Rapide Croche Intermediate Thermal Treatment Test Report

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Introduction

The Fox River Navigation System Authority would like to make the entirety of the Fox River navigable or at least passable by boat between Green Bay and Lake Winnebago. They have completed refurbishment of the operational locks on the system in 2016 and now seek to establish a boat transfer station at the Rapide Croche lock, which was closed in 1988 to prevent the upstream spread of sea lamprey from Lake Michigan. Sea Lamprey and other aquatic invasive species could pose a threat to the robust and highly managed lake sturgeon population and the walleye fishery in Lake Winnebago.

A boat transfer station has been proposed to move boats over the closed lock. The transfer and cleansing station will lift the boats from the downstream water and then use high pressure spray and a hot water bath to cleanse boats of aquatic invasive species (AIS). The boats will then be moved to the upstream side of the transfer station and returned to the water. The cleansed boats will then be able to navigate upstream to Lake Winnebago. Boats headed downstream will not need to be cleansed, but will need to be lifted and moved to the downstream side of the transfer station. Prior laboratory work (Beyer et al. 2011) indicated spiny waterfleas will perish in five minutes when subjected to hot water at a temperature of 110^{O}F. The current report describes the results of intermediate-scale testing using a portable hot water system carried out to determine the potential effectiveness of hot water application in actual boat compartments. We did not use live organisms to test the effectiveness; rather we measured the temperature of the compartments through the duration of hot water application to assess whether the sensors reached 110^{O}F for five minutes. Review of the 2008 Wisconsin DNR boat registration data indicated over 98% of boats registered that year had fiberglass or aluminum hulls; therefore we focused on these two hull materials and tested wood hulls as we were able to obtain them.

Objectives

A pilot test using the portable hot water system suggested ten minutes of hot water application would raise the temperature of thermometers placed in a bilge compartment to 110^{O}F for five minutes. Therefore, we targeted a ten-minute application period. The objectives of the current study were to:

- Treat the live well, bilge and anchor locker compartments with 112-114^{O}F water
- Record the temperature increase using remote data loggers
- Determine if temperature at the data loggers reached 110^{O}F for five minutes
- Treat boats with fiberglass, aluminum and wooden hulls
- Identify any needs to modify or improve the proposed boat cleansing process

Materials and Methods

We tested 9 fiberglass hull boats, 10 aluminum hull boats and two wooden hull boats. Nine boats were in the water including the two wooden hulled boats; twelve were on trailers including one sailboat. Hot water was applied to the target compartment for at least a ten minute period. The portable hot water treatment system was comprised of an inline Eccotemp L10 propane-fired tankless water heater mounted on a cart (Figures A and B). We carried a portable propane tank and used garden hoses to convey water to and from the heating system. The system generated 74,000 BTU with output temperatures ranging between 80 and 140^{O}F. We used tap water (city or well water) for the supply. Heated water was introduced to the target compartment at a rate of about 2 Gal/min. The target inflow temperature was 112-114° F. Water was discharged from the compartment via a bilge pump, drain or overflow ports. If there was a bilge pump present, it operated several times during the treatment process automatically or manually, depending on the pump type.

Figures A and B left to right. Figure A - Side view of the portable water heating system used for the intermediate testing. Figure B – Bottom view of the propane heater illustrating propane connection, incoming (green) and outgoing (red) water connections.

Testing was conducted in livewells, anchor and bilge compartments, and center compartments. For each test, two to six Onset HOBO Pendant data loggers were placed in the compartment. Logger location was determined by the shape and size of the compartment, with small, narrow compartments receiving two sensors, small, square compartments received four, and larger compartments received six sensors (Figure C). The sensors were connected to a weight in order to remain stationary during the test. Temperature data was logged at 10 second intervals, with the sole exception of one sensor in one test on August 16 that logged at one minute intervals; the logging interval was not set to 10 second time at the start of the test. Temperature of each compartment prior to testing was measured with an Extech Mini infrared thermometer.

