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Zebra Mussel and Fouling Problems in the Euphrates Basin*

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Abstract: The Zebra mussel, *Dreissena polymorpha* Pallas, is one of the most important fouling organisms in freshwater ecosystems. Infestations by Zebra mussels have caused chronic problems in both raw water(incoming water into facilities) intakes and man-made structures such as water treatment facilities, power plants and industrial facilities. In the mid-1980s, this pest, a species non-indigenous to North American freshwaters, was introduced into the Great Lakes of North America. This introduction probably occurred by means of the ballast water of a transoceanic ship, and concern has focused again on this nuisance and its impact.

Recently, the Zebra mussel, a species native to Turkish freshwaters, has caused important technical and economic damage in Atatürk dam and hydropower plants built on the Euphrates River. Fouling by Zebra mussels will become an increasingly significant technical, economic and ecological problems in the Euphrates Basin in the near future. In this study, the general biology and potential impacts of the Zebra mussel are summarized and its impacts on engineered structures in the Euphrates Basin are emphasized.

Key Words: Zebra mussel, its biology, fouling problems by Zebra mussel in the Euphrates Basin, hydropower plants

Zebra Midye ve Fırat Havzasında Yarattığı Sorunlar

Özet: Zebra midye, *Dreissena polymorpha* Palas, tatlısu ekosistemlerinde yaşayan en önemli tutunucu-kirletici canlılardan(fouling organisms) biridir. Bu iki kapakçıklı(bivalva) yumuşakçalar tutundukları yüzeylerde oluşturdukları biyokütle ile su akışını aksatma ya da tamamen engelleme, yenime(korozyona) yol açma, su filtre ya da eleklerini tıkama, teknelerin ağırlığını arttırarak dengelerini bozma ve yakıt harcamalarını arttırma, teknelerin motor aksamları içine girerek sağlıklı çalışmalarını engelleme, sucul ekosistemde doğal olarak bulunan diğer canlıların yaşamasını kısıtlama gibi birçok önemli soruna yol açarak hem teknik-ekonomik hem de ekolojik anlamda zararlı olabilmektedirler. 1980'li yılların ortalarında Kuzey Amerika'nın Büyük Göllerinde yabancı bir tür olarak kaydedilen Zebra midye, daha sonraki yıllarda Kuzey Amerika'nın tüm tatlısularına yayılmıştır. Zebra midyenin Kuzey Amerika'nın tatlısu ekosistemine girişinin, bir transatlantiğin balast suyu aracılığıyla olduğu tahmin edilmiş; bütün ilgi bu zararlı tür ve onun etkileri üzerine odaklanmıştır.

1997 yılında Fırat Havzasındaki Atatürk Barajı ve Hidroelektrik Santralinde, 2000 yılında ise Birecik ve Karkamış Baraj ve Hidroelektrik Santrallerinde zararlı olmaya başlayan bu hayvan, aslında yurdumuzun doğal sucul türleri arasında yer almaktadır. Bu çalışmada, Zebra midye ve yaşam döngüsü ayrıntılı olarak ele alınmış; Fırat Havzasındaki Baraj ve Hidroelektrik Santrallerinde neden olduğu zararlara değinilerek dikkat çekilmeye çalışılmıştır.

Anahtar Sözcükler: Zebra midye, biyolojisi ve yaşam döngüsü, yayılışı, hidroelektrik santrallerde yarattığı sorunlar

Introduction

When any nontoxic material is exposed in coastal waters or harbors, it will become colonized by a number of visible animal and plant species within a short period. These visible creatures are called macrofouling organisms. Animals such as barnacles, mussels, bryozoans, hydroids, tunicates, tubeworms, sea squirts and plants such as species of Enteromorpha, Ectocarpus, Ulva and Laminaria are the principal fouling members in the marine environment. The principal representatives of fouling organisms in fresh and brackish waters are bivalves.

Fouling organisms increase the frictional resistance of solid objects causing a large increase in fuel consumption

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of vessels and weight of navigational buoys. Additionally, they interfere with operating equipment and sound devices (WHOI, 1952; Pınar, 1974; Bobat et al., 2001a).

If sea- or fresh water is passed through a system of pipes at high velocity, there is little or no risk of any fouling organisms settling in the system. However, there are always parts of the system through which the velocity is reduced or which are used only intermittently, allowing foulers to accumulate. The materials used in the construction exclude light so that fouling by seaweeds cannot occur. The problem is therefore somewhat different from that of the fouling of an underwater hull. The most important effects under these circumstances are first the restriction of flow because of the buildup of settlements of barnacles, hydroids, polyzoans and in particular mussels. Secondly, complete blockage of the pipes and/or valves may occur either by the growth of a large number of fouling organisms, by accumulation of shells from detached living mussels or by the shells of those that have died. This type of accumulation is particularly serious in raw water systems used for fire fighting and cooling purposes. The settlement of organisms in condenser tubes is also highly undesirable, because of the risk of impingement attack on the tubes, resulting in their perforation. In large seawater intakes, the settlement of barnacles and hydroids in most cases can be tolerated, unless the buildup of shells is very pronounced. This is not so in the case of mussels where there is again the risk of shells accumulating in large masses that may be torn away, thereby blocking the system (Houghton, 1970).

When compared with economically important marine fouling species, little information is available on freshwater fouling organisms in Turkey. This is particularly true with regard to their biology and technical/economic damage to engineered structures, and their ecological impact in aquatic environments.

Its ability to attach to hard surfaces with byssal threads makes the Zebra mussel, *Dreissena polymorpha* (Pallas, 1771), a major macrofouler and a serious threat to water supplies, industrial processing, power stations, transportation and recreation. Problems created by the Zebra mussel in Europe have occurred for more than 100 years (Wilhelmi, 1923; Clarke, 1952; Mikheev, 1961; Kirpichenko et al., 1962; Gillet and Micha, 1985; LePage, 1993). Europeans have witnessed the Zebra mussel's ability to severely foul both industrial and domestic facilities, as well as significantly alter freshwater ecosystems during this invasion.

In North America, industrial and utility plants have experienced clogged or blocked intakes, clogged or blocked distribution piping throughout facilities, an increase in the corrosion of iron or steel piping and riveting, as well as the fouling of pumps, forbays, and cooling and fire-fighting tanks, trashracks and condenser units (Greenshields and Ridley, 1957; Kovalak et al., 1993).

