Proceedings of a Workshop to Develop a Decision Framework to Support Winged Mapleleaf Management in Response to the Zebra Mussel Threat

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Final Report

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Abstract. A workshop was conducted in 13-14 January 2009 in St. Paul, MN to generate the essential inputs needed to use Multi-Criteria Decision Analysis (MCDA) to support management of the Federally endangered winged mapleleaf (WML) mussel, *Quadrula fragosa*, in the St. Croix River, WI. The need for a decision framework is based on potentially deleterious effects of infestation by the increasingly threatening distribution of the invasive zebra mussel (ZM), *Dreissena polymorpha*. The workshop supported the MDCA by accomplishing several objectives. First, twenty seven potential management actions were identified. Then, a set of ZM threat conditions were conceptually defined that can guide scenario-based planning. Next, a set of criteria were developed for use in evaluating the probable performance of potential management actions. Relative importance weights were assigned to evaluation criteria for each ZM threat condition. Then, criteria-specific performance estimates were made for each management action, using a qualitative index of 1 (worst) to 5 (best). From these estimates, a decision model was built in which performance estimates were integrated with the relative importance of the evaluation criteria to yield a comprehensive "decision score" for each management action under each ZM threat scenario.

A full report of the results of the MCDA is not yet ready, but an overview of those results is briefly summarized herein. Essentially, management actions of a preventive nature aimed primarily at slowing or preventing the spread of ZMs are preferred under the low threat scenario. In contrast, more active management is preferred under a high threat conditions, mostly involving removal and relocation of adult WML or development and implementation of mass-rearing capability leading to seeding of juveniles into less-threatened sites and rivers. The full report of results will soon be made available to participants for review and comment, potentially leading to revision of the decision model. It is important to recognize that MCDA decision scores support decision-making, enhance communication, and encourage a common understanding of a complex decision problem. MCDA is not intended to dictate but rather is intended to inform decisions.

Background and Objectives

At the request of the St. Paul District of the Corps of Engineers, the authors were asked to develop a decision framework, using multi-criteria decision analysis (MCDA), to inform future decisions concerning management of winged mapleleaf mussel (WML, *Quadrula fragosa*) in response to the increasing threat of the invasive zebra mussel (ZM, *Dreissena polymorpha*) on the long-term survival of the endangered mussel. We facilitated a 2-day workshop sponsored by the District designed to obtain to elicit the required input of the technical group to support an initial MCDA analysis of this WML management challenge. The workshop brought together a technical group of participants. The participants where chosen for their knowledge and experience with various aspects of mussel ecology, conservation, management, and supportive research associated with protection of the Federally-endangered WML in the St. Croix River (SCR).

The workshop was conducted on 13 and 14 January at the Crowne Plaza Hotel in downtown St. Paul, MN. During the first morning, welcomes and introductions were made and an overview given to explain the St. Paul District's interests as well as the role of ERDC in supporting development of a decision framework for WML management actions in relation to ZM infestation threats. Then a series of presentations were made by various participants, providing up-to-date information on the status of the ZM population in the SCR, WML population condition, and various research efforts aimed at improving WML management options. In addition, the relationship of the workshop to prior aspects of interagency coordination, including the Biological Opinion, was discussed.

During the afternoon of day 1, an overview was given of how MCDA can be used to structure the consideration of information and inform management decisions to protect WML in the face of multiple objectives and uncertainties surrounding such management decisions. MCDA is a methodological approach designed to inform difficult decisions that involve multiple criteria, often conflicting objective and or a diverse set of stakeholders, and input some of which might be relatively quantitative and certain and other of which might be relatively qualitative and less certain. A set of specific objectives was set out to structure the remainder of the workshop. The workshop discussions continued with emphasis on accomplishing the following objectives:

- Develop a list of management actions available to deal with WML conservation needs.

- Delineate a set of ZM threat conditions (low, medium, and high threat levels) against which the evaluation criteria would be considered.

- Develop a set of evaluation criteria that could be used to evaluate and compare the potential benefits of those management actions.

- Have individuals estimate the relative importance of the evaluation criteria under each ZM threat conditions.

- Have individuals estimate the expected performance of each management action with respect to each evaluation criterion.

- Describe the risk setting – those risks other than ZM infestation that may affect the SCR WML population (this objective is not addressed in the present report that focuses only on the MCDA aspect of the workshop).

Day 2 of the workshop involved a series of discussions and exercises to accomplish these objectives. Criteria weights were elicited from all participants for each ZM threat condition. Because ZM threats are one of many factors that threaten the continued existence of WML, some time was spent describing important factors affecting the "baseline risk condition." The last session of the workshop was spent having participants provide estimates, using an assigned scale of 1-5 with one being worst and 5 being best, of the expected performance of each action in relation to each 9 evaluation criterion.

A list of individuals that participated in the workshop is provided in Table 1. Not all individuals fully participated; some individuals either could not attend the entire workshop or were students or others not as full engaged in the WML management issue as was the main body of participants. The principal participants, who assigned weights to the evaluation criteria and estimate performance scores for each management action using those criteria, are indicated in Table 1. ERDC facilitators (Payne and Farr) led the workshop and discussions but did not assign weights or scores.

Management Actions

Early discussions resulted in the listing of 27 different management actions. An attempt was made to be comprehensive, with each action being reasonably distinct from others. The actions are considered to be potential components of management alternatives that might be implemented. In other words, it is unlikely that only one action would be taken. Any management alternative would probably engage several different actions at once or in sequence. Furthermore, the list was not constrained to just those actions that typically fall under the Corps of Engineers' purview, but rather was intended to deal with all things that might be done to prevent, minimize, or counteract detrimental effects of ZM infestations on WML. For example, reservoir operation changes for the Excel-owned and operated dam just upstream of Osceola clearly is not within the Corps jurisdiction. Yet such operations theoretically could be altered either to benefit WML habitat or hinder ZM infestations. Thus, various reservoir operation actions were listed.

