas, 1771)]'in yaşamıvesavaşımı, YayınlanmamışNotlar, 6 pp
3. Bobat, A. (2001a). Tatlısuekosistemindeteknik, ekonomikveekolojikbirzararlı: Zebra midye, KırsalÇevreYıllığı, 112-127.
4. Morton, B. 1993. The anatomy of *Dreissena polymorpha* and the evolution and success of the heteromyarian form in the Dreissenoidea. In T. F. Nalepa and D. W. Schloesser (eds.), Zebra mussels: Biology, impacts, and control, pp. 185—216. Lewis/CRC Press, Inc., Boca Raton, FL. 810 pp. FL.
5. Bobat, A., Hengirmen, M.O., Zapletal, W. (2001b). Zebra Mussel Research Project in Birecik HPP, First Progress Report. 19 pp.
6. Bobat, A., Hengirmen, M.O. and Zapletal.W. (2001c). Zebra Mussel Research Project in Birecik HPP, Second Progress Report, June-September 2001, 18 pp.
7. Bobat, A., Hengirmen, M.O. and Zapletal, W. (2002). Problems of the zebra mussel at dams and hydro projects on the Euphrates river, Hydro 2002, Conference Proceedings, 475-484.
8. Geldiay, R., Bilgin, F. (1973). BatıAnadolununBazıTatlıSularındaYaşayanBirBivalvTürü *Dreissena polymorpha* (Pallas)" Hakkında, E.Ü.FenFak. İlmiRaporlarSerisi No. 58, 10 pp.
9. Holland, R.E. (1993). Changes in planktonic diatoms and water transparency in Hatchery Bay, Bass Island area, western Lake Erie since the establishment of the zebra mussel (*Dreissena polymorpha*) colonization, J. Great Lakes Res., 19: 617-624.
10. USGS, (2017). Nonindigenous Aquatic Species, *Dreissena polymorpha*, https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=5, Retrieved: June 16th, 2017.
11. Nalepa, T. F. and Schloesser, D.W. (1993). Zebra mussels: biology, impacts, and control. Boca Raton, Fl: CRC Press. 810 p.
12. Budd, T.W., Lewis, J.C. and Tracey, M.L. (1979). Filtration feeding in *Orconectes propinquus* and *Cambarus robustus*, Decapoda, Cambaridae, Crustaceana Supplement, 131-134.
13. Covich, A.P. 2015. Freshwater Crustaceans: Adaptations to Complex Inland Habitats and Species Interactions, In: The Natural History of the Crıstacea, Life Styles and Feeding Biology (eds: Martin Thiel and Les Watling), 337-378, Oxford Univ. Press, Oxford.
14. Strayer, D.L., Caraco, N.F., Cole, J.J., Findlay, S. and Pace, M.L. (1999). Transformation of freshwater ecosystem by bivalves. BioScience, 49: 19-27.
15. Bobat, A. veErtem, B. (2004). TürkiyetatlısularındabulunanDreissenidve Corbiculidtürleriarasındak ifarklarveonlarınyayılışalanları, Türk Sucul Yaşam Dergisi 2: 1-16.
16. Bobat, A., Altınayar, G., Üstündağ, S., Çevlik, H. (2005). Hidroelektrik Santralarda Zebra Midye Sorunuve Savaşımı, EÜAŞ Eğitimve BilgiİşlemDairesiBaşkanlığı,Yayın No: 2, Ankara.
17. Birnbaum, C. (2011). NOBANIS - invasive alien species fact sheet – *Dreissena polymorpha*. Online Database of the European Network on Invasive Alien Species-NOBANIS. http://www.nobanis.org/globalassets/speciesinfo/d/dreissena-polymorpha/dreissena_polymorpha, Retrieved: June: 8th, 2017.
18. Gillis, P.L. and Mackie, G.L. (1994). Impact of the zebra mussel, *Dreissena polymorpha*, on populations of Unionidae (Bivalvia) in Lake St. Clair. Can. J. Zool., 72: 1260-1271.