It is clear that the Zebra mussel also presents a substantial threat to reduce or block water flow in power plant systems outside North America. Fouling problems caused by the mussel were first observed in Kovada I Hydroelectric Power Plant (HEPP) situated in the south western Mediterranean region of Turkey in 1964. Subsequently, the canals and penstocks of Kovada II HEPP were contaminated by mussels (DSİ, 1969). Although the occurrence and damage of the Zebra mussel in HEPPs and raw water systems have been known since the 1970s, corrective or preventative measures have not been taken to date except for mechanical cleaning and pressured water or backwash of water supply piping. Damage by this pest to the Atatürk Dam and HEPP on the Euphrates River has been continuing since 1997. However, the negative operational impacts resulting from this mussel have been newly noticed after the Birecik Dam and HEPP were built in 2000.

The objectives of this article are (i) to describe the biology and ecology, and economic impacts of the Zebra mussel, and (ii) to emphasize the technical and economic impacts of the Zebra mussel on man-made structures in the Euphrates Basin.

Zebra Mussel - *Dreissena polymorpha* (Pallas, 1771)

Taxonomically, the Zebra mussel, *Dreissena polymorpha* (subclass Lamellibranchia), is distinct from other byssate mussels (Turgeon et al., 1988; Brusca and Brusca, 1990). *D. polymorpha* is a member of the family Dreissenidae and the superorder Eulamelliobranchia (order Veneroidae). Although it is phylogenetically distinct from the marine mussels *Mytilus* spp. of the order Mytiloida, there are many similarities between the 2 groups. For instance, in addition to showing the heteromyarian condition, both groups are important aquatic fouling animals, both have a larval veliger stage as part of their life cycles, and both have byssi (Morton, 1993). In brief, the Zebra mussel is grouped in the class Bivalvia (bivalves), mollusks characterized as having 2 shells.

The common name of the mussel is derived from the Zebra-like stripes on their shells. 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 populations. Sometimes mussels lack distinct stripes and appear cream-colored or completely black. Shell color can also range from beige to solid black or brown with many or few stripes. The Zebra mussels collected from the Atatürk, Birecik and Karkamış dams and HEPPs appear cream-colored or completely black (Altınayar et al., 2001; Bobat et al., 2001b,c; Bobat et al., 2002a). Zebra mussels in Eğirdir Lake located in the southwestern Mediterranean region of Turkey can also range from cream to black (Geldiay and Bilgin, 1973). However, the shells of mussels taken from Kesikköprü Dam Lake are brown (those collected from surface water) or black (those collected from deep water) (Figure 1).

Distribution and Occurrence in Freshwaters

Dreissena was first found in the lower course of the Ural River in 1769 and was later described as a zoological species in 1771 by the Russian zoologist and explorer Pyotr Simon Pallas. Aided by the expansion of commercial boat traffic through newly constructed canals, this species spread west from Russia into most of Europe during the 19th century.

Dreissena polymorpha originated in the Balkans, Poland and the former Soviet Union (Çağlar, 1952). The breakup of the Tethys isolated *D. polymorpha* and other (now extinct) species of *Dreissena* with very restrictid distributions, in an area of central Europe and northern Asia Minor as far east as the Aral Sea and the Euphrates River (Babak, 1983). During quaternary glacial epochs, the distribution of *Dreissena* was reduced considerably to small pockets including the slightly brackish areas of the Caspian and Aral Seas, and the freshwater Azov and Black Seas and the Balkan Peninsula from this area. *D. polymorpha* has recolonized much of its original distribution and has spread throughout western Europe in the rivers and canals of inland waterways interconnected for trade during the industrial revolution (Haas, 1929; Archambault-Guezou, 1976).

This bivalve mollusk is also a species indigenous to Turkish freshwaters and is found in many lakes in Turkey (Demirsoy, 1998). The occurrence of the Zebra mussel in certain regions of Turkey may be directly related to the distribution of the Tethys Sea in Anatolia. This form and some others are looked upon as Tethys relicts due to the uprising of the Tethys Sea in the Tertiary period in Anatolia. They have been left at high altitudes in Anatolia. In western Anatolia, Zebra mussel has already been found in small lakes such as Kovada, Eğirdir, Burdur and Beyşehir, and in northwestern Anatolia, in Lake Sapanca (Geldiay and Bilgin, 1973; DSİ, 2001). Recently, the Zebra mussel has invaded all the dam lakes of the

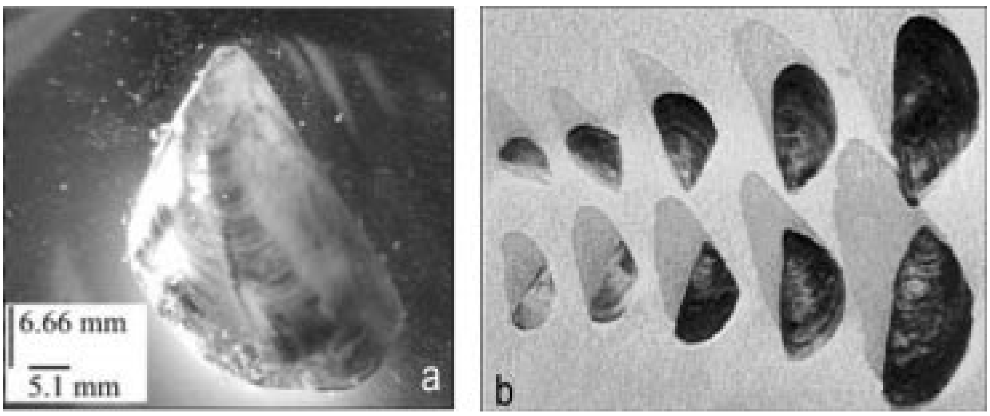


Figure 1. Zebra mussels collected from Birecik(a) and Kesikköprü Dam Lake(b).

Euphrates Basin (Keban, Karakaya, Atatürk, Birecik and Karkamış dams and HEPPs), Kesikköprü, Hirfanlı and Kapulukaya dams on the Kızılırmak, Balıkesir, İkizcetepeler Dam Lake, Bafa Lake on the Büyük Menderes River, İstanbul Terkos Dam Lake, Bolu Gölköy Lake, Poyrazlar Lake, Taşkısığı Lake, Akgöl and Acarlar Lakes in the Sakarya Basin (DSİ, 2001) (Figure 2).

Dreissena generated great interest during the 1820s when it was found at the London docks and then in different places in western Europe (Morton, 1969). In Germany it acquired the name of the wandering mussel (wundermuschel) because of its ability to spread rapidly to different areas (Zhadin, 1946). Since then, the Zebra mussel has expanded its range into Denmark, Sweden, Finland, Ireland, Italy, and the rest of western Europe.