This list is one that presumably can be shortened as the process continues. For example, action H (see below), relocation of WML to ponds, is of suspect value relative to the other relocation alternatives. This option was listed because it has been used for other species; it probably in not appropriate for WML. In general, the list probably can be improved by deleting some actions and more specifically defining the remaining ones. For the purposes of the present workshop, the following 27 management actions were carried forward into the MCDA analysis:

A. Clean and Replace WML**.** This management action would involve removing as many WML as feasible, cleaning infestations of ZMs from their shells and replacing the winged mapleleaf back to the location where they were obtained. Use of this action (or the several following actions involving relocation of WML) would be limited by the difficulty of finding WML in the riverbed and the amount of disruption of the bed that would be associated with intensive and extensive searching that would be required to obtain many WML. Therefore, it is not likely that a large fraction of the population could be dealt with by this action. The following relocation actions (B-H) would all involve WML taken from the SCR, cleaned, and then placed in new locations.

B. Relocate to SCR Aggregation Area. Due to the difficulty of finding individual WML, a prudent action associated with cleaning of mussels would be to move cleaned individuals to an area that has been historically used to aggregate WML in the vicinity of the main assemblages in the SCR.

C. Relocate to Less-Threatened SCR Sites. This action would involve relocating WML not to their site of collection or a nearby aggregation site, but rather to sites in the SCR that might be identified as having lesser threat of ZM infestation (e.g., upstream sites or sites with hydraulic or other characteristics that reduce the likelihood of ZM infestation).

D. Relocate to Sites in Other Rivers. This action would involve moving cleaned WML from the SCR to other rivers, presumably less-threatened or with sites less-threatened by ZM infestation.

E. Relocate to Engineered Refugia. Specially-engineered refugia (in or not in the river) would receive WML retrieved from an infested site. These refugia might be hydraulically engineered sites in the river or flumes or similar facilities adjacent to the river that would supply flow-through of natural river water but allow protection and ease-of-repeated access to collected WML.

F. Relocate to Modified SCR Hatcheries. In this case, those WML lifted and cleaned would be taken to abandoned fish hatcheries along the SCR that will have been modified to serve as rescue and maintenance facilities.

G. Relocate to Other Modified Hatcheries. This is the same action as the previous one, except that the hatcheries used would be in other river drainages (e.g., take advantage of facilities already being put to similar uses).

H. Relocate to Ponds. This action has been tried with other species and sites (e.g. *Plethobasus cooperianus* in the lower Ohio River). It may not be a reasonable alternative for WML in the SCR.

I. Treat with ZM-Selective Biocide. Two products in development were discussed in relation to this action. These were potassium chloride "biobullets" under research and development by Aldridge and his colleagues and a *Psuedomonas*-based biocidal product under research and development by Malloy and his associates. Neither is presently available as off-the-shelf technology of known specificity, but both products show substantial promise for improving ZM treatment options.

J. Cryogenic Genome Preservation. This action would involve long-term cryogenic preservation of WML DNA that might in the future be used in cloning efforts aimed at restoring the species if it is lost.

K. Seed Additional SCR Sites with Juveniles. Several actions involve using reared juveniles, and are based on recent developments in juvenile rearing capabilities for another endangered unionid, *Lampsilis higginsii*. This action presumes a mass-rearing capability that presently does not exist. In the presently proposed action, reared juveniles would be added used at selected SCR sites in an attempt to create a more ubiquitous distribution of WML in this river.

L. Seed Existing SCR Populations with Juveniles. In this instance, reared juveniles would be added to the existing SCR populations in an active management effort to bolster recruitment rate.

M. Seed Other Rivers with Juveniles. This action is similar to the previous two actions, but the attempt would be to seed populations in rivers within the historic range that presently do not support WML.

N. Develop Mass Rearing Capability. In recognition that a rearing capability is presently lacking, this was listed as a distinct management action to provide a bridge to the aforementioned "seeding" options. Without this capability, the prior three options are premature for consideration.

O. Alter Reservoir Operations to Improve Mussel Habitat. Unionid populations just downstream of dams, like the one operated by Excel Energy near Osceola, are greatly affected by reservoir operations. The idea of this action is that reservoir/dam operations might be altered in some fashion to improve WML habitat in the tail water.

P. Alter Reservoir Operations to Improved WML Condition. This action is closely related to the one just described, but would be aimed more at bolstering the physiological condition of WML (probably via food delivery) than at improving the physical habitat.

Q. Discharge Reduction to Expose Tail water ZMs. This action would involve reduction of reservoir discharge to expose any ZMs infesting WML habitat in the tail water to air for a sufficient period to kill the invasive mussels.

R. Reservoir Drawdown to Exposure ZMs. If ZMs colonized the reservoir just upstream of the major assemblages of WML, then drawdown of the reservoir could be an option for eliminating such colonists.

S. Boat Inspection and Cleaning. Mandatory boat inspection and cleaning at major access and egress locations is an often-used management option to slow dispersal rates of aquatic nuisance species.

T. Heat Treatment Station in the UMR. A novel treatment alternative that has been suggested is to force commercial navigation traffic to cycle through a heated water station periodically to prevent upstream transport of attached ZMs in the UMR system.

U. Restrict Upriver Movement of Boats. In the SCR, upriver movement of boats (small recreation craft and larger tourist vessels) can be a significant source of upstream dispersal of ZMs in a system where upstream dispersal is naturally difficult. Boating restrictions have been used to limit such dispersal by smaller recreational craft.

V. Strengthened Laws and Regulations. Legal and regulatory options are used to help reduce risk of aquatic nuisance species dispersal. Strengthened enforcement is perhaps as important as strengthened laws.

W. Public Awareness and Education. Education and awareness efforts help make the public more aware of ZM problems, and in this case, related WML conservation challenges in the SCR. Such awareness and education is an integrated component of upriver boating restrictions and effective enforcement of laws and regulations.