19. Fahnenstiel, G.L., Bridgeman, T.B., Lang, G.A., McCormick, M.J. and Nalepa, T.F. (1995). Phytoplankton productivity in Saginaw Bay, Lake Huron: Effects of zebra mussel (*Dreissena polymorpha*) colonization, J. Great Lakes Res., 21: 465-475.
20. Ricciardi, A., Neves, R.J. and Rasmussen, J.B. (1998). Impending extinctions of North American freshwater mussels (Unionoidae) following the zebra mussel (*Dreissena polymorpha*) invasion, Journal of Animal Ecology 67(4):613-619.
21. Sousa, R., Pilotto, F., Aldridge, D.C. (2011) Fouling of European freshwater bivalves (Unionidae) by the invasive zebra mussel (*Dreissena polymorpha*), Freshwater Biology, 56(5): 867-876.
22. Bobat, A. (2003). Hidroelektriksantralardaekolojikbirsorun: Zebra midye . Türkiye 9. EnerjiKongresi, BildirilerKitabı, Cilt I, 327-347.
23. Bobat, A., Hengirmen, M.O. and Zapletal, W. (2004). Zebra mussel and fouling problems in the Euphrates Basin, Turk. J. Zool., 28: 161-177.
24. DAISIE. (2006). Delivering Alien Invasive Species Inventories for Europe. *Dreissena polymorpha*. http://www.europe-aliens.org/pdf/Dreissena_polymorpha.pdf, Retrieved: June 8th, 2015.
25. Ricciardi, A., Snyder, F.L., Kelch, D.O. and Reiswig, H.M. (1995). Lethal and sublethal effects of sponge overgrowth on introduced dreissenid mussels in the Great Lakes-St. Lawrence River system. Can. J. Fish. Aquat. Sci., 52: 2695-2703.
26. Molloy, D.P., Karatayev, A.Y., Burlakova, L.E., Kurandina, D.P. and Laruelle, F.(1997). Natural enemies of zebra mussels: Predators, parasites, and ecological competitors. Rev. Fish. Sci., 5: 27-97.
27. French, J.R.P. (1993). How well can fishes prey on zebra mussels on North America? Fisheries 18:13-19.
28. Hamilton, D.J., C.D. Ankney and R.C. Bailey. 1994. Predation of zebra mussels by diving ducks: an exclosure study. Ecology, 75: 521-531.
29. Stempniewicz, L. (1974). The effect of feeding of the coot (Fulicaatra L.) on th character of the shoals of *Dreissena polymorpha* Pall. in the Lake Goplo. Acta Univ. Nicolai CopemiciBiol,. 34: 84-103.
30. Smit, H., bij de Vaate, A., Reeders, H.H., van Nes, E.H. and Noordhuis, R. (1993). Colonization, ecology, and positive aspects of zebra mussels (*Dreissena polymorpha*) in the Netherlands. In Zebra mussels: biology, impacts, and control. (T.F. Nalepa and D.W. Schlosser, eds.), Lewis Publ., Ann Arbor, Mich. pp. 55-77.
31. French, J.R.P. and Bur, T. (1993). Predation of zebra mussel (*Dresissena polymorpha*) by the freshwater drum in western Lake Erie, 453-464. In: Zebra mussels: Biology, impacts, and control (T.F. Nalepa and D.W. Schloesser eds.), Lewis Publ. Inc., Ann Arbor, Michigan.
32. Karatayev, A.Y., Burlakova, L.E. and Padilla, D.K. (1997). The effects of *Dreissena polymorpha* (Pallas) invasion on aquatic communities in eastern Europe, J. Shellfish Res., 16: 187-203.
33. Serrouya, R., Ricciardi, A. and Whoriskey, F.G. (1995). Predation on zebra mussels (*Dreissena polymorpha*) by captive-reared map turtles (Graptemys geographyca). Can. J. Zool., 73: 2238-2243.
34. MacIsaac, H.J. (1994). Size-selective predation of zebra mussels (*Dreissena polymorpha*) by crayfish (*Orconectes propinguus*). J. North Am. Benthol. Soc., 13: 206-216.
35. MacIsaac, H.J. (1996). Potential abiotic and biotic impacts of zebra mussels on the inland waters of North America, Am. Zool., 36: 287-299.
