Lethal Temperatures

U.S. ARMY CORPS OF ENGINEERS **Building Strong®**

ANS Control: Lethal Temperatures — Carbon Dioxide (CO_2) Pellet (Dry Ice) Blasting, Dessication, Freezing, Hot Water Thermal Barrier, and Pressurized Hot Water/Steam Treatments

An employee of the Tahoe Resource Conservation District uses a high pressure hot water nozzle to remove adult mussels from the hull of a boat.

Targeted Species: Lethal water temperature is an effective control method for many types of organisms, and may be effective at preventing the transfer, via aquatic pathways, of all ANS of Concern – CAWS[1].

Selectivity: This technology was designed to manage the majority of aquatic organisms and is not selective.

Developer/Manufacturer/Researcher: Thermal barriers are being studied by the University of Illinois at Urbana-Champaign HydroSystems Lab in cooperation with the Metropolitan Water Reclamation District of Greater Chicago (Asian Carp Regional Coordinating Committee 2012). Manufacturers of pressurized hot water units and dry ice are readily available throughout the United States.

Pesticide Registration/Application: Pesticides must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: The preferred, upper, and lower lethal temperature ranges for all aquatic life forms vary between and among species and are dependent on genetics, developmental stage and thermal histories (Beitinger et al. 2000). Free swimming aquatic organisms tend to gravitate to a narrow range of temperatures, referred to as a preferred temperature zone (Figure 1). In fish, avoidance will occur as water temperature exceeds the preferred temperature zone by 4 to 18 °F (1-10 °C) (Coutant 1977).

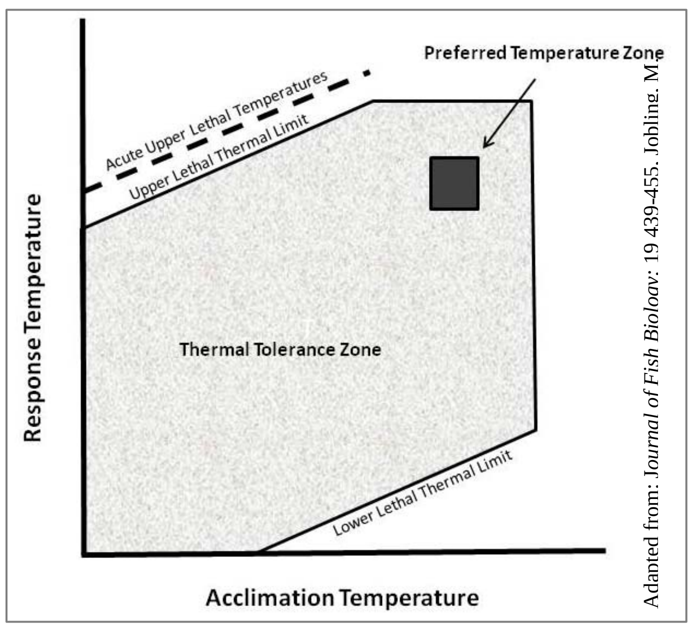

Figure 1: Diagram showing temperature relations of fish

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.

Aquatic nuisance species are susceptible to temperatures that exceed their thermal tolerance. Two types of upper lethal thermal limits exist: acute upper lethal temperatures, and chronic or incipient upper lethal temperatures. Acute upper lethal temperatures are the temperatures at which death occurs when water temperature is raised rapidly. Chronic or incipient upper lethal thermal limits involve continuous exposure of the target organism to constant lethal temperatures for a time period long enough to achieve significant mortality. The zone of resistance, within which there is a strong interaction between temperature and exposure time, lies outside the tolerance temperatures.

Death occurs when temperatures exceed the thermal tolerance of an organism. There are two types of upper lethal thermal limit. The first, acute upper lethal temperature, is the exposure to high temperature, beyond the tolerance of the organism. Death is relatively rapid. The second, chronic or incipient upper lethal thermal limit, involves the exposure of an organisms to a high temperature for a longer period of time. Organisms can survive thermal discomfort for a while, but cannot survive sustained exposure. Temperature tolerance is dependent upon previous thermal history (Reynolds & Casterlin 1979; Jobling 1981).

An organism that is acclimated to cold temperatures will be more susceptible to lower upper lethal temperatures than it would be if it were acclimated to a warmer temperature. Because organisms become seasonally adjusted to different water temperatures, hotter water must be applied in the summer than in the winter to achieve a lethal temperature.