X. Upriver Lakes Risk Identification. The naturally lotic nature of the WML sites makes an upriver source of ZMs a likely necessity to sustain infestations of WML beds. Thus, risk identification of upriver lakes is an important component management action in a drainage-wide management scheme.

Y. Improve Host Fish Populations. Increased abundance of ictalurid fish hosts for WML glochidia might be (or might not be) an important component for enhanced recruitment of the endangered mussel. This management action would be aimed at increasing ictalurid abundance in hopes of increasing recruitment opportunities.

Z. Improved Predatory Fish Populations. Invasive carp are effective ZM predators, although it is less clear than can effectively control invasive populations. The proposed management actions presume increased predatory fish abundance would help control infestation levels.

AA. Establish Sanctuary Zones. The establishment of special sanctuary zones, kept off-limits of public and other uses, might be useful for enhancing protection of WML and SCR.

Zebra Mussel Threat Conditions

Management actions ranged from those appropriate before or during early infestation scenarios (e.g., those aimed at slowing dispersal of zebra mussels) to those tailored more to extremely stressful infestations (e.g., interventions aimed at either removing zebra ZMs from WML or at removing WML from sites heavily infested by zebra mussels). Given both spatial and temporal uncertainty concerning future conditions of zebra mussel infestation, a robust planning exercise required the consideration of multiple threat scenarios. Three threat conditions were categorized a three levels to correspond to a low, moderate, and high threat of ZMs to WML.

These categories were intended to make qualitative distinctions in the expected rate and magnitude of decline in the WML population. It was not the goal to quantitatively define the threat conditions but rather to establish a basic framework under which different threat conditions could be dealt with. A low threat condition was defined as one in which ZM mussel infestations were either not evident or so low that the likelihood of measurable effects on the physiological condition or population demography of the WML population is unlikely. A moderate threat condition corresponds to a ZM-infestation condition in which ecological or direct physiological consequences are relatively certain to cause measurable but not rapid decline in the abundance of WML. Many decades or several generation times is required under a sustained moderate threat to eliminate the WML population in the SCR. However, a trajectory toward elimination is likely. Thus, under a moderate threat there still is substantial time to act. In contrast, a high threat condition corresponds to one in which sustained, dense infestation by ZMs are almost certain to be sufficient to eliminate the WML in the near term (several year, perhaps no longer than one generation or 2-3 decades). Under the high threat scenario, aggressive and rapidly implemented management actions are needed.

Perhaps not surprisingly, concern was expressed that consideration of multiple threat conditions might be an attempt to alter decisions made in relation to prior discussions of the ZM threat to WML, such as those associated with the Biological Opinion. The threat conditions used herein are meant solely to support a decision process in which a wide range of management actions can be considered in light of a range of threat conditions. Scenario-based planning is wise given the uncertainty that surrounds future conditions of ZM infestation throughout the SCR and nearby drainages.

Evaluation Criteria and Importance Weights

After much discussion, nine criteria were determined to be an appropriate set for evaluating the predicted performance of each management action. A brief narrative description of each criterion is provided in Table 2. It was determined that the relative importance of these criteria is different under low, moderate, and high zebra mussel threat conditions. For example, the importance of slowing zebra mussel dispersal is more important when the threat of ZM infestation to WML populations is low and still emerging than when that threat high and fully manifest.

Participants were asked to assign importance weights to the full criteria set - under each of the three threat conditions. The rules for assigning importance weights were straightforward. First, the sum of importance weights for all nine criteria, for each threat condition, had to equal 100. The higher the allocation made to a particular criterion, the more important was that criterion. If a participant thought a particular criterion was of no importance, a zero value could be assigned. In addition, equal point allocations were permitted (e.g., three criteria might each receive the same number of points).

Resulting weight estimates are summarized in Table 3. Inspection of individual participants' "score sheets" showed the maximum allocation given to any criterion was 60. Not surprisingly, 0 was the minimum score. Most participants allocated at least some points to most if not all criteria. A few participants allocate points to just a few criteria.

Under a low threat condition the most important criterion was the degree to which a management action was likely to slow zebra mussel dispersal, which received an average of 33.3 of 100 possible points. Next in importance under a low threat condition was the degree to which a management action was likely to increase the SCR WML population's resistance to infestation. This criterion received an average score of 19.1. The criterion "minimize adverse impacts" was moderately important, with an average score of 10.4. The criteria "transferability" and "minimize legal issues" scored lowest among the set of nine. The standard deviations shown in Table 3 indicate variability among participants. In general, higher ratios of standard deviation-to-mean reflected instances when most participants assigned a zero or very low score, but an individual or two scored a criterion substantially higher than the main body of participants.

In contrast, under a high threat condition the criterion "slow zebra mussel dispersal" was among the least important criteria, with an average score of only 4.9. The most important criterion under the high threat scenario was the degree to which a management action was envisioned to relieve infestation pressure, with an average score of 30.3. "Increase population resistance" and "increase species resistance," with average scores of 19.9 and 18.3, respectively were of substantial importance under the high threat condition. All other criteria scored moderately low or low. With the exception of the three highest ranked criteria, no criterion received an average score greater than 7.

As might be expected, the importance among criteria for the moderate threat condition was indicative of the shifts seen from the least to most stressful condition. Under the moderate threat condition, four criteria had average values indicating moderately high importance under the moderate threat conditions. In rank order these were: "increase population resistance" at 22.2; "relieve infestation pressure" at 19.4; "increase species resistance" at 14.0; and, "slow zebra mussel dispersal" at 12.9.

In summary, preventative actions (i.e., slow dispersal, increase WML resistance), applied with caution (i.e., minimize adverse effects), took priority under the low threat condition. Palliative or rescue actions (i.e., relieve pressure, increase resistance) took priority under the high threat condition. These were the large and prominent shifts in criteria weights.