36. Perry, W.L., Lodge, D.M. and Lamberti, G.A. (1997). Impact of crayfish predation on exotic zebra mussels and native invertebrates in a lake-outlet stream. Can. J. Fish. Aquat. Sci., 54: 120-125.
37. Stewart, T.W., Miner, J.G: and Lowe, R. (1998). An experimental analysis of crayfish (*Orconectes rusticus*) effects on a Dreissena-dominated benthic macroinvertebrate community in western Lake Erie. Can. J. Fish. Aquat. Sci., 55: 1043-1050.
38. Molloy, D.P., Powell, J., and Ambrose, P. 1994. Short-term reduction of adult zebra mussels (*Dreissena polymorpha*) in the Hudson River near Catskill, New York: an effect of juvenile blue crab (*Callinectes sapidus*) predation? J. Shellfish Res. 13: 367-371.
39. Perry,W.L., Lodge, D.M. and Lamberti, G.A. (2000). Crayfish (*Orconectes rusticus*) impacts on zebra mussel (*Dreissena polymorpha*) recruitment, other macroinvertebrates and algal biomass in a Lake-outlet stream. Am. Middl. Nat., 144: 308-316.

40. Harlıoğlu, M.M., Barın, Ö., Türkgülü, İ. and Harlıoğlu, A.G. (2004). Potential fecundity of an introduced population Keban Dam Lake, Elazığ, Turkey, of freshwater crayfish, *Astacus leptodactylus* (Esch., 1852). Aquaculture 230: 189-195.
41. Akhan, S., Bektas, Y., Berber, S. and Kalaycı, G. (2014). Population structure and genetic analysis of narrow-clawed crayfish (*Astacus leptodactylus) populations in Turkey. Genetica*, 142: 381-395.
42. Aydın, H., Harlioglu, M.M., Deniz, T. (2015). An investigation on the population parameters of freshwater crayfish (*Astacus leptodactylus* Esch., 1823) in Lake İznik (Bursa), Turk J Zool. 39: 660-668.
43. Erençin, Z., Köksal, G. (1977). On the crayfish, *Astacus leptodactylus*, in Anatolia, Freshwater Crayfish 3: 187-192.
44. Schloesser, D.W., Nalepa, T.F. and Mackie, G.L. (1996). Zebra mussel infestation of unionid bivalves (Unionidae) in North America, Am. Zool., 36: 300-310.
45. Weihhrauch, F., Borcherding, J. (2002). The zebra mussel, *Dreissena polymorpha* (Pallas), as an epizoonof an isopteran larvae (Anisoptera: Gomphidae, Corduliidae, Libellulidae). Odonatologica 31: 85-94.
46. McCauley, S.J. and K. E. Wehrly. 2007. Zebra mussel, *Dreissena polymorpha*, attachment to Odonata larvae. Odonatologica 36(1): 63-69.
47. Kulmatycki W. (1932). On preserving sturgeon in Polish rivers-Ochrona Przyrody, Roczn. XII: 1-21 (in Polish).
48. Lamanova, A. I. (1970). Attachment by zebra mussels and acorn barnacles on crayfish. Hydrobiological J., 6: 89-91(English translation of Gidrobiologicheski Zhurnal 6:105-107).
49. Ďuriš Z, Horka I, Petrusk A. (2007) Invasive zebra mussel colonization of invasive crayfish: a case study, Hydrobiologia 590: 43-46.
50. Brazner, J.C. and Jensen, T.A. (2000). Zebra mussel [*Dreissena polymorpha* (Pallas)] colonization of rusty crayfish [Orconectes rusticus (Girard)] in Gren Bay, Lake Michigan, Am. Midland Naturalist, 143 : 250-256.
51. Wetzel, J.E., Poly, W.J., Fetzner, Jr. J.W. (2004). Morphological and genetic comparison of golden crayfish, *Orconectes luteus*, and rusty crayfish, *Orconectes rusticus*, with range corrections in Iowa and Minnesota. Journal of Crustacean Biology 24: 603–617.
