Forthcoming in *Environmental Values* ©The White Horse Press http://www.whpress.co.uk

Avoiding the invasive trap: policies for aquatic non-indigenous plant management

Paul Radomski and Donna Perleberg
Minnesota Department of Natural Resources, 1601 Minnesota Drive, Brainerd, MN, 56401, USA.

Address for correspondence: paul.radomski@state.mn.us

ABSTRACT

Many aquatic invasive species (AIS) management programs are doing important work on preventing non-indigenous species movement to our wild places. Attitudes and perspectives on aquatic non-indigenous species and their management by ecologists and the public are fundamentally a question of human values. Despite eloquent philosophical writings on treatment of non-indigenous species, management agency rhetoric on 'invasive' species usually degenerates to a good versus evil language, often with questionable results and lost conservation dollars. We assess and learn from an established AIS program. We discuss an ethic framework and operational directives to minimize the trap of a binary classification of species into bad or good, and we advocate for a principled pragmatic approach to minimize conflicts. We make a case for not labeling species and instead focusing on managing nuisance conditions and protecting ecosystem health.

KEYWORDS: invasive species, indigenous species, non-native aquatic plants, management policy

INTRODUCTION

Natural resource management should continuously evolve and that evolution should be based on ethical behavior and good governance. In the last 30 years, many agencies have initiated and expanded management of aquatic invasive species (AIS). The purpose and focus of this biopolitical initiative have shifted in response to professional and public perceptions, funding, and new aquatic species arrivals. New philosophies and approaches are emerging from decades of lessons learned and with the recognition that we live in a changing, global environment (Cordell et al 2016).

There is a wide continuum in the range of non-indigenous species management policies, from acceptance of some species as naturalized to killing offending organisms at high cost (Marris 2013). Ecologists disagree on non-indigenous species management policies and often take offense with each other in the scientific literature (Schlaepfer et al. 2011, Richardson and Ricciardi 2013). These debates sometimes appear to be misplaced and unproductive. There are several reasons for the debate: limited resources, uncertainties in ecological impacts, and the language used by management agencies. Management agencies often use the language of war in their communications (Larson 2005). War language divides nature into two groups – good or bad species. Such language is used and deemed more effective to alert citizens on the seriousness of accidental transport of non-indigenous species and to motivate agency staff and citizens on virtuous actions with regard to natural resource management. Some ecologists have reacted strongly at the language used and the consequences of using such language on public understanding, actions taken, and funding provided (Davis et al. 2011, Schlaepfer et al. 2012, Fall 2014, Bach and Larson 2017). Colautti and MacIsaac (2004) propose a neutral terminology and, like other proposals for classifying species, the adoption of their terminology has generally been unsuccessful.

Keulartz and van der Weele (2009) discuss the resulting professional controversies and through use of metaphors describe the continuum of attitudes toward non-indigenous organisms. They place reasonable non-indigenous policy options on a scale from low to highly altered communities of species. This approach requires individual professionals to be flexible in their views of non-indigenous species.

Attitudes and perspectives on aquatic non-indigenous species by ecologists and the public are and will continue to be fundamentally a question of human values (Qvenild 2014, Radomski and Van Assche 2014). Fall (2014) identifies the concept of biodiversity as an enigma that is a root problem of invasive species management. Nature and ecosystems continue to function, change, and evolve regardless of our policies on and management of species arrivals in the age of the Anthropocene. Humans have caused the extinction of many species with the colonization of North America (Harari 2015), and we have so altered Minnesota's lake ecosystems that defining what is natural can be quixotic (e.g., Radomski and Goeman 1995, Radomski 2006). What ecosystems should look like and how they function is open to serious question, and ecological restoration may need to shift to ecological futuration where resiliency and beauty are more important measures of success than native biodiversity (Norgaard 2016). Scientists are beginning to probe those natural resource manager values. For example, Fischer et al. 2014 investigated professional versus public attitudes on non-indigenous species in a limited context. They stated: "Professionals tended to have more extreme views than the public, especially in relation to nativeness and abundance of a species." They also found that professionals perceived non-indigenous species to be less beautiful, more abundant, and detrimental than the public. We struggle to understand why professionals find non-indigenous species less beautiful.