The Zebra mussel, a nonindigeneous aquatic species in North America, was first discovered in North America in the vicinity of Lake St. Clair – the waterbody connecting Lake Huron with Lake Erie – in 1988 (Hebert et al., 1989; Mackie et al., 1989; Griffiths et al., 1989). It was believed to have been released into the Great Lakes region from the emptying of ballast water of Eurasian vessels sometime in the mid-1980s (Nalepa and Schloesser, 1993). This mollusk is also a nonindigeneous species in North America, and was likely transported there as planktonic larvae or as attached juveniles or adults in the freshwater ballast of a transatlantic ship.

Reproduction (general), Survival and Development

Zebra mussels are usually diecious (i.e. separate sexes) and the numbers of males and females in most populations are approximately equal. Hermaphrodism is rarely encountered. Gonad development commences during the winter (Gist et al., 1997), and then accelerates as temperatures increase in the spring, leading to gamete maturation within 2 months at temperatures around 12 °C (Borcherding, 1991). The optimal temperature for spawning is 12-14 °C. In temperate climates, peak spawning often occurs at 15-17 °C during the early summer (Claudi and Mackie, 1994), but there are numerous exceptions. Gamete release by adults can be a highly synchronized event, focused over a 1-2 week period (Nichols, 1996).

A female Zebra mussel releases eggs, visible as tiny white dots, into the water column via the exhalant siphon. Depending on their sizes, female Zebra mussels can spawn more than a million eggs, and males up to nearly 10 billion sperm, contributing to more than 30% of their body weight prior to spawning (Sprung, 1991). The eggs are usually 40-50 mm in diameter. Internally, the paired gonads make up much of the visceral mass, releasing eggs or sperm after being stimulated by environmental factors including temperature, rates of temperature change, food density, and the effects of neighboring mussels (Stanczykowska, 1977; Ram et al., 1996). Since fertilization occurs externally in the water column, the release of eggs and sperm must be concurrent. Within a temperature range of 12-24 °C, eggs can be fertilized within 2.5-4.75 h after release, while the sperm normally remain motile longer (2-22 h) (Sprung, 1993).

Zebra mussels are almost always capable of reproducing within their initial 12 months of life. Mussels settling in late spring or early summer typically grow and mature quickly during the warm summer months. Adults of shell lengths exceeding 8 to 9 mm can start to spawn as early as May of the following year. In cold waters, spawning is generally completed by fall. In the warmer aquatic systems and in thermally enhanced waters, the spawning period of populations may extend for a longer period during the year, with individual mussels possibly spawning twice per year. In Atatürk, Birecik and Karkamış dam lakes, where the water temperature is suitable for reproduction, spawning occurs from March to November (Bobat et al., 2002b). Fertilized eggs (zygotes) pass through an embryonic stage where their development is nourished by materials stored in the egg rather than by direct feeding (Nichols, 1993).

Fertilization and Trochophore Stage

The life of a Zebra mussel begins with the external fertilization of a mature oocyte (egg) by sperm in the water column. Temperature appears to be a major trigger in initiating gamete release, which can last for 6 to 8 weeks. Exposure to ripe eggs and sperm in the water may also trigger the release of gametes by other Zebra mussels (Nichols, 1996). After fertilization, embryological development occurs, including spiral cleavage, blastulation and gastrulation, ultimately resulting in the formation of a free-swimming ciliated larval form (the trochophore), which is 80-100 µm long (Figure 3).

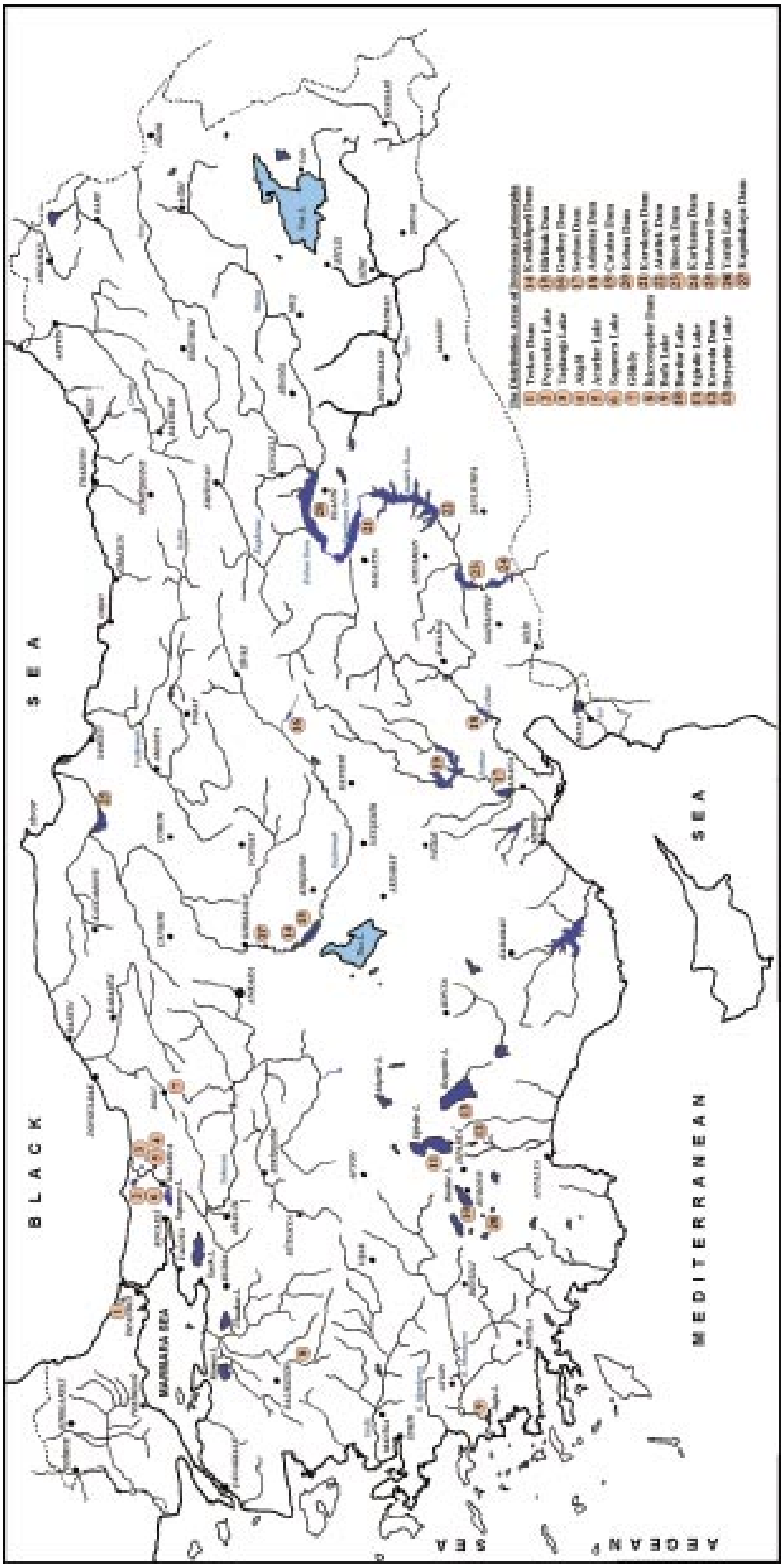


Figure 2. The preliminary data on the distribution of Zebra mussel (*Dreissena polymorpha*) in freshwaters and dam lakes in Turkey.