The temperature of the incoming treatment water was logged at the end of the delivery hose with an Onset InTemp Bluetooth Low Energy Temperature Data Logger (CX402-TxM). An additional Onset Intemp Logger was used at the outlet of the compartment (bilge pump, overflow pipe, etc.). When there was no outlet (e.g. rowboat open floor), then temperature was logged in the compartment. Each treatment test was carried out for at least 10 minutes.

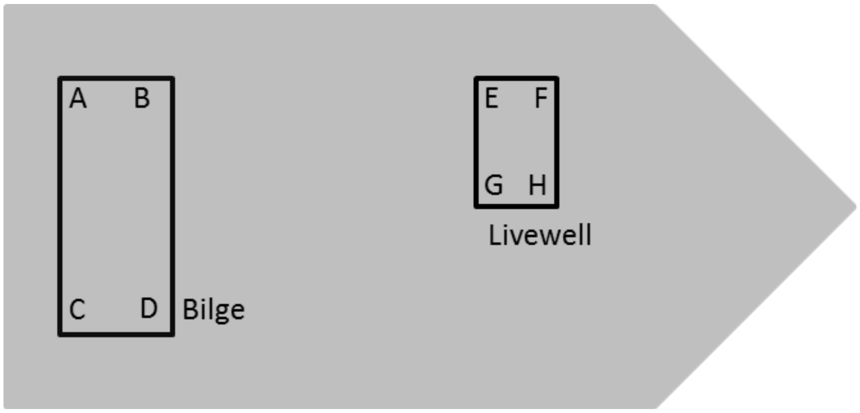
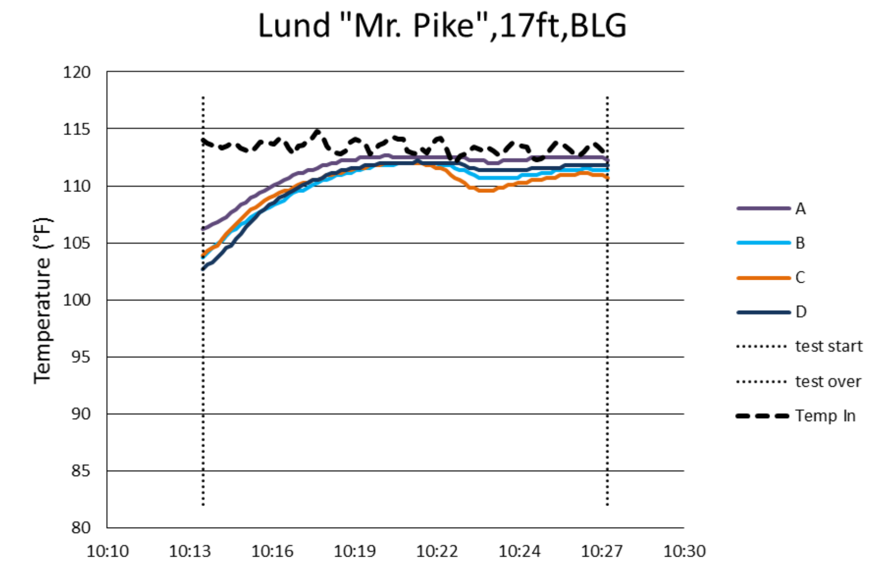


Figure C. Typical sensor placement as indicated by the letters, in a bilge and livewell.

Other parameters recorded were: air temperature, river or lake temperature, incoming water temperature, weather conditions, boat make, model and length (if available), hull material, date, start time, end time, location, personnel, type of compartment, temperature of the treatment water, whether the boat was in the water or on a trailer, and full duration of the test treatment. If air temperature was not recorded on site, it was obtained later from the closest National Weather Service location.