There are alternative policies on recent species arrivals, and several resonated with us. Davis (2009) stated:

> in instances where non-native, and even non-native invasive, species are not causing a significant harm… altering one's perspective is certainly much less costly than any other sort of management program.

Davis et al. (2011) encouraged natural resource professionals to prioritize species control efforts that mitigate the negative consequences of a species that harms something we value. Moles et al. (2012) advocated for the consideration of the long-term presence of introduced species in ecosystems. Such critics of invasion biology have been dismissed as "deniers" (Russell and Blackburn 2017) and compared to critics of global warming and child vaccination programs. We are not denying science and the consequences of non-indigenous species to ecosystems. Like Davis and Chew (2017), we are seeking "more emphasis on understanding effects and discerning functions, and less on date of arrival and place of origin."

We acknowledge that new species arrivals can alter ecosystems and may reduce or eliminate indigenous species but we recognize the complexity of this issue. While we agree that the range expansion of common carp (*Cyprinus carpio*), zebra mussel (*Dreissena polymorpha*) and other non-indigenous species are not desired, we also recognize that well-adapted species are better able to live in altered ecosystems and that with human-induced climate change, traditional concepts of ecosystems and invasive species now require discussions of space and scale (Fall 2014). We advocate for an evolution of aquatic invasive species (AIS) management.

Within the broad field of non-indigenous species management, we focus our review on the management of non-indigenous aquatic plants which is particularly difficult for several reasons. First, most new aquatic plants arrivals are recent. While human-caused introductions of terrestrial organisms have been arriving to North America since colonization by Europeans, human introductions of aquatic organisms have increased in the last 50 years, likely due to greater mobility of watercraft. Natural resource agencies have reacted to this increase in new arrivals through creation of AIS programs. Second, citizens, specifically lakeshore property owners in this context, generally don't like plants in lakes, and they typically consider all aquatic plants weeds and often make great effort to rid or reduce plants along their shorelines (Radomski 2006). It takes concerted effort of control and wisdom to go against our basic preferences and prejudices against plants in water. For non-indigenous species, especially aquatic plants, humans may find no attribute worthy of appreciation yet find no undesired attribute too trivial to ignore. The result of this stereotyping is that these species are often unconditionally blacklisted and to support that designation, false injury claims are made against them.

To avoid this absolutist trap and other pitfalls in managing invasive species, Woods and Moriarty (2001; Environmental Values Issue 10) identified five criteria to distinguish between an indigenous species and an exotic species (a non-indigenous invasive species) and then listed four policies for managing invasive species. The distinguishing criteria included human introduction, evolutionary origin, historical range, invasiveness, and integration into a community of species. We review these criteria in the context of minimizing professional conflict and avoiding simplified AIS policies within a natural resource management agency. We provide examples where the application of the criteria still left significant challenges

remaining for managers.

Our objective is to build on the four policy guidelines provided by Woods and Moriarty (2001) to create a more robust operational policy for AIS. Our review focuses on Minnesota's Department of Natural Resources (MDNR) AIS Program, and we believe a review by aquatic biologists that regularly work on these issues may help others. We emphasize non-indigenous aquatic plants given their importance on fish and wildlife habitat in lakes and their unique management challenges. We start with a description of Minnesota's AIS program, which is likely illustrative of the negative outcomes of focusing on nativeness rather than focusing in on the consequences of high abundances of organism to ecosystem health. This description is followed with a discussion of an ethical framework and practical operational directives to minimize the trap of a binary classification of species into bad or good. Throughout we make a case for not labeling species and instead focusing on managing nuisance conditions and protecting ecosystem health.