Interestingly, the “cost effectiveness and practicality” criterion was not deemed to be especially important under any circumstance. As might be expected, “cost and practicality” did score higher under the low (8.2) than moderate (5.9) or high (6.5) threat conditions. Similarly, the “demonstration status” of a management actions was never deemed to be particularly important (4.0 to 6.7 range in average score), perhaps indicating the somewhat “trial and error” nature of many management actions combined with the necessity to trust that reasonably conceived, if not fully proven, methods. A need to “minimize legal issues” was not particularly important; oddly, this criterion scored highest under the moderate (8.3) compared to the low (3.3) or high (3.1) threat conditions. Somewhat similarly, “transferability” was never particularly important (3.0 to 5.7 range in average score), perhaps indicating that this criterion relates more to extrapolation of actions to other species at other places rather than the specific focus here on WML mainly in the SCR. In general, it is from among such criteria that do not score highly that a few deletions might be considered. Fewer criteria can simplify analysis and communication by increasing the focus on the more important criteria.

Management Action Performance Estimates

A summary of predicted performance scores for each of the 27 management actions based on the 9 evaluation criteria is provided in Table 4. As a visual aid, scores of 3.5 or higher (moderately high to high) have been highlighted. Thus for example, actions R, S, U, V, W, and X can be readily identified as the higher performing actions with respect to evaluation criterion 1, “slow zebra mussel dispersal.” Space limitations make it difficult to include criteria and management action labels in the column and row headers. Thus, a key to action and criteria lists is provided in the notes at the bottom of Table 4.

Some patterns are apparent upon inspection of Table 4. For example, the higher performing actions with respect to criterion 1, “slow zebra mussel dispersal,” tend to be those actions that are essentially designed for such a purpose. Namely, boat inspection and cleaning, restriction of upriver boating, stronger laws and enforcement, public awareness and education, and risk identification of upper lakes are high scoring management actions with respect to slowing dispersal. Conversely, none of these actions score well with respect to relieving infestation pressure or increasing WML population resistance.

Different actions scored well for other criteria that reflected goals more aligned with alleviating infestation pressures. For example, relocation of mussels to less-threatened SCR sites or sites in other rivers both scored highly based on criterion 2, “relieve infestation pressure.” Similarly, juvenile seeding of new SCR sites, development of mass rearing capability, reservoir operations to improve WML habitat and condition, and establishment of sanctuary zones all scored moderately high based on criterion 3, “increase SCR WML population resistance.” Not surprisingly, relocating WML to other rivers or seeding other rivers with juveniles score highly with respect to criterion 4, “increase WML species resistance.” In essence, this criterion directly reflects the goal of increasing the distribution of WML in the species’ historic range.

Only one management action never scored moderately high (greater than or equal to 3.5). This action was "Z," invasive predator management. However, several actions scored moderately high only for evaluation criteria that also never were weighted especially high. In general, criteria 1-4 had high importance weights under at least one of the ZM threat conditions (Table 3); criteria 5-8 tended to have lesser importance weights under any threat condition. Those management actions that scored moderately high only for one or several of the less important criteria tend to be actions that can be considered for elimination if this analysis is done iteratively to narrow focus to fewer actions and criteria.

A wide array of many different kind of management actions scored highly with respect to many of the consistently lower weighted criteria (e.g., cost efficiency and practicality (criterion 7); minimize legal complications (8), and transferability (9)). Thus, these criteria tended not be very good discriminators.

In general, participant's views were uniform. The ratio of the standard deviation-to-average score rarely approached 1, and was nearer to 0.5 in most instances. There was a high level of agreement as to the expected performance of particular actions with respect to particular criteria.

Multi-Criteria Decision Analysis Results

Multi-criteria decision analysis integrates the performance scores with the importance weights assigned to the evaluation criteria. Essentially, criteria weights are normalized as are performance scores, then the normalized weights and scores are multiplied. The products are summed (for all criteria) to arrive at a "decision score" for each management action – on a scale in which decision scores mathematically can range from 0 to 1. Because the evaluation criteria were weighted differently for the three ZM threat conditions, decision scores are considered separately for each threat condition. Table 5 summarizes the decision scores for each action under each threat condition *(Note-standard deviations of scores yet to be determined and not yet included in Table 5 or indicated in Figures 1-3).*

Under a low ZM threat, seven management actions had normalized scores of greater than 0.5, the score at which a graphical portrayal showed a break in the distribution of decision scores (Figure 1). In rank order, these highest scoring management actions under a low threat were: U, restrict upriver boating; S, boat inspection and cleaning; V, stronger laws and enforcement; W, public awareness and education; R, reservoir drawdown; X, upper lakes risk identification; and Q, reservoir operations to expose ZMs in the tail water. These results are somewhat intuitive, as most of the actions directly aim to slow dispersal of ZMs. However, both of the reservoir-related action scores are not as intuitive. Presumably, reservoir drawdown (action R) and tail water drawdown (Q), were thought of by many participants as useful actions for aiding in the monitoring and rapid response to initial colonization of critical locations by ZMs.

Perhaps not surprisingly, under a moderate ZM threat condition, MCDA results were more muddled (Figure 2). There were no clear winners or losers among the management actions, but rather a more or less continuous spread of scores between rather narrow ranges of slightly greater than 5 to slightly greater than 3. Nonetheless, the seven top-scoring actions were W, S, U, R, N, C, and V (all with scores just greater or just lesser than 5.0). These actions, in rank order from higher to lower, include public awareness and education (W), boat inspection and cleaning (S), restriction of upriver boating (U), reservoir drawdown (R), develop mass rearing capability (N), relocate WML to less-threatened SCR sites C, and stronger laws and enforcement (V). Thus, the highest scoring actions under a moderate threat scenario are aimed both at slowing dispersal (W, W, U, R, and V) and at actions to overcome actual infestation effects (N, C).