52. Wetzel, JE., Poly, W.J., Fetzner, Jr. J.W. (2005). *Orconectes pardalotus*, a new species of crayfish (Decapoda: Cambaridae) from the lower Ohio River with notes on its life history, Journal of Ichthyology and Aquatic Biology 10: 57-72
53. Piesik, Z. (1974). The role of the crayfish *Orconectes limosus* (Raf.) in extinction of *Dreissena polymorpha* (Pall.) subsisting on Steelon-Net. Pol. Arch. Hydrobiol., 21: 201-410.
54. Kornobis, S. (1977). Ecology of *Dreissena polymorpha* (Pall.) (Dreissenidae, Bivalvia) in lakes receiving heated water discharges. Polskie Archiwum Hydrobiologii 24:531-545.
55. Kutluyer, F., Aksu, Ö., Aksu, Ö. 2013. Kerevitlerinbeslenmesinde (*Astacus leptodactylus* Eschscholtz, 1823) alternatifbesinolarak Zebra midyesinin (*Dreissena polymorpha* Pallas, 1771) Kullanılması, Tunceli Üniversitesi Bilimve Gençlik Dergisi, 1(2), 63-70.
56. Reynolds, J.D. and Donohoe, R. (2001). Crayfish predation experiments on the introduced zebra mussel, *Dreissena polymorpha*, in Ireland, and their potential for biocontrol. Bull. Fr. PechePiscic., 361: 669-681.
57. Crocker, D.W., and Barr, D.W. (1968). Handbook of the crayfishes of Ontario, University of Toronto Press, Toronto.
58. Capelli, G.M. (1980). Seasonal variation in the food habits of the crayfish *Orconectes propinquus* (Girard) in Trout Lake, Vilas County, Wisconsin, U.S.A. (Decapoda, Astacidea, Cambaridae). Crustaceana 38:82-86.
59. Feminella, J.W. and Resh, V.H. (1989). Submerged macrophytes and grazing crayfish: an experimental study of herbivory in a California freshwater marsh. Holarctic Ecology 12:1-8.
60. Chambers, P. A., Hanson, J.M., Burke, J.M. and Prepas, E.E. (1990). The impact of the crayfish *Orconectes virilis* on aquatic macrophytes. Freshwater Biology 24:81-91.

61. Olsen, T. M., Lodge, D.M., Capelli, G.M. and Hamilton, R.J.(1991). Mechanisms of impact of an introduced crayfish (*Orconectes rusticus*) on littoral congeners, snails and macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 48:1853-1861.
62. Hill, A. M., Sinars, D.M. and Lodge, D.M.(1993). Invasion of an occupied niche by the crayfish *Orconectes rusticus*: potential importance of growth and mortality. Oecologia 94:303-306
63. Lorman, J.G. (1980). Ecology of the crayfish *Orconectes rusticus* in northern Wisconsin. Ph.D.Thesis, University of Wisconsin, Madison, 252 p.
64. Mather, M.E. and Stein, R.A. (1993). Direct and indirect effects of fish predation on the replacement of a native crayfish by an invading congener. Can. J. Fish. Aquat. Sci., 50: 1279-1288.
65. Lodge, D.M., Kershner, M.W., Aloi, J.E. and Covich, A.P. (1994). Effects of an omnivorious crayfish (*Orconectes rusticus*) on a freshwater littoral food web. Ecology, 75:1265-1281.
66. Charlebois, P.M. and Lamberti, G.A. (1996). Invading crayfish in a Michigan stream: Direct and indirect effects on periphyton and macroinvertebrates, J. North Am. Benthol. Soc., 15: 551-563.
67. Love, J. and Savino, J.F. (1993). Crayfish (*Orconectes virilis*) predation on zebra mussels (*Dreissena polymorpha*), J. Freshwater Ecol. 8:253-259.
68. Bauer, R. T. (1981). Grooming behaviour and morphology in the decapod crustacea, J. Crust. Biol., 153-173.
69. Bauer, R.T. (1989). Decapod crustacean grooming: functional morphology, adaptive value, and phylogenetic significance, Crustacean Issues 6:49-73.
70. Bauer, R.T. (1997). Efficacy of crawfish defenses against zebra mussel fouling, Poster presentation, 7th International Zebra Mussel and Aquatic Nuisance Species Conference, January 28-31, New Orleans, LA.