MINNESOTA'S AIS PROGRAM

The MDNR has a history of managing both indigenous and non-indigenous species that includes both intentional introductions of desired species (common pheasant, *Phasianus colchicus*) and control of undesired species (common carp). Its Exotic Species Program (hereafter referred to as the Program) began in 1991 when Eurasian watermilfoil (*Myriophyllum spicatum*) was detected in Minnesota. The Program was responsible for the management of this submerged lake plant and the wetland emergent plant, purple loosestrife (*Lythrum salicaria*). Notably excluded from the Program were non-indigenous aquatic

species that had been present in Minnesota lakes for decades and considered naturalized: common carp and the submerged plant, curly-leaf pondweed (*Potamogeton crispus*). After efforts to eradicate Eurasian watermilfoil failed, the Program reevaluated its objectives, stressed that eradication was not a cost-effective goal and emphasized that in some lakes Eurasian watermilfoil acts similar to indigenous species. The original Program also made efforts to remind the public that numerous non-indigenous have beneficial uses.

In the last decade, presumably in response to the public, the Program has taken a more aggressive approach to non-indigenous species with a specific focus on aquatic species. It has expanded in staff and funding and changed its title, with "exotic" being replaced by "invasive". There is a concerted effort to alert the public on the presence of non-indigenous organisms and the need to take action. Eradiation of non-indigenous species in a lake is often advocated as a reasonable goal and herbicide applications and other management actions are permitted in what appears to be a haphazard fashion in order to appease the public. While the public outcry seems large, we question if it has been largely triggered by these agency warnings. Lakehome owners and lake users, who often have little background in ecology, did not urge for the control of specific plants until they were alerted by people with authority that the plant was bad and did not belong in the lake.

Minnesota's more aggressive AIS policy can be illustrated with two non-native plants – one long-time non-indigenous species considered naturalized and one recent arrival. First, this shift started with control efforts directed at curly-leaf pondweed. Curly-leaf pondweed has a statewide distribution in Minnesota: found in over 750 lakes and in 70 of 87 counties. This plant is often most abundant in lakes with high phosphorus concentrations and/or poor water clarity. It provides cover for fish and invertebrates and several waterfowl species feed

on the seeds or eat the winter buds; as a perennial that acts like a winter annual providing cover during winter months when many other submerged plants are senesced. Although it originated in Eurasia, it has been present in North America since the mid 1800's (Stuckey 1979) and in Minnesota since at least 1910. The MDNR has evolved its approach from promoting its introduction into lakes that would not support indigenous species (Moyle 1937), to not managing it and calling it naturalized, to issuing permits and providing funding to lake groups for whole-lake or bay herbicide applications. Of late, the MDNR has annually permitted over 100 lake- or bay-wide curly-leaf pondweed control efforts, where no or few such efforts existed 20 years ago (Enger and Jorgenson 2016). In these efforts agency staff hoped that activities to destroy curly-leaf pondweed would create a diverse native plant community. They were often disappointed when curly-leaf pondweed returned or when coontail (*Ceratophyllum demersum*) or other tolerant aquatic plant species became abundant. Hoping for high biodiversity in lakes with poor water clarity is likely unrealistic. Many lake residents hoped that the destruction of curly-leaf pondweed would create areas free of vegetation. They were often disappointed when curly-leaf pondweed continued to exist or if another aquatic plant took its place. These and other sentiments on aquatic plants have been captured by surveys of Minnesota lakeshore property owners (Payton and Fulton 2004, Schroeder and Fulton 2013). Many control effort outcomes resulted in continual dissatisfaction, yet a continual outlay of funds.

Second, the change in AIS policy can be seen with the deliberations about what actions should be directed to the haplotype M genetic variety of common reed (*Phragmites australis*). Common reed is a native wetland grass and emergent lake plant. The species has a cosmopolitan distribution with considerable genetic variation (Lambertini 2016). The Program now targets haplotype M common reed, by issuing permits to destroy the plant.