Under a high threat scenario, decision scores showed somewhat greater distinctions among management actions (Figure 3) than under the moderate threat condition. Scores for action C, relocated WML to less-threatened SCR sites, and action D, relocate WML to sites in other rivers, both stood out as reasonably clear "winners" compared to all other actions. Both had scores of approximately 5.5. Only one other action, N, develop mass rearing capability, scored higher than 5 under the high threat scenario. Thus, the higher scoring options given the high threat condition were those aimed at removing adult WML or seeding juvenile WML in less-threatened locations – in the SCR and elsewhere.

Risk Setting

Obviously, invasion of the St. Croix River by ZMs is not the only risk faced by WML. The following factors were listed as additional risks to the WML. No attempt was made to prioritize this list.

- Pharmaceutical compounds in the water (such as hormones that are known to affect fish populations)
- Asian carp
- Human poaching of mussels, including WML
- Chemical spills
- Sewage inflows
- Fish hatchery discharges
- Non-point source water pollution
- Construction impacts
- Recreation impacts

- Adverse impacts of hydropower operations
- Global climate change
- Other potential invasives (e.g., quagga mussels, New Zealand mud snails, fish diseases)
- Sedimentation
- Land use changes.

Summary

This initial use of an MCDA approach is one that can be used to inform WML management decisions in response to ZM threats. A caveat that must be stated concerning MCDA is that decision scores are intended to inform but not dictate decisions. As was the case in this effort, when several management options score similarly in an MCDA analysis, choices among them might be made based on considerations not strictly reflected in the decision model that MCDA provides.

Now that participants have gained basic familiarity with the process and initial results, it might be useful to reconsider the management actions, evaluation criteria, and performance estimates and estimation process. Greater focus is often achieved with an iterative process. A reduced list both of actions and criteria, along with greater clarification of certain actions and criteria, might be of benefit.

Regardless, several outcomes are important and will probably stand. First, assumptions concerning the ZM threat condition are crucial. The importance weights given to different evaluation criteria change substantial as one move from one threat condition to another. Given the high level of uncertainty surrounding future conditions of ZM threat in the SCR, the pattern of differences among threat levels is worth considering. Emphasis should be on those more preventive actions aimed at slowing ZM dispersal until infestation levels are sufficient to warrant management actions aimed more at palliative or rescue objectives.

In the meantime, continued advancement of management options via research would be a wise investment of time and resources. It is clear that if high threat conditions prevail, then relocation efforts using both adults removed from threatened to less threatened sites will be the main avenue of desired response. This is likely to involve both adult and reared juveniles, if an adequate juvenile rearing capability can be developed.

It is important to note that these results are based on inputs of a group mostly of biologists, ecologists, and resource managers that have long been invested in monitoring, field and laboratory studies, and conservation-oriented management activities related to WML and other endangered mussels. Other stakeholders, representing commercial, recreation, and power industry interests were not part of this particular effort. Results should be viewed in light of that relatively narrow stakeholder focus, as well as the broader risk setting in which management actions must be considered.

Despite the essential similarity of perspectives among this stakeholder group and a focus only on ZM-related management, there was high diversity and complexity in both the management actions and evaluation criteria. MCDA is a tool that attempts to untangle a complex decision process in a manner that improves a common understanding of critical factors affecting a decision and the decision options, and makes communication simpler and more direct. Hopefully, the result of this initial use of MCDA will focus continued communications of this group on the most salient factors affecting and options available to manage WML in reaction to the ZM threat.

Continuing Effort

A full report and analysis of the MCDA results will be made available in the next few months. This report will include analyses of relationships criteria-specific performance scores. When such scores are strongly correlated, there is the opportunity to refine and simplify the decision model by eliminating criteria that are not sufficiently distinct and independent. In addition, the overall decision scores for all management actions under a particular threat scenario will be compared to the performance scores for those actions according to each evaluation criterion. These comparisons will help identify potentially redundant criteria, a few management actions of minor consequence, and the principal factors contributing to preferences among management actions as indicated by their high decision scores.

The more fully anis report will suggest particular decision model changes that may need to be considered by the workshop participants based on a more full analysis of the initial model.

Table 1. List of participants in 13-14 January 2009 decision support workshop for WML management in response to ZM threat, Crowne Plaza Hotel, St. Paul, MN.

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Note: Persons indicated in italics did not participate in evaluation criteria weighting or performance scoring of management alternatives.

Table 2. List and description of evaluation criteria used to evaluate management actions to protect WML from ZM infestation effects.

Evaluation Criterion	Narrative Description
1. Slow ZM dispersal	Ability to slow the dispersal of ZMs from presently infested to uninfested waters or to reduce rate of increase in infested waters.
2. Relieve infestation pressure	Ability to reduce or counteract negative physiological or ecological effects of ZMs on WML.
3. Increase population resistance	Ability to physiologically strengthen individual WML or demographically enhance the WML population in the SCR to better withstand negative effects of ZM infestation.
4. Increase species resistance	Ability to demographically or otherwise enhance WML in a spatial context larger than the SCR.
5. Minimize adverse impacts	Ability to minimize risk of undesired consequences, especially to WML.
6. Demonstration status	Degree to which a management actions has been shown to be efficacious.
7. Cost effective and practical	Cost effectiveness and practicality of both implementation and maintenance.
8. Minimize legal issues	Degree to which burdensome or difficult legal issues are minimized.
9. Transferability	Ability to extrapolate and use actions in other places for other species.

Table 3. Summary of importance weights assigned to nine criteria for evaluating performance of potential management actions for each of three conditions of zebra mussel infestation threat to the *Quadrula fragosa* population in the St. Croix River. Averages and standard deviations are computed from separate assignments of weights by 15 participants.