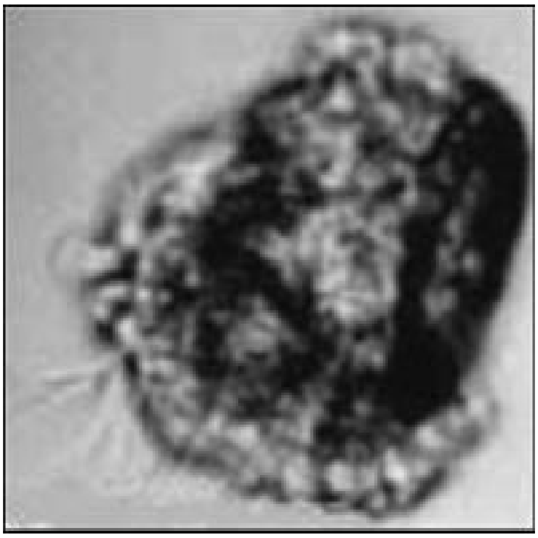


Figure 3. Trochophore stage of Zebra mussel.

Trochophores emerge within 6 to 20 h or 3 to 5 days depending on ambient water temperature. The trochophore stage is relatively brief and rarely seen outside of laboratory cultures. Nourishment is supplied by the yolk from the egg in this shell-less, non-filter-feeding larval stage (Nichols, 1993).

Veliger Stages

The trochophore metamorphosizes into a veliger with the development of the velum, a ciliated feeding and swimming organelle used popularly to refer to all planktonic (i.e. floating in the water column) stages in the life cycle. However, veliger stages and velum include the straight hinged stage (≅ 97-112 μm), the umbonal stage (≅ 112-347 μm), and the pediveliger stage (≅ 231-462 μm) (Figure 4).

Several days after fertilization, veligers secrete an unornamented D-shaped shell from their shell glands. The larvae are then referred to as D-shaped or straight-hinged veligers, since the body side where the hinge forms is straight while the open valve side is rounded. A rudimentary shell may be forming in this stage, but the larval mussel is still quite transparent. Straight-hinged veligers feed on small (1- to 4-μm diameter) algae (Nichols, 1993), which they filter out of the water column using the bands of cilia located on the velum.

The next stage of development generally occurs 7-9 days after fertilization, when an ornamented larval shell is secreted by the mantle tissue. The shell has a more pronounced umbonal region near the hinges and is round in profile. The "umbone" is the extended bump of the mussel's shell that covers the hinge. This umbonal stage also known as a "veliconcha" resembles a very small native clam and represents the last veliger stage that is completely planktonic. Veliger larvae feed on plankton until they reach the postveliger stage (Ackerman et al., 1994).

As the veliconcha or umbonal larva grows, the velum slowly develops into the siphons, the foot lengthens, and the blood and some organ systems begin development. With the loss of the velum the veliger larvae enter the settling stage. The acquisition of a foot leads to a change in behavior and the larva is known as the pediveliger at this stage. The pediveliger marks the beginning of the post-veliger stage. The organism attains a size of 200 to 450 μm at the post-veliger stage. The foot can be used for swimmimg near the bottom as well as crawling on surfaces. This behavior is typical of the post-veliger stage. Once a pediveliger encounters an appropriate surface, it secretes a byssal thread and undergoes metamorphosis to become a plantigrade larva. Without an appropriate

Figure 4. D-shaped(a) umbonal stage(b) and pediveliger stage(c).

surface to settle upon, a pediveliger may delay byssal attachment and metamorphosis. Primary settlement generally occurs between 18 and 90 days after fertilization, when a pediveliger will attach onto a substrate (Ackerman et al., 1994; ZMIS, 2001). The byssal thread provides the anchor that enables the pediveliger to stay securely attached during its tranformation into the plantigrade stage (Ackerman and Claudi, 1991).

Plantigrade Stage

The plantigrade is an attached larval stage and typically measures less than 500 μm in its longest dimension (Figure 5).

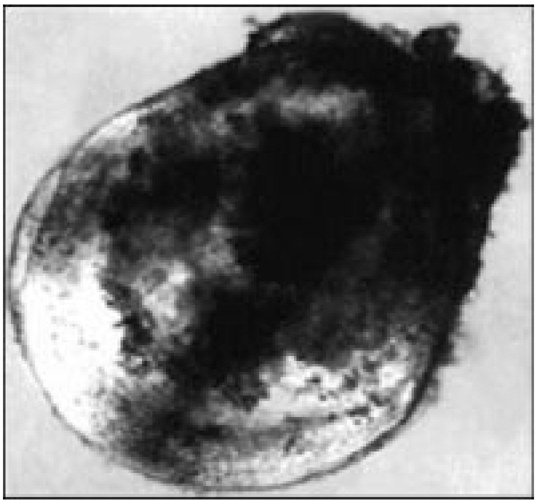


Figure 5. Plantigrade stage of Zebra mussel.

In contrast to previous larval stages that possessed a velum for feeding and swimming, the mussel now feeds using gills, which occupy most of the mantle cavity, and moves solely with its foot. Labial palps develop around the mouth. Further metamorphosis transforms the plantigrade larva into a juvenile Zebra mussel, thus completing the larval phase of the life cycle (ZMIS, 2001).

Juvenile and Adult Stages

When the mussel enters the juvenile stage the Zebra mussel's clam-like shape is replaced by a more triangular or mussel-like shape. The juveniles move freely to areas that have higher concentrations of plankton. They attach themselves to suitable substrates by means of a bysus, an organ outside the body near the foot consisting of many threads. Although juveniles prefer a hard or rocky substrate, they have been known to attach to freshwater vegetation. Juvenile and adults have a difficult time staying attached when water velocities exceed 1.5-2.0 m/s (Ackerman, 1999).