Genetic comparisons and historical distribution data have shown that haplotype M is the most common variety worldwide and that itis the ancestral source of North America varieties. This variety was likely introduced or re-introduced by humans to North America, possibly from sources in the United Kingdom, sometime before 1910 (Saltonstall 2002, Plut et al. 2011). All common reed varieties provide critical ecosystem services including formation and stabilization of soil and lake sediments, carbon sequestration, wave attenuation, cooling of habitats, and removal of nutrient and metal pollutants from surface waters (Cronin et al. 2016). The haplotype M variety has become abundant in many areas of North America (Saltonstall 2002). It is scattered across Minnesota and conditions are such that rapid spread is likely, even with extensive management. Many agencies have control programs for common reed haplotype M variety and treatment costs are not related to management success (Martin and Blossey 2013). Control of haplotype M variety stands may be possible at the site level (Gucker 2008). However, over a dozen state agencies have failed to hold back the expansions of this variety — it continues to move across North America. Therefore, an *a priori* estimate of the probability of success would be that there is a low chance of holding the expansion back or control on a statewide basis using existing practices.

In 2012, the haplotype M variety was listed as a Minnesota restricted noxious weed thereby prohibiting the importation, sale, and transportation of their propagating parts in the state except as allowed by law. Plants on this list are considered detrimental to human or animal health, the environment, public roads, crops, livestock or other property, but because they are already widely distributed in Minnesota, management options are limited. In 2016, the Minnesota Noxious Weed Advisory Committee drafted a risk assessment to recommend the haplotype M variety for listing on the Prohibited Control list. Species on this list must be controlled, meaning efforts must be made to prevent the spread, maturation and dispersal of

any propagating parts, thereby reducing established populations and preventing reproduction and spread as required by law. The main reason cited for placing the haplotype M variety on a list requiring control was to "motivate control and containment within the state." This recommendation, which would require State and private property owners to control the haplotype M variety of Phragmites, raised many questions about why it was listed and the feasibility of control. Identifying common reed varieties require botanical experience (Swearingen and Saltonstall 2012) and varieties hybridize (Blossey et al. 2014). While common reed stands are often monotypic, this in itself does not cause environmental harm. Monotypic stands of common reed can reduce biodiversity in an area, but that is not bad in itself. While high biodiversity is often the ideal for resiliency, many unaltered ecosystems have low biodiversity — forcing high biodiversity into wild ecosystems is a flaw in reasoning (affirming the consequent logical fallacy; i.e., there are other ways ecosystems are resilient). The purpose and the goals of various common reed control projects around the state were unclear. It was unknown what the reduction of common reed stands would accomplish. The only measure of success continued to be a measure of hectares treated.

To manage objectively and pragmatically, it is important to identify the factors that determine which non-indigenous species are to be controlled. The Program defines an invasive species as:

> *a nonnative species that causes or may cause economic or environmental harm or harm to human health; or threatens or may threaten natural resources or the use of natural resources in the state.*

We elaborate on this definition and the application of a blacklisting. Several of criteria of

Wood and Moriarty (2001) are embedded in the definition. It should be noted however that the "invasive" label may 'poison the well'. When government officials attach an unfavorable label to a species, other biologists' views about the species are often discredited. We'll make a case for not labeling species.

Origin

For Minnesota, a species origin is a binary decision and is simple if evidence exists that a species was present in Minnesota before European settlement. Minnesota law states that a native species can also include organisms that naturally expanded from its historic range into the state ("naturally" is interpreted here to exclude human assistance). Determining species origin for aquatic plants can be difficult because (1) aquatic plant taxonomy and systematics remain largely based on phenotypic characteristics and genetic work to distinguish plants to the species level is recent and incomplete, and (2) this group has historically been under-collected and many aquatic plants rarely produce seeds or other structures that would survive in the fossil record. Determination of origin is based on professional judgement using existing herbarium records or, often, information on how neighboring states have classified a species.