Evaluation Criterion	Zebra Mussel Threat Condition					
	Low		Moderate		High	
	Avg.	S.D.	Avg.	S.D.	Avg.	S.D.
1. Slow ZM dispersal	33.3	17.2	12.9	9.6	4.9	9.0
2. Relieve infestation pressure	8.1	9.2	19.4	11.4	30.3	16.5
3. Increase population resistance	19.1	12.9	22.2	14.1	19.9	11.0
4. Increase species resistance	7.8	5.5	14.0	9.1	18.3	15.9
5. Minimize adverse impacts	10.4	11.8	6.7	5.9	5.3	4.8
6. Demonstration status	5.6	6.2	4.0	3.4	6.7	5.9
7. Cost and practicality	8.2	7.0	5.9	5.2	6.5	6.2
8. Minimize legal issues	3.3	4.7	8.3	15.3	3.1	4.8
9. Transferability	3.7	4.0	5.7	4.6	3.0	3.7

Table 4 Predicted performance of 27 management actions based on 9 evaluation criterion. Averages are based on separate assignments of performance scores by 15 participants; scores were assigned using a qualitative scale of 1 (worst) to 5 (best). Highlighted scores are those of 3.5 or greater.

Action	Evaluation Criterion																	
	1		2		3		4		5		6		7		8		9	
	Avg	S.D.	Avg	S.D.	Avg	S.D.	Avg	S.D.	Avg	S.D.	Avg	S.D.	Avg	S.D.	Avg	S.D.	Avg	S.D.
A	1.0	0.0	2.8	1.4	2.9	1.4	2.4	1.4	3.1	0.9	3.9	1.1	3.7	1.2	4.7	0.6	4.2	1.3
B	1.1	0.5	2.9	1.5	2.5	1.5	2.0	1.2	3.0	0.7	3.9	1.2	3.8	1.0	4.7	0.6	3.9	1.5
C	1.1	0.5	3.7	1.3	2.9	1.4	2.5	1.5	2.9	0.6	3.9	1.0	3.3	1.1	4.3	0.8	3.9	1.5
D	1.1	0.5	3.6	1.3	2.1	1.2	3.7	1.3	3.0	0.9	3.5	1.1	3.5	1.0	3.5	1.2	4.1	1.1
E	1.3	1.0	3.4	1.4	2.5	1.5	3.1	1.3	2.7	0.8	2.8	1.1	2.2	0.8	3.3	1.2	4.3	0.8
F	1.2	0.8	3.3	1.4	2.3	1.3	2.3	1.3	2.7	0.7	2.7	1.1	2.3	0.7	3.3	1.2	3.9	1.2
G	1.2	0.8	2.9	1.5	2.2	1.4	2.5	1.4	2.7	1.0	2.7	1.0	2.5	1.0	3.2	1.3	4.0	1.4
H	1.1	0.5	2.7	1.5	1.9	1.4	2.1	1.5	2.4	0.9	2.7	1.4	2.5	1.1	3.4	1.5	3.7	1.4
I	2.4	1.2	2.9	0.9	2.3	1.3	2.0	1.3	2.3	0.9	2.0	0.9	1.9	0.8	2.1	1.2	3.9	1.4
J	1.4	1.1	1.5	1.0	1.3	0.6	1.7	1.0	2.8	1.4	2.6	1.4	2.7	1.4	3.4	1.3	4.1	1.2
K	1.0	0.0	2.1	1.2	3.5	1.1	2.3	1.1	3.5	1.1	3.1	1.3	3.0	1.1	3.7	1.1	3.9	0.9
L	1.0	0.0	1.8	1.1	3.4	1.3	2.3	1.2	2.9	1.2	2.9	1.3	3.1	1.1	3.9	1.1	3.9	0.9
M	1.0	0.0	2.3	1.5	2.4	1.7	3.5	1.3	3.9	0.9	3.2	1.4	2.8	1.2	3.3	1.0	3.7	1.1
N	1.0	0.0	2.4	1.5	3.6	1.4	3.7	1.2	4.0	0.9	2.9	1.2	2.7	0.9	3.8	0.9	4.0	1.3
O	1.5	0.9	1.7	0.7	3.9	0.8	2.3	1.4	3.2	0.7	2.8	1.0	3.2	1.1	2.9	0.6	3.2	1.1
P	1.5	0.7	1.9	0.7	3.9	0.9	2.3	1.3	3.3	0.7	2.4	1.1	3.1	1.1	2.9	0.7	3.1	1.2
Q	3.1	1.3	3.3	1.0	3.0	1.4	1.8	1.1	2.7	0.8	3.1	1.2	3.5	1.2	3.1	0.6	3.3	1.0
R	3.5	1.3	3.2	1.2	3.1	1.4	1.8	1.1	2.9	1.1	3.3	1.2	3.7	1.2	3.2	1.0	3.3	0.9
S	4.3	0.7	2.6	1.6	2.1	1.3	2.1	1.4	4.8	0.4	4.3	1.0	3.7	1.1	4.0	1.3	3.7	1.4
T	3.3	1.4	2.4	1.5	1.9	1.4	1.9	1.1	3.9	1.1	2.7	1.3	1.7	0.7	2.2	0.9	3.2	1.4
U	4.5	0.9	2.7	1.6	2.5	1.6	1.7	1.1	4.5	0.9	4.1	1.1	3.6	1.2	3.2	1.1	3.0	1.3
V	4.0	0.9	2.3	1.4	2.5	1.6	2.3	1.4	4.4	0.9	3.8	1.1	3.5	1.4	2.8	1.4	3.7	1.1
W	3.5	0.6	2.3	1.3	2.5	1.5	2.3	1.3	4.6	0.6	4.0	0.9	4.3	0.7	4.6	0.7	3.9	1.1
X	3.5	1.2	2.1	1.4	2.1	1.5	1.6	1.2	4.5	1.1	3.6	1.4	4.0	0.9	4.5	0.9+	3.5	1.4
Y	1.3	0.9	1.3	0.5	3.4	1.2	3.1	1.2	3.9	0.9	3.0	1.1	2.9	1.1	3.3	1.0	3.3	1.1
Z	2.3	1.3	2.3	1.3	2.1	1.3	2.1	1.2	2.4	1.2	2.1	1.1	2.1	1.1	2.4	1.4	3.3	1.3
AA	1.7	1.2	1.9	1.2	3.5	1.0	2.7	1.4	3.9	1.0	3.1	1.3	3.7	1.0	2.9	1.2	3.7	1.1