Mussels are considered adults when they become sexually mature. Adult mussels range from approximately 6 to 45 mm in shell length and generally live to be 2-3 years old in temperate climates. In the Euphrates basin, Zebra mussels have lived 2 to 3 years (Bobat et al., 2002c)

Zebra mussels are filter-feeders. Food consists of micro-algae, micro-invertebrates, bacteria, detritus and other organic materials. Thus, Zebra mussels filter both organic and inorganic particles from water. They are capable of filtering from 1 to 8 l of water per day depending on food density in the aquatic environment and their sizes (Bunt et al., 1993; Aldridge et al., 1995; Fanslow et al., 1995).

Some Important Environmental Factors in the Survival of the Zebra Mussel

The calcium level of a water body is a very critical characteristic for Zebra mussel population establishment. Zebra mussels do not survive when there is a low calcium concentration in the water, since it is an essential element in the composition of the bivalve shell. Calcium of 40-55 mg/l is sufficient for larval development and 24 mg/l is necessary for 10% larval survival (Sprung, 1987). Calcium levels of 28-109 mg/l in lakes are required for successful Zebra mussel populations. Shell growth is affected negatively at calcium levels less than 8.5 mg/l (Hincks and Mackie, 1997). Water temperatures of 15-17 °C are optimal for larval development. Temperatures above 31 °C are usually lethal (Claudi and Mackie, 1994). Zebra mussels are rarely found in waters with a pH less than 7.2 or greater than 9.5 (Sprung, 1987; Kornobis, 1977; Bowman and Bailey, 1998). Well oxygenated waters, 8-10 ppm, are preferred by Zebra mussels (Karatayev et al., 1998).

Even though they are freshwater animals, they have recently been found living in brackish water with salinity levels of 1 or 2 parts per thousand (Wilcox and Dietz, 1998).

One of the most critical factors that affects the distribution and abundance of the Zebra mussel is suitable substrate for attachment (Karatayev et al., 1998). Juvenile and adult Zebra mussels are epifaunal and sessile. They are most abundant on hard surfaces, and on macrophytes. Zebra mussels can often live in such silty sediments by initially attaching to small fragments of plants, wood, shells and stones and subsequently attaching to each other to form druses (Berkman et al., 1998).

Food density is another important factor for the survival of Zebra mussels. When food resources are limited, intraspecific competition within a Zebra mussel population for food is probably a significant mortality factor and a major density-dependent, population-regulating mechanism (Borcherding, 1995; Strayer et al., 1996).

General Impacts on the Aquatic Environment and Man-Made Structures

The Zebra mussel has the ability to tolerate a wide range of conditions and is extremely adaptable. It has the potential to significantly alter the ecosystem in any body of water it inhabits. Moreover, on facilities that rely upon water intake, Zebra mussel fouling can have serious technical and economical impacts (Claudi and Mackie, 1994; O'Neill, 1997).

Negative Effects

The Zebra mussel's most serious risk is its impact on the food chain. By consuming the base of the food chain, which consists of phyto- and zooplankton, it disrupts the aquatic environment. As a result of their filter feeding, *Dreissena* populations shift suspended matter from the water column to the benthos (Strayer et al., 1999; Lyakhnovich et al., 1988; Reeders et al., 1993; Karatayev et al., 1997). As a result, Zebra mussels decrease chlorophyll, and phytoplankton abundance and production (Lyakhnovich et al., 1988; Leach, 1993; Nichols and Hopkins, 1993; Fahnenstiel et al., 1995a; Fahnenstiel et al., 1995b). These pelagic impacts have also been documented in the former Soviet Union and other European freshwaters (Karatayev et al., 1997). The suppression of zooplankton populations due to Zebra mussel filtration is thought to affect the feeding of some fish. This reduction in zooplankton in the water column may affect the growth of fish that are planktivorous at some point in their development (MacIsaac, 1996). Additionally, 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.

In man-made structures such as water treatment and power plants, and raw water and irrigation systems, Zebra mussel colonization can result in losses in hydraulic capacity, the clogging of strainers and filters, the obstruction of valves, and nuisance problems associated with the decay of proteinaceaus flesh and the removal of shells (Clarke, 1952; Hebert et al., 1989; Mackie et al., 1989; McMahon and Tsou, 1990). Mussel infestation of natural and artificial constructions increases the operation and maintenance of water systems (Roberts, 1990), thereby affecting individual residents, municipalities and industries. Zebra mussel densities can be so high that the diameter of pipes at some plants have been reduced by two-thirds in water treatment facilities.

Zebra mussels cause expensive problems, blocking pipes that deliver drinking and process water to cities and factories and cooling water to power plants, attaching in enormous numbers to ship and boat hulls, freshwater structures and navigational buoys, and covering beaches with sharp-edged mussel shells and rotting mussel flesh. For water treatment plants and private homes where water is drawn directly from infested source water, Zebra mussel infestation can impede proper function by altering the water chemistry. Zebra mussel pseudofeces can affect the taste of drinking water. As the uneaten particles of ingested matter are expelled from the inhalant siphon, they are bound by mucous. This mucous-wrapped pseudofeces accumulates and creates a foul environment that uses up oxygen. This lack of oxygen, in turn, increases the acidity of the water, giving it a bad taste (Van Benschoten et al., 1993).

Zebra mussels may colonize fishing nets and navigational buoys where the added weight of colonization can render them useless by dragging them under the water. The cost of retrieving, cleaning and deploying additional buoys can be a further expense. Colonization on engine outdrives and engine cooling water intakes can lead to engine overheating and damage to cooling system parts. Mussels in or around the shafts and propellers of recreational boats can cause drivetrain wear. Boaters and recreational facilities experience the fouling of boat hulls and engines, and the heavy fouling of navigational buoys, which render many of them useless. Along shorelines, windrows of mussels destroy beaches and the decaying mussels produce an extremely foul smell. The sharp shell of the Zebra mussel is razor-like and is a hazard to barefoot swimmers and beachcombers. This combination spoils the most pristine of locations and prohibits recreational activities (ZMIS, 2001).

Additionally, increasing water transparency because of the filtration activities of Zebra mussels allows the macrophytes to grow. Increased macrophyte growth can also have a recreational impact. For example, shorelines may foul and some beaches may close due to high bacteria counts and the large amounts of decaying macrophyte stranding. Large amounts of decaying macrophytes can also cause water quality problems.