Judgements of nativeness can also be swayed by personal biases. For many species, it is feasible to follow the noted recent increase of a plant across the continent and make a logical conclusion that it is a recent introduction. Judging nativeness is more challenging for species with disjunct distributions and species at the edge of their natural range. A good example is spiny naiad (*Najas marina*), a submerged aquatic plant species with a disjunct distribution across North America with isolated populations in the Midwest. In Minnesota, its

nativeness was in question. Wisconsin considered it non-native and supported their conclusion with anecdotal information that this species was historically planted as a wildlife food. The Program was ready to follow suite (Madsen 1999) but it realized that another Minnesota program had already classified this plant as a state-listed rare species. The initial native classification is scientifically supported by fossil records of the organism (Birks et al. 1976, Stuckey 1984). Another example is the difference in management approaches (protection versus eradication) between two submerged plants that can create recreational nuisances: purple-flowered bladderwort (*Utricularia purpurea*) and Carolina fanwort (*Cabomba caroliniana*). Both species are considered native to eastern North America with a less frequent distribution westward. Purple-flowered bladderwort was first observed in Minnesota in 1992. The plant has unique habitat requirements and has been detected in so few waterbodies that it is listed as a State endangered species. By contrast, Carolina fanwort, which has not yet been detected in Minnesota, is listed as an invasive species. These judgements are only as sound as the supporting evidence, but when in doubt, do we err on the side of labeling an organism native or invasive?

Invasiveness

The Program recognizes that both species origin and invasiveness should play a role in management. But the determination of invasiveness has been even more subjective than origin. The agency must use scientific information on the ability of a non-native species to naturalize, displace native species, and harm natural resources. This information is to include the potential to introduce disease and compete with indigenous species. Often such science has not been conducted and no findings of facts are compiled to support blacklisting. In many cases the Program has used evidence that the non-native organism has created a nuisance in

another state. As all species are capable of creating a nuisance depending on environmental conditions, such evidence can be weak.

The term invasive is problematic from an ecological perspective. Plant life history traits are often used to determine invasiveness and include growth rate, fecundity, tolerance to disturbance and phenotypic plasticity. In classic plant ecology terms, these are ruderal, colonizing, and r-strategist species (Grime 1966, MacArther and Wilson 1967, Bazzaz 1979) that can describe both native and non-native species attributes.

Harm

Environmental harm is purely a human concept. The addition of a new species to an ecosystem may or may not result in a reduction in ecosystem health or economic harm. It appears that the Program generalizes harms and files false injury claims against some species. The late conservationist Aldo Leopold recoiled on the anti-weed talk in his time (What Is a Weed; 1943). Leopold stated "we forget that no species is inherently a pest, and any species may become one." Second, to Leopold's point, if a species causes serious economic harm or threatens human health, then natural resource management agencies will manage the species whether native or not (Van der Wal et al. 2015).

By Minnesota rule, decisions on allowing the destruction of aquatic plants require that a full set of criteria and tradeoffs be considered. The rule gives guidance on how to balance control efforts to reduce nuisance conditions created by aquatic organisms for recreational users with the protection of fish and wildlife habitat. A nuisance condition is defined such that the abundance of an organism interferes with boating, swimming, or other aquatic

recreation or beneficial water use. In discussions with Program staff it was clear that the intent of the rule was not often followed and that staff issued permits only because of the presence of blacklisted species without determination of harm or presence of nuisance conditions (for reasons of appeasement of public discord or the firm belief in an eradication goal; see below).