Figure 2: Thermal Tolerance of Various Non-native Species in the Great Lakes and Mississippi River Basins

		Temperature			
Species	**Size or Age**	**Acute Upper Lethal**	**Upper Avoidance**	**Preferred**	**Reference**
Alewife (*Alosa psuedoharengus*)	Large	-	71.6 °F (22 °C)	-	Coutant
coho salmon (*Oncorhynchus kisutch*)	Adult	-	-	57.2 - 62.6 °F (14 - 17 °C)	Brown
common carp (*Cyprinus carpio*)	Large	-	94.1 °F (34.5 °C)	84.4 - 89.4 °F (29.1 - 31.9 °C)	Gammon
grass carp (*Ctenopharyngodon idella*)	Adult	100 °F (38 °C)	-	-	Fedorenko & Fraser
skipjack herring (*Alosa chrysochloris*)	Adult	-	84.2 °F (29 °C)	78.8 - 83.3 °F (26 - 28.5 °C)	Gammon
spiny waterflea (*Bythotrephes longimanus*)	Adult	110 °F (43 °C)	-	-	Beyer et al.
zebra mussel (*Dreissena polymorpha*)	Adult	104 °F (40 °C)	-	-	McMahon et al.

Thermal shock can occur under natural conditions, however it is most frequently observed as a result of changes in thermal effluents from power generation and production industries and at various water control projects. Thermal shock can occur when aquatic organisms are rapidly subjected to temperature changes greater than 18 °F (10 °C) of acclimation temperature (Coutant 1977; Donaldson et al. 2008). Depending upon the degree of shock, the organism may react with instantaneous or delayed mortality. Thermal shock is a potential threat only to those fish resident and acclimated to temperatures in the thermal plume, and has no effect on fish outside of the plume, including those migrating through the system (USEPA 2008).

There are a variety of thermal treatments for managing ANS:

Carbon Dioxide (CO_2) Pellet Blasting – CO_2 pellet blasting is similar to sand blasting except that frozen CO_2 pellets are used instead of sand. CO_2 pellet blasting leaves no blasting medium residue because the CO_2 pellets turn into a gas at room temperature. CO2 pellet blasting flash freezes the target organism, both killing it and making it brittle and easier to remove (Boelman et al. 1997).

Desiccation – Desiccation refers to the drying out of a living organism. In lakes and rivers, it would involve the use of water level drawdowns to expose ANS to the air and interfere with habitat utilization and reproduction. Exposure to the air quickly leads to death for active water-breathing organisms like fish, but mollusks and plants are more tolerant to desiccation and would require a long drying period and have life stages that can be highly resistant to desiccation (Boelman et al. 1997; Richards et al 2004).

Freezing - Freezing involves the lowering of temperature and the formation of ice. Most living cells can tolerate low temperatures; however the formation of ice within the cell results in injury and death. This technique is often attempted in conjunction with water level drawdowns during cold weather to freeze exposed ANS (Richards et al 2004).

Hot Water Thermal Barrier – A hot water thermal barrier is a lethal zone created in a section of the waterway by mixing heated water throughout the water column, creating a kill zone for ANS (Boelman et al. 1997)..

Pressurized Hot Water/ Steam Treatments – Pressurized hot water/steam treatment involves spraying pressurized hot water or steam to kill and remove ANS from boats, pipes and structures (Jonelle Bright, Tahoe Resource Conservation District, telephone communication, 2011) .

Prior Applications:

Lethal water temperature has varied and far reaching uses that include pressurized hot water sprays that are applied to clean boats to thermal barriers that alter the water temperature to a level that is not sustainable for viable organisms. Because of its non selectivity, it can be highly effective in targeting multiple organisms at once but can be limited by the physical or flow characteristics of the water body. Following are more specific applications of each specific method:

Carbon Dioxide (CO_2) Pellet Blasting – This method has been used extensively to remove of organics from aircraft, producing no deterioration of surfaces (Boelman et al. 1997).

Desiccation – Desiccation has been studied as a control for zebra mussels (McMahon et al. 1993). Winter drawdowns with prescribed fire have been used to reduce the invasive plant torpedograss on Lake Okeechobee, Florida (University of Florida 2012).

Freezing – Freezing has been attempted to control Asian clams in Owasco Lake, one of the Finger Lakes in New York, during the winter of 2011-12 (Bruce Natale, Cayuga County Planning , E-mail communication, 2011). Freezing has also been studied for controlling the New Zealand mudsnail (Richards et al. 2004).

Hot Water Thermal Barrier – This type of control has been proposed for the CAWs because of the availability of existing sources of heated industrial water in the vicinity. The USEPA commissioned a study of the existing conditions of water temperature in the CAWS and their effect on non-indigenous species. The report concluded that current thermal conditions in the CAWS present a very small obstacle (1 to 12%) to passage of approximately half of the non-indigenous species considered. Warm temperatures which would impede movement occur only in the summer months, leaving nine months for completely unimpeded passage. The report identified the Lockport region with the highest water temperatures and thus the greatest temperature barrier to fish movement (USEPA 2008). A hot water thermal barrier would also require downstream cooling to restrict the length of the heat zone.

Pressurized Hot Water/ Steam Treatments –This technique is commonly used to kill zebra and quagga mussels at municipal and industrial facilities. High pressure hot water spray is used to clean ANS off of recreational boats at cleaning stations by the Tahoe Resource Conservation District (Jonelle Bright, Tahoe Resource Conservation District, telephone communication, 2011). Hot water and steam are commonly used in the food and medicine industry to sterilize equipment (autoclaving), purify water (boiling), and preserve foods (pasteurization) to destroy harmful microorganisms. These methods are intended to treat small objects, equipment, and structures but are impractical for treating flowing waters.