Results

The sensors responded quickly to the incoming water temperature. The sensors in larger boats (>21' in length) took longer to reach 110^{O}F and had fewer sensors reach 110^{O}F than boats less than 21' in length (Figure D). Hull material did not significantly affect the temperatures achieved in the bilge compartments (Figure E; ANOVA $p>0.05$). This result allows us to combine hull types within a location – water or trailer – for statistical comparison. In compartments where 110°F was not reached, the sensors still showed an increase in temperature to near the target value. Whether the boat was in the water or on a trailer significantly affected the results. Sensors in boats on trailers reached a statistically significant higher average temperature than boats in the water (Figure F; ANOVA $p=0.0048$). At least one sensor in over 91% of the boats on trailers reached 110^{O}F or more for at least five minutes during the test treatments, while only 55% of boats in the water had at least one sensor reach 110^{O}F for the required duration. However, trailer versus water is not the only confounding factor. The average length of boats on trailers was 19 feet while that of those boats in the water was over 25 feet. The larger boats have a greater volume of the bilge compartment to treat (see Appendix).



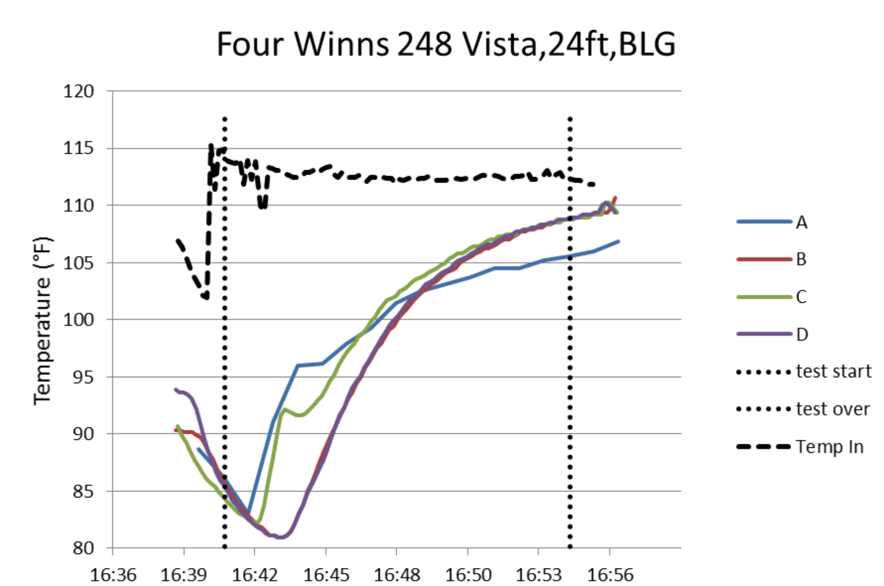


Figure D. Line graphs illustrating rise in temperature of sensors (letters) in the bilge compartment of a boat less than 21' (Lund) and one larger than 21' in length (Four Winns). The drop in sensor temperature at the beginning of the test is a consequence of taking the sensor out of the storage box or sunshine and placing it in the bilge compartment. This pattern was observed in many of the tests (see appendix).

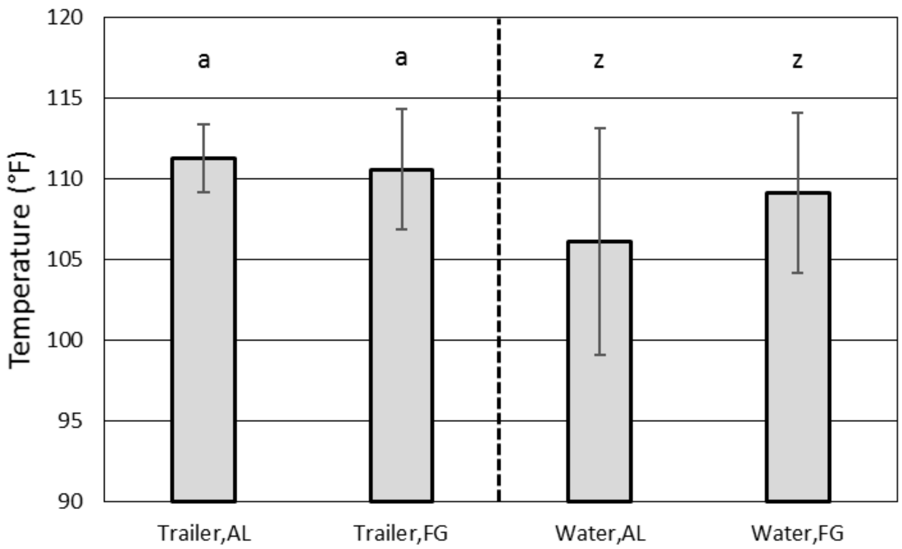


Figure E. Mean maximum sensor temperature for location (water or trailer) and hull material in bilge tests. Error bars represent +/- 1 standard deviation. There were no significant differences between the bilge sensor temperature measurements when compared by hull type (ANOVA p>0.05).