The deterioration of dock pilings can increase when they are encrusted with Zebra mussels. The continued attachment of Zebra mussels can cause the corrosion of steel, iron and concrete, affecting their structural integrity (Claudi and Mackie, 1994; ZMIS, 2001)

Positive Effects

The establishment of dense *Dreissena* populations can have large impacts on benthic communities, such as increases in benthic plant and algal abundance (Griffiths, 1993; Lowe and Pillsbury, 1995; Stuckey and Moore, 1995), increases in the density of benthic invertebrates (Stewart et al., 1998), and changes in the overall benthic community structure (Dermott and Munawer, 1994; Stewart and Haynes, 1994; Botts et al., 1996; Howell et al., 1996). The large increase in macrophyte coverage and biomass in waters infested with Zebra mussels is the result of increased water clarity and transparency (Hebert et al., 1991; Holland 1993; Leach, 1993; Fahnenstiel et al., 1995) and decreases in turbidity (Skubinna et al., 1995; MacIsaac, 1996; Strayer et al., 1999). Improved water transparency allows sunlight to penetrate to deeper levels where macrophytes can now become established. This increased macrophyte abundance may act as a barrier hindering the influx of nutrients used by phytoplankton (Karatayev et al., 1997).

Zebra mussels also play an important beneficial role in various freshwater ecosystems. They are the main calcium source of food for diving ducks in some ecosystems, and for some commercially important species of fish (Suter, 1982; Molloy et al., 1997).

Some Observations on the Zebra Mussel Population of the Euphrates Basin

Research in the Euphrates Basin indicates that Zebra mussels have not caused important problems in Keban and Karakaya dams and HEPPs situated nearby the source water, probably because of the physical conditions of the water such as low temperature and pH, and food scarcity, although Zebra mussel populations have been observed in dam lakes (Bobat et al., 2002c).

The water temperatures on the Euphrates River are generally quite suitable for the spawning and larval development of Zebra mussel. Water temperature measurements in the Birecik and Atatürk reservoirs show that larval development goes on throughout the year, and the reproduction of Zebra mussel occurs for at least 9 months from March to December (Figure 6) (Bobat et al., 2002c; Bobat et al., 2003).

The threshold temperature for the larval development of Zebra mussel was found to be 8.5 ºC, and that for reproduction to be 11.5 ºC in Birecik HEPP reservoir, while veliger density was found to be highest in May and lowest in January.

Using a plankton net with openings of 55 μ, the veliger densities of Zebra mussel in Birecik Reservoir ranged from 4 to 20,651 per cubic meter of water (Figure 7), while those in Atatürk Reservoir ranged from 1 to 73,000 per cubic meter of water (Bobat et al., 2002b,c; Bobat et al., 2003)

Impacts of Zebra Mussels on the Man-Made Structures Built in the Euphrates Basin

There are 5 dams and HEPPs on the Euphrates River: Keban, Karakaya, Atatürk, Birecik and Karkamış. They have been built in cascade form on the Euphrates River (Figure 8).

In the Euphrates Basin, the fouling problems caused by Zebra mussel were first seen in the COD (Commercial Operation Date) of Birecik HEPP on 19th October 2000.

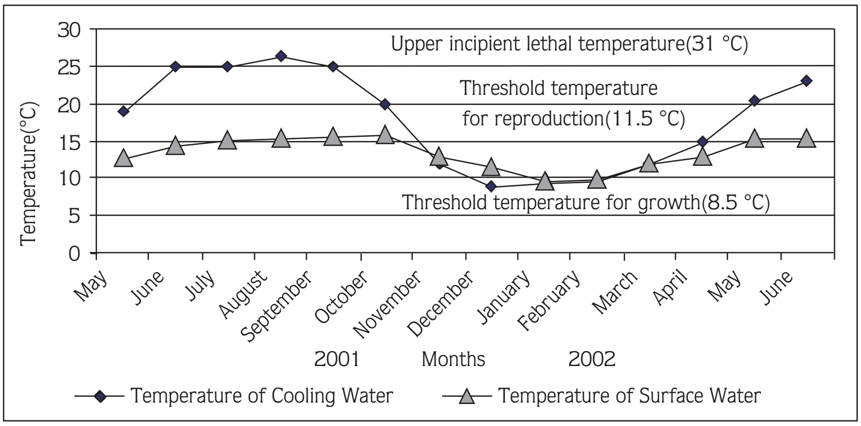


Figure 6. Changes in the water temperature of Birecik Reservoir.

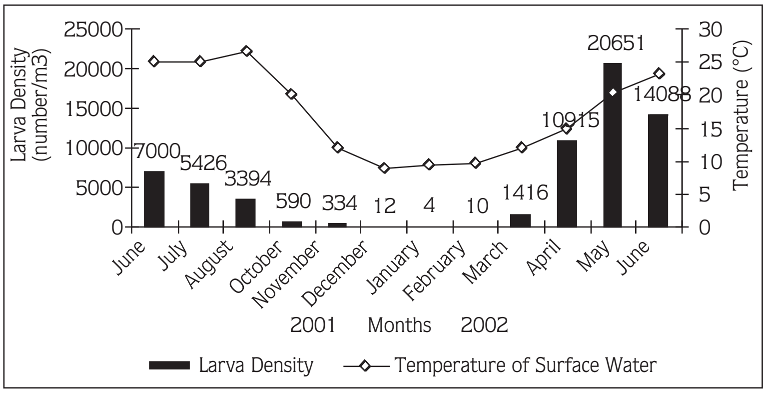
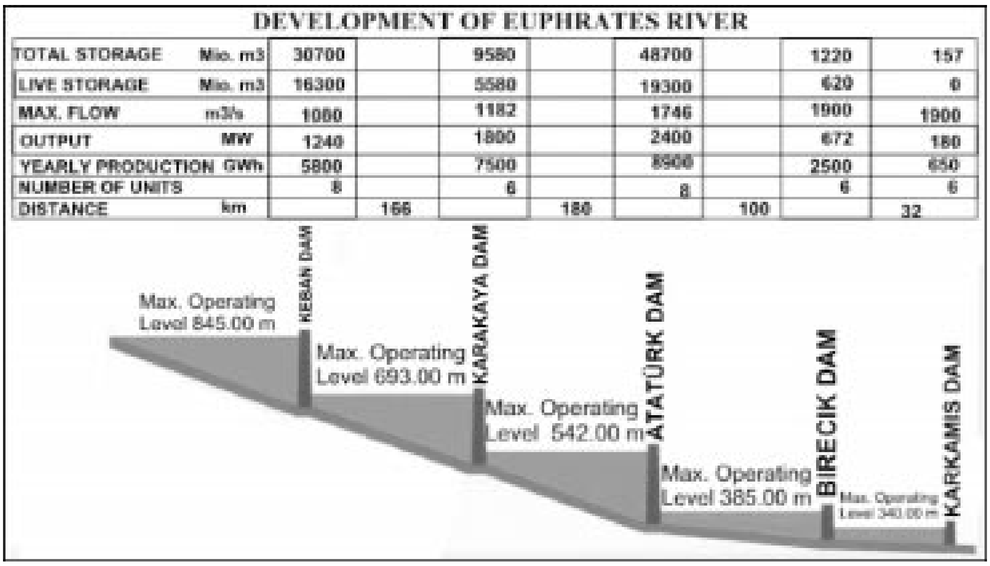


Figure 7. Changes in veliger density and temperature of surface water in Birecik HEPP Reservoir.