General Effectiveness: Lethal water temperature can be 100% effective in preventing ANS transfer when ANS are exposed to the correct temperatures for the appropriate duration. Sub-lethal water temperatures are an attractant to many species, particularly in the fall, winter, and spring.

Carbon Dioxide (CO_2) Pellet Blasting – CO_2 pellet blasting is preferred over conventional sand blasting for removing encrustations of zebra mussels. CO_2 pellet blasting freezes zebra mussels, making them brittle and more easily removed, and when solid carbon dioxide converts to a gas, it penetrates voids and the area of zebra mussel attachment, lifting the organism off the surface. Unlike sandblasting, carbon dioxide pellet blasting is less likely to damage surfaces (Boelman et al. 1997).

Desiccation – This technique may be effective and managing aquatic plants and mussels. Temperature is positively related and humidity negatively related to zebra mussel mortality. To ensure 100 percent mortality, aerial exposure must last nearly a month at moderately low temperature (5ºC) and high humidity (95%) but only 2 days at moderately high temperature (25ºC) and extremely low humidity (5%). However, even at high humidity (95%), 100% mortality is expected in approximately 5 days at 25ºC (Payne 1992). Aquatic plants can be dried and burned, however rooted vegetation may resprout if the soil is not dried sufficiently.

Freezing - Zebra mussels can be effectively controlled by winter drawdown and exposure to subfreezing air temperatures. Clustered mussels are more tolerant of reduced air temperatures than are individual organisms. Exposure time for 100% mortality of individual mussels range from 15 hr at -1.5º C to less than 2 hr at -10 ºC. For clustered mussels, these times range from over 48 hours at -1.5 ºC to 2 hr at -10 C (Payne 1992).

Hot Water Thermal Barrier – This method was previously examined by a report from Midwest Generation in the CAWS (USEPA 2008). Most industrial sources would find it difficult to generate a thermal load to the receiving water that would ensure that the lethal zone would be maintained to allow sufficient exposure time. For some industrial facilities, it may be possible to establish a thermal barrier in the summer, but for most it would be impossible in the winter due to the increase in thermal load that would be necessary to result in lethal water temperatures. Where ANS are mobile and able to preferentially avoid or seek a thermal plume, hot water thermal barrier will not have the desired effect, because ANS could pass the thermal barrier in the winter months.

Beyer et al. (2011) found that a water temperature of 110 °F (43 °C) was necessary to kill the spiny waterflea (*Bythotrephes longimanus)*. Grass carp, a close relative of the silver, bighead, and black carps, cannot tolerate temperatures greater than 100 °F (38 °C) (Fedorenko & Fraser 1978). Zebra mussel mortality occurs at 104 °F (40 °C) (McMahon et al. 1995).

Pressurized Hot Water/Steam Treatments – This ANS Control is effective for treating small objects, equipment, and structures.

Operating Constraints: Below are general operating constraints associated with the Lethal Temperature ANS Controls.

Carbon Dioxide (CO_2) Pellet Blasting – CO_2 pellet blasting is limited to controlling ANS on objects that have been removed from a water body.

Desiccation – Desiccation requires the draining of a water body.

Freezing – Depending on site conditions, freezing may require winter drawdown of water in a water body. The ambient temperatures must reach the threshold temperature for a sufficient duration to be an effective ANS Control.

Hot Water Thermal Barrier – Water hot enough to create a thermal barrier must be supplied on a continuous basis and be adequately mixed throughout the water column to ensure the target temperature throughout the water column is reached. Maintaining temperature and exposure time is a significant challenge due to the following potential non-static conditions of a water body: fluctuating flow velocities driven by wet vs. dry weather, inconsistent flow direction, including reverse flows, driven by storm surges, density currents, and flat gradients; and abrupt changes in flow velocity.

The thermal tolerance of all life stages of an organism must also be considered; many aquatic plants can tolerate a wide range of temperatures, especially in the seed stage (Lacoul & Freedman 2006).

Pressurized Hot Water/Steam Treatments – Pressurized hot water/steam treatment is limited to controlling ANS on objects that have been removed from a water body.

Cost Considerations:

Implementation: Implementation costs for this Control would vary depending on the type of Lethal Temperature implemented. A very general description of implementation cost considerations follows. CO_2 pellet blasting and pressurized hot water/steam would require a land-based hand-application systems and waste collection and removal. Desiccation and freezing would require infrastructure (i.e. dams and levees) to control water levels. Hot water thermal barriers would require a means of heating water or a source of hot water, such as a neighboring industrial source. To treat a flowing system, hot water thermal barriers would require a distribution and mixing component to ensure the required temperature is reached throughout the water column.

Planning and design activities in the implementation phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would vary with the technique selected for heating and mixing water. An effectiveness monitoring program would be required.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

Citations:

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