Management Actions:

A. Clean and replace
B. Relocate, aggregation area in SCR
C. Relocate, lesser threat SCR sites
D. Relocate, sites in other rivers
E. Relocate, engineered refugia
F. Relocate, SCR hatcheries
G. Relocate, other hatcheries
H. Relocate, ponds
I. Selective biocides
J. Cryogenic preservation
K. Juvenile seeding, new SCR sites
L. Juvenile seeding, SCR pop
M. Juvenile seeding, other rivers
N. Develop mass rearing
O. Reservoir ops, improve WML habitat
P. Reservoir ops, improve WML condition
Q. Reservoir ops, expose ZMs
R. Reservoir drawdown
S. Boats, inspect&clean
T. Heat station in UMR
U. Restrict upriver boating
V. Stronger laws&enforcement
W. Public awareness&education
X. Upper lakes risk ID
Y. Improve host fish pop.
Z. Inavisve predator management
AA. Sanctuary zone(s)

Evaluation Criteria:

1. Slow ZM dispersal
2. Relieve infestation pressure
3. Increases SCR WML population resistance
4. Increase WML species resistance
5. Minimize adverse consequences
6. Demonstration status
7. Cost efficiency and practicality
8. Minimize legal complications
9. Transferability

Table 5 Decision scores for 27 management actions assuming a low, moderate, and high threat condition. Decision scores integrate weights assigned to the evaluation criteria under each threat scenario (see Table 4) with the predicted performance of each management action with respect to each criterion (see Table 5). Scores of 0 and 1 representing the lowest and highest possible, respectively.

Management Action	Decision Score		
	Low	Moderate	High
	Average	Average	Average
A–Clean and replace	0.37	**0.47**	**0.48**
B-Relocate to SCR aggregation area	0.35	0.44	**0.45**
C-Relocate to less-threatened SCR sites	0.38	**0.51**	**0.54**
D-Relocate to sites in other rivers	0.36	**0.48**	**0.54**
E-Relocate to engineered refugia	0.33	**0.45**	**0.48**
F-Relocate to modified SCR hatcheries	0.29	0.39	0.42
G-Relocate to other modified hatcheries	0.29	0.38	0.40
H-Relocate to ponds	0.25	0.33	0.34
I-Treat with ZM-selective biocides	0.34	0.36	0.36
J-Cryogenic genome preservation	0.22	0.25	0.21
K-Seed additional SCR sites with juveniles	0.36	0.44	0.42
L-Seed existing SCR population with juveniles	0.33	0.41	0.38
M-Seed other rivers with juveniles	0.33	0.42	0.43
N-Develop mass rearing capability	0.40	**0.50**	**0.51**
O-Reservoir operations to improve habitat	0.39	0.42	0.40
P-Reservoir operations to improve mussel condition	0.38	0.42	0.41
Q-Discharge reduction to expose tailwater ZMs	**0.50**	**0.48**	**0.47**
R-Reservoir drawdown to expose ZMs	**0.54**	**0.51**	**0.49**
S-Boat inspection and cleaning	**0.64**	**0.52**	**0.47**
T-Heat-treatment station in UMR	0.42	0.35	0.33
U-Restrict upriver movement of boats	**0.64**	**.051**	**0.46**
V-Strengthen laws and enforcement	**0.60**	**0.50**	**0.45**
W-Public awareness and education	**0.59**	**0.53**	**0.47**
X-Upper lakes risk identification	**0.54**	**0.46**	0.38
Y-Improve host fish populations	0.37	0.41	0.39
Z-Improve predatory invasive fish populations	0.32	0.32	0.31
AA-Establish sanctuary zone(s)	0.44	**0.46**	0.44

Figure 1. Decision scores for each management action under the low ZM threat condition, showing relative contribution of each evaluation criterion.