DEVELOPMENT OF EUPHRATES RIVER

TOTAL STORAGE	Mio. m3	30700		9580		48700		1220		157
LIVE STORAGE	Mio. m3	16300		5580		19300		620		0
MAX. FLOW	m3/s	1080		1182		1746		1900		1900
OUTPUT	MW	1240		1800		2400		672		180
YEARLY PRODUCTION	GWh	5800		7500		8900		2500		650
NUMBER OF UNITS		8		6		8		6		6
DISTANCE	km		166		180		100		32	

Figure 8. Longitudinal view of the cascade of power plants on the Euphratres River.

However, the same fouling problems have been continuing in Atatürk Dam and HEPP since 1997. Fouling problems by Zebra mussel have infected Karkamış Dam and HEPP situated downstream of Birecik HEPP in 2001 (Bobat et al., 2001a).

Some parts of the HEPPs on the Euphrates River have been particularly affected by Zebra mussel infestation. These parts include the reservoirs (dam lakes), trash racks, intake gates, penstocks, turbine headcovers, raw water cooling systems and stoplogs (Figure 9).

Most of the biological impacts of Zebra mussel in the reservoirs of the Euphrates Basin are not yet known, but it has been estimated that Zebra mussel has had a minimal effect on fish populations in the reservoirs. It may be too soon to determine some of the effects, which may take longer to develop.

If an intake gate becomes fouled with Zebra mussel and associated debris, it does not close easily. In the dams and HEPPs, Zebra mussel infestation has made the closing and opening of intake gates difficult. The accumulation of Zebra mussel on trash racks has caused unbalanced flow, excessive loadings on the racks, corrosion and slower operation (Figure 10a).

Penstocks are the specialized intake structures at many hydraulic plants. Although the water flow in the penstock during full operation is too fast to settle on, settlement is possible if the penstock is not fully dewatered. Furthermore, if water flow in the interior walls of the penstock approaches zero, some parts of the penstock could be contaminated by Zebra mussel (Figure 10b). Infestation of the penstock by Zebra mussel would result in increased hydraulic roughness, which would then translate into a loss of power production.

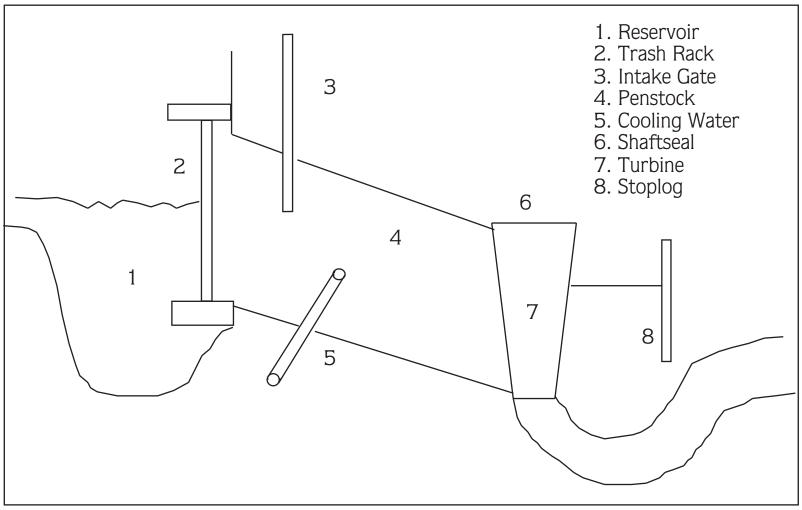


Figure 9. The parts of a HEPP affected by Zebra mussel infestation.

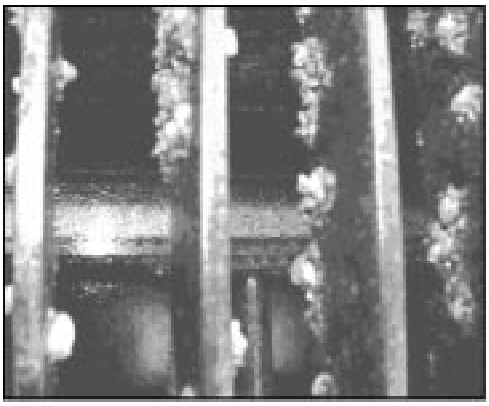
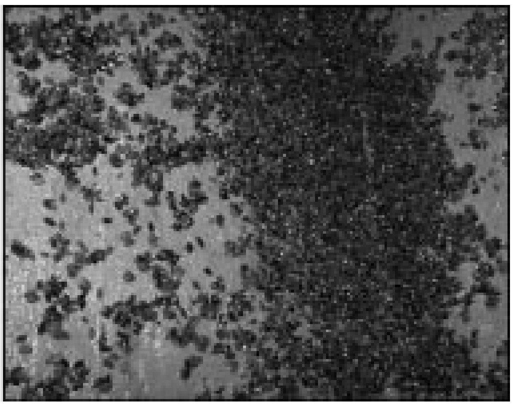
a  b 

Figure 10. Acccumulation of Zebra mussel on the trash racks(a) and penstock(b).

The largest volume of raw water in hydro power facilities is used for cooling and heat transfer. The rest of the volume is used for plant processes other than cooling, such as cleaning, air conditioning, fire fighting, and human consumption. All systems are susceptible to Zebra mussel infestation. Main condenser cooling systems usually flow at rates greater than 2 m/s. This generally prevents the settling of veligers in most areas of the system. However, if scale is present on the walls of the system, Zebra mussel may settle in the available cracks and crevices. Moreover, Zebra mussel can clog water cooling filters (Figure 11a), and heat exchangers (Figure 11b). Sometimes, a velier larva can even obstruct the filters together with silt and very tiny debris (Figure 12a), and the attachment of Zebra mussel on the shaft seal can hinder hydro power generation (Figure 12b).

In addition, stoplogs are vulnerable to Zebra mussel infestation. Clustering of Zebra mussel on stoplogs has made their function difficult (Figure 13).