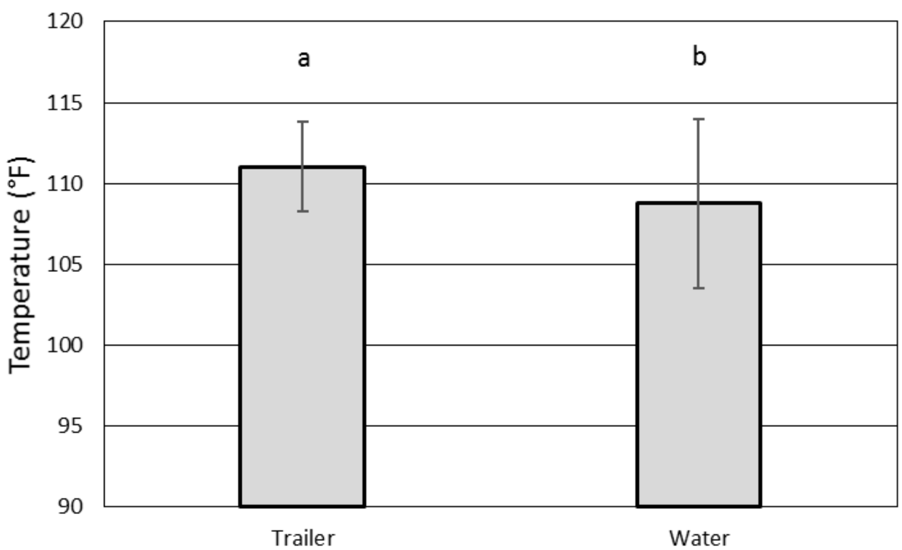


Figure F. Mean bilge sensor temperature by location of boat (water or trailer). Error bars represent +/- 1 standard deviation. There was a significantly lower bilge temperature for boats that were in the water, compared to boats on trailers (ANOVA p=0.0048).

The effect of compartment size or volume is easily seen when examining the following results:

Overall, 48% of sensors reached at least 110^{O}F for five minutes or more, while 68% of the sensors reached 110^{O}F for some period of time. If we parse this out by compartment, we find that only 40% of the sensors in the bilge compartments reached 110^{O}F for the required duration, but 61% of the sensors in bilge compartments reached 110^{O}F for some period of time. In terms of the other compartments (i.e. anchor lockers and livewells) 61% reached 110^{O}F for five minutes or more and 80% reached 110^{O}F at some point in the test. In the smallest compartments – livewells – 71% of sensors reached 110^{O}F for at least five minutes and 93% of the sensors attained a maximum temperature of 110^{O}F or more (Table 1).

Table 1. The number of sensors used in each compartment category, number of sensors (percent) for which the target temperature of 110^{O}F was achieved for at least five minutes, and the number of sensors (percent) on which the maximum temperature achieved equaled or exceeded 110^{O}F.

Compartment	# of Sensors	Time (%)	Max Temp (%)
Overall	159	76 (48)	108 (68)
Bilge	100	40 (40)	61 (61)
Other – Anchor, Center, Livewell	59	36 (61)	47 (80)
Livewell Only	31	22 (71)	29 (93)

In terms of the anchor lockers, the rapid draining of the compartment and mass of the anchor, anchor chain and/or anchor rope appeared to adversely affect the treatment in that compartment. It is anticipated that during full-scale application, the anchor and associated rope or chain will be removed from the locker and placed in the external hot water bath so that the anchor locker can be treated separately.