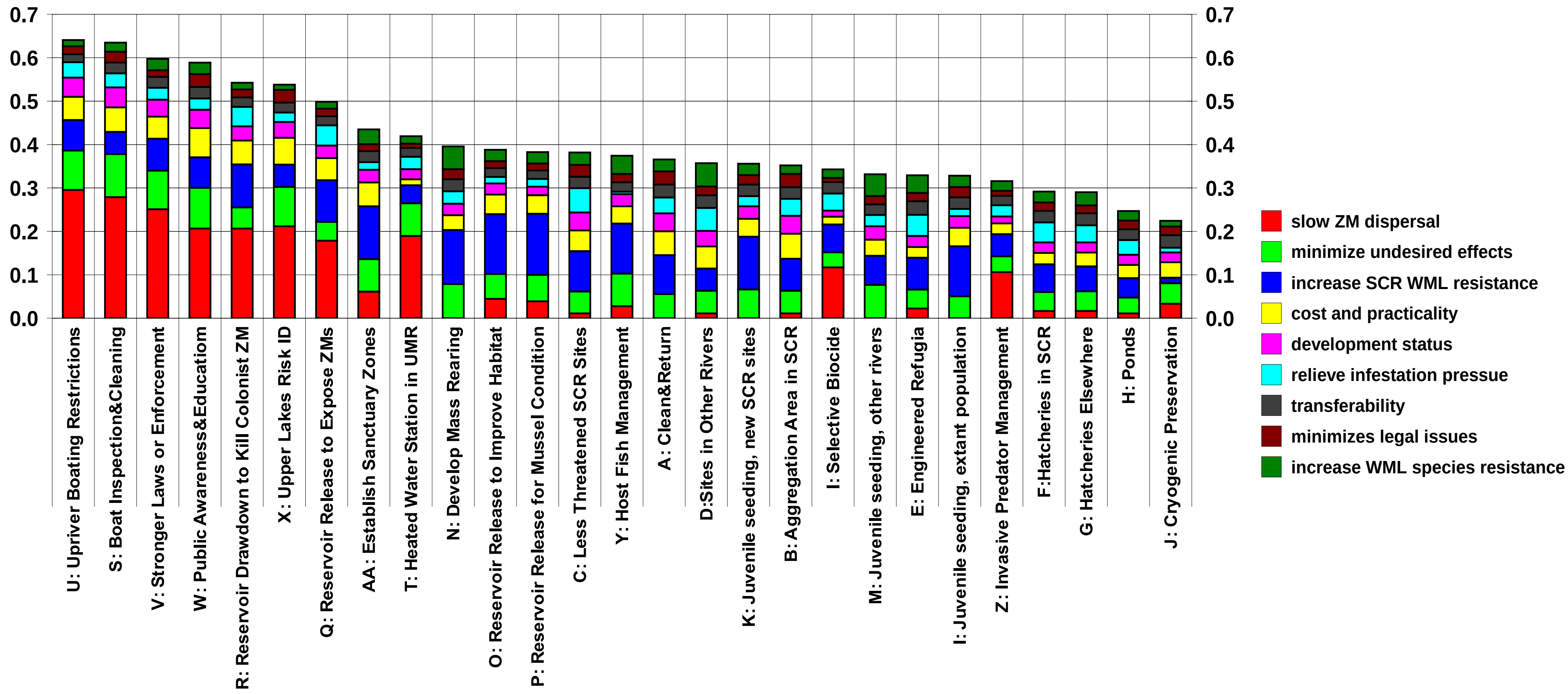

Figure 2. Decision scores for each management action under the moderate ZM threat condition, showing relative contribution of each evaluation criterion.

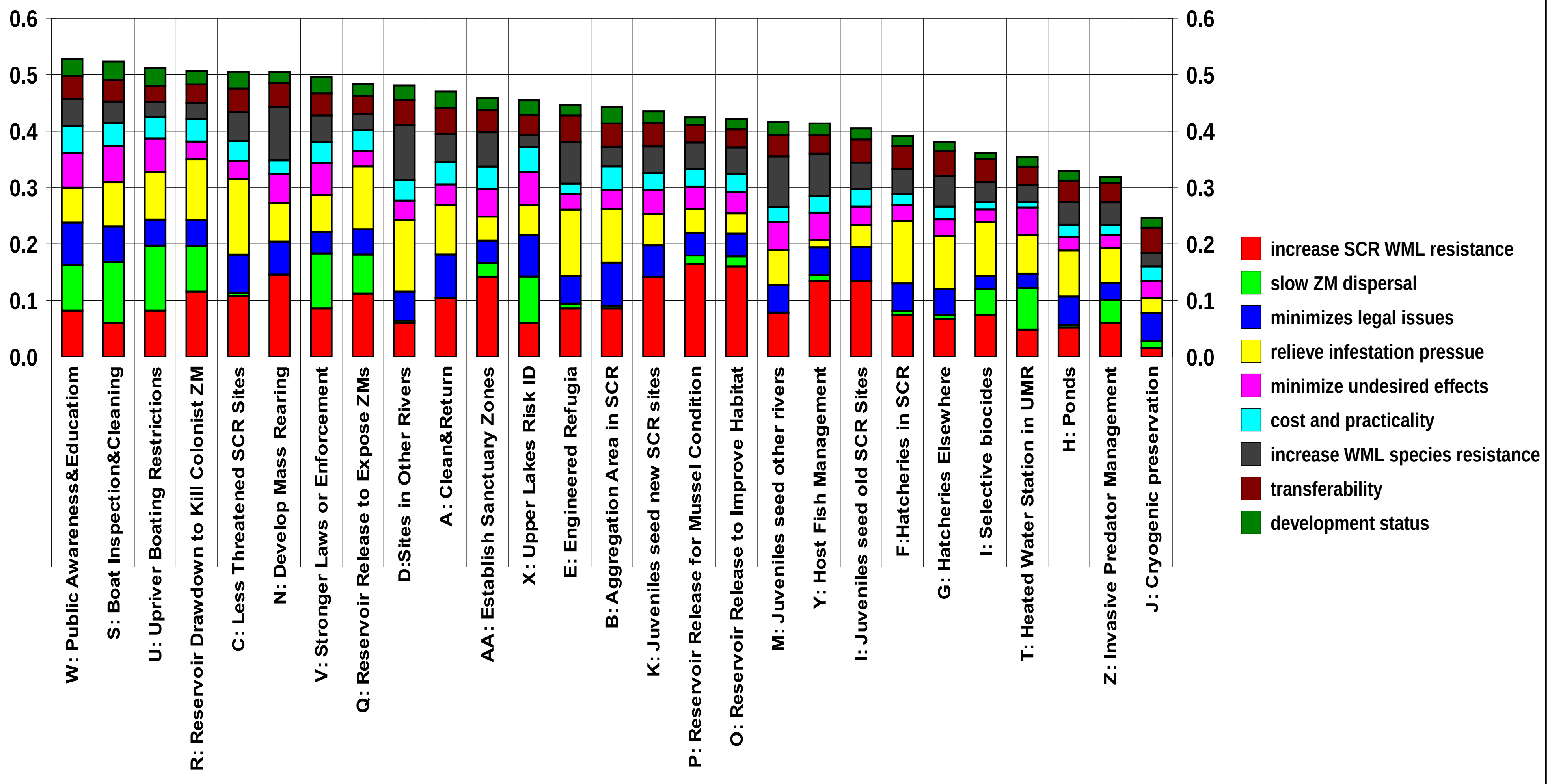

Figure 3. Decision scores for each management action under high ZM threat scenario, showing relative contribution of each evaluation criterion.