Two irrigation channels were constructed downstream of the Atatürk Dam and HEPP. The irrigation channels at Şanlıurfa on the Euphrates River are exposed to Zebra mussel infestation. Zebra mussel has bioaccumulated on the covers of irrigation channels (Figure 14), and thus caused problems in both maintaining and the closing and opening of the covers.

Conclusion and Suggestions

The impacts of Zebra mussel on a facility or water body relate directly to the biological characteristics of this pest. Major problems for man-made systems result from mussel attachment to a structure with byssal threads, the mussel's high fecundity under suitable environmental conditions, its ability to translocate to more suitable areas, its high tolerance for a wide range of conditions, and its microscopic, free-swimming veliger stage.

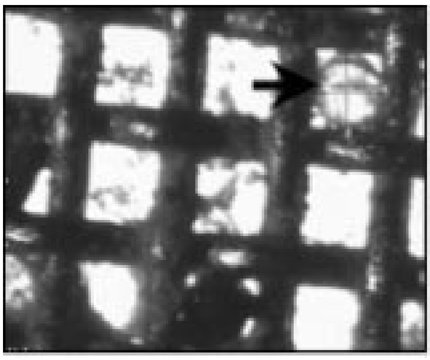
Large numbers of even very small mussels can produce enough byssal threads to disturb the laminar

a

b

Figure 11. Water cooling filters(a) and heat exchanger(b) clogged by Zebra mussel.

a



b

Figure 12. A veliger larva obstructing filter of 100 µm (a) and shaft seal (b).

Figure 13. Zebra mussel clusters on certain parts of stoplogs.

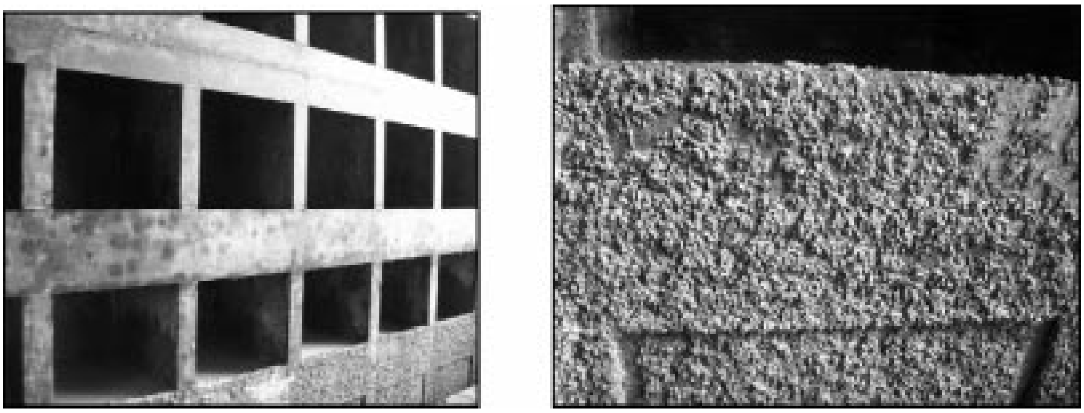


Figure 14. Contamination by Zebra mussel on the cover of irrigation channels at Şanlıurfa.

flow of water through pipelines. Only dreissenids produce byssal threads that can affect the integrity of iron and steel pipelines through potentially increasing corrosion rates underneath the points of attachment. Veliger and juvenile mussels will settle in internal piping where the water flow is sufficiently slow to allow attachment (less than 1.5-2.0 m/s). Zebra mussel colonizing such piping will cause a decreased supply of water to vital areas, obstruction of valves, and loss of heat exchanger efficiency. There are enormous safety hazards if systems such as the fire fighting system are invaded. Therefore, before Zebra mussel infestation begins, the necessary measurements must be taken, and structural or constructional designs should be planned before a facility is built.

In natural waters, the amount of suitable substrate for the settlement of mussel is an important factor regulating population size. Unfortunately, raw water intake and cooling sytems with concrete walls form an excellent substrate for mussel attachment. The growth of mussel in pipes and canals is rapid because the environment is protected against unsuitable conditions such as storms and ice and has a continuous flow of water supplying food and oxygen, and mussel is free of predation. Growth in rivers can be twice as high as in open lakes.

There are numerous methods for the management and control of Zebra mussel. These methods can be essentially classified into 3 categories: chemical, physical and biological. While each of these management types have some advantages and disadvantages, given the nature of each strategy, one type may be more appropriate for a particular habitat or situation than the others. Some of these strategies are primarily reactive, while others are proactive/preventive. Preventive control methods include toxic construction materials, antifouling paints or coatings, chemical treatments, and mechanical filtration and some non-chemical processes such as acoustical vibration and electric fields. Reactive control methods, those applied after infestations have been detected, consist of mechanical cleaning, high-pressure water jetting, carbon dioxide pellet blasting, freezing, and desiccation. Thermal treatment and chlorination can be used initially as a reactive treatment to clean a system, and then preventively as regular maintenance to prevent further fouling. Moreover, the use of extremely low-frequency electromagnetism may prove to be a viable means of nonchemical Zebra mussel control.

When developing a management and control program, it is important to clearly identify the objective of the program prior to implementation. Plans should be based on existing physical data, as well as on information on the size, structure and location of the mussel population. One must consider facility conditions such as water chemistry, water flow rates, temperature, and the types and numbers of vulnerable structures within a raw water system in the design of a successful management and control program. The relative importance of these parameters will depend largely on the descriptive data available from monitoring efforts.

Fouling problems caused by the Zebra mussel are not generally solved by one control methodology. For each location or situation the best solution can be a combination of physical, chemical and biological applications in that declining order of acceptance. Criteria for selecting an appropriate control method must include environmental and economic concerns and ease of application. Moreover, careful attention must be given before, during and after the implementation of control strategies to ensure that there are minimal adverse environmental impacts.

In the Euphrates Basin, the regime of flowing water has changed into that of lakes (i.e. stagnant water), due to the cascade of dams and HEPPs. Furthermore, the discharge of domestic wastes into Atatürk Dam Lake has played a role in enhancing mussel reproduction and population development. Therefore, Zebra mussel has reproduced in appropriate aquatic conditions. However, the fouling problems associated with Zebra mussel in the Euphrates Basin are less severe than those in the freshwaters of North America and Europe at present. Zebra mussel is likely to cause more severe consequences in both the Euphrates Basin and freshwater systems in other geographical regions of Turkey in the near future. For these reasons, a Geographic Information System to monitor Zebra mussel spread should be constituted and updated immediately. Great effort is required to stop this bivalve mollusk from spreading further into other extensive systems of artificial lakes and canals and thereby reaching other drainage basins.

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