The bilge compartments of most boats were dry, though one 33-foot fiberglass boat had several inches of water and oil in the bilge well before the test began. Ultimately, no sensors in this particular boat reached 110^{O}F during the treatment period.

Discussion

The results suggest that at least four factors and possibly a fifth affected the efficacy of the test treatment. First, size of boat, or essentially the size of the compartment being treated, adversely affected the treatment effect. Second, whether the boat was in the water or on a trailer had a significant effect. However as pointed out above, boat length was related to whether the boat was in the water or on a trailer and is a factor in bilge compartment size as well. In the proposed full-scale treatment process, the boat will be resting in heated treatment water which should facilitate treatment of the compartments.

The third factor is incoming water temperature. In the Tracker Targa 165 test (boat 817-AL-AC-18) two sensors in the second livewell did not quite reach target temperature. The other six sensors (4 in one livewell, two in livewell 2) reached 110^{O}F but not for the full five-minute duration. The incoming water temperature for the test in livewell 2 was about 111^{O}F instead of 114^{O}F. We see a similar effect in the center compartment trial for the trailered Boston Whaler. Incoming water temperature for this test was about 111^{O}F; three of the sensors did not reach 110^{O}F.

The fourth factor that appears to have affected treatment effectiveness was weather. Warmer air temperatures and sunny conditions appeared to facilitate warming of the compartments. The air temperature during the Tracker Targa test was slightly cooler than that on other days and the boat was inside, out of the sun. Though the results are inconsistent, the results are in fact promising and suggest several items to consider when moving ahead to the full-scale application.

First, in full scale application, the hull will be immersed in hot (114^{O}F) water which should augment the application of hot water in the interior compartments. Second, there should be a larger delivery volume of hot water to the compartments to be treated. Our garden hose running through the flow-through heaters operated at about 2 Gal/min. A higher flow rate of hot treatment water delivery would likely improve the treatment effect. In addition, slightly warmer water (115^{O}F) consistently applied for a longer duration (15 min) would likely augment the efficacy of the treatment. It is clear based on our retrospective data analysis that real-time temperature sensors will need to be placed in the target compartments to assure the required temperature is achieved for the minimum treatment time.

Larger boats (>23 feet in length) with large, flooded and poorly accessible bilge compartments should, like boats with heavily encrusted hulls, be either turned away before entering the treatment area or have the bilge fully drained prior to treatment. It was relatively easy to reach target temperature in the live wells when incoming water temperature was at or near 114^{O}F. The lower incoming water temperature in the Tracker boat test indicates the importance of consistently high temperature of the treatment water.

Conclusions

We demonstrated it is possible to raise the water temperature in bilges, live wells and anchor wells to 110^{O}F for five minutes using treatment water of 114^{O}F applied for at least ten minutes. Compartment size appears to play a significant role in the success of the treatment, as live wells were more successfully treated than bilge compartments in that a greater number of sensors in the live wells reached target temperature and sustained that temperature for the required five-minute duration. Treatment water temperature plays a significant role in the ability to achieve the required target temperature. With this in mind, FRNSA may want to consider a slightly higher (115-116^{O}F) water bath temperature and will need to recognize that a longer treatment time may be required. Also, the input flow rate of the supplemental treatment water for interior compartments should be greater than 2 gal/min. This may ultimately displace water coming in through the bilge drain or other through-hull fittings; however at some point the flow of water entering via the through-hull openings may slow such that it is no longer effective in raising the temperature of the compartment.

The variability among compartments in the time required to reach target treatment temperature indicates it will be important to have real-time thermal monitoring devices in the treated compartments to assure that the target temperature is achieved for the proper duration. Further, the transfer system operator should have access to an additional hot water supply that can be pumped into compartments on the boat in the event that the raw water pumping systems are insufficient to achieve the target temperature or that the water coming in through the bilge drain is insufficient to achieve the target treatment temperature.

Citation

Beyer, J., Moy, P., and De Stasio, B. 2011. Acute Upper Thermal Limits of Three Aquatic Invasive Invertebrates: Hot Water Treatment to Prevent Upstream Transport of Invasive Species. *Environmental Management* 47(1):67-76.