ETHICAL FRAMEWORK

The management of invasive species may benefit from an elucidated ethical framework. We suggest the employment of the 'First, Do No Harm' principle. 'First, Do No Harm' is an important ethical principle of contemporary medicine. Medical students are educated on the moral obligation on this axiom (Edge and Groves 2005, Vaughn 2016). The origin of the 'First, Do No Harm' expression is obscure (Smith 2005), although it is generally recognized that the concept dates back to ancient Greek medical works (Hippocratic Corpus), which instructed physicians to help and to abstain from harming the sick (Hippocratic Oath). From this first ethical principle, physicians have added four prima facie moral principles: respect for autonomy, beneficence, non-maleficence, and justice (Beauchamp and Childress 2012). Physicians should respect their patient autonomy, which requires consultation and informed consent for care. They should seek net benefits with their care, and they should define for the patient the benefits and potential harms, as well as likelihood of those potential negative consequences. Justice, in the context of a reasonable scope and scale for a physician, implies fair distribution of medical resources, respect for patient rights, and the respect for the law.

The 'First, do no harm' principle applied to invasive species management may have

some benefit. In our observations on the struggles with recent arrivals, collateral damage is often not seriously considered. Control efforts may cause significant and substantial short- and long-term harm to non-target organisms. For many control projects involving Eurasian watermilfoil, curly-leaf pondweed and other non-indigenous species, we may be harming native plant communities with little benefit (Heiskary and Valley 2012, Nault 2016), and following this ethical principle would force us to think before we, perhaps, acted imprudently. In addition, it is the morally the right thing to do. Just as physicians commit to this axiom, natural resource managers could profess to commit to this moral obligation.

Many ecologists and natural resource management professionals are trained in conservation ethics, often through the discussion of Aldo Leopold's writings. Aldo Leopold's first-order principle for conservation asserts that our conduct is just if it does not harm the ecological health and beauty of place ("A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community" – Leopold 1949). Leopold provided four second-order principles for conserving nature of which three are appropriate here: our conduct should not result in the loss of ecosystem elements, our actions should be moderate and gentle in consequence, and we should care more for ecological health and beauty than economic benefits (Callicott and Freyfogle, editors, 1999; in addition, see Radomski and Van Assche 2014 for a listing of Aldo Leopold writings that supported his second-order principles).

As physicians have added four *prima facie* moral principles and consistent with Aldo Leopold's teachings, we too suggest additional considerations that focus on the potential consequences of our conduct. The right course of action against invasive species is one that advances or ensures ecosystem health in all places while striving for biological integrity

where and when appropriate. Ecosystem health and biological integrity are important conservation concepts. Callicott et al. (1999) clarified normative concepts of conservation and provided a pluralistic approach for application in natural resource management. They organized the numerous conservation concepts into two schools of conservation philosophy. One school has a worldview focused on conserving ecosystem health and the other focused on the preservation or restoration of biological diversity and integrity. Ecosystem health was defined as ecosystems undiminished in providing critical ecosystem services and resilient to perturbations, and biological integrity defined as self-sustaining communities with indigenous species composition and diversity. While they viewed these two schools as complimentary, they suggested that the conservation norms for nature reserves related best to conservation of biological integrity; whereas, the conservation norm for exploited and developed ecosystems was conservation of ecosystem health. Lake ecosystems fall on a continuum of human development, disturbance and alteration, and we advocate that non-indigenous species management recognize that striving for biological integrity is most important in low impacted lakes and in locations where a plan or management goal is to protect rare organisms.

In practice, the best decision or path is uncertain, but one could make estimates of the probability of ensuring ecosystem health and biological integrity or projections on potential consequences of various actions or no action. With any new situation, a review of the lake ecosystem and the nature of the population of the newly arrived species and a balanced and unbiased discussion could occur following the use of a devised decision tree or other decision support tool. A decision on a newly arrived species could consider the path of least ecological resistance. Metaphorically, the paths of least ecological resistance are the directions that the management agency can choose to take that are most likely to provide the easiest paths to

ensure ecosystem health and biological integrity. When a species invasiveness character is certain, the principle can be reasonably used to take proactive action to control a recent arriving organism where practical. That is to say, a failure to act to protect ecosystem health from an invasive organism would be irresponsible. However, if a species is not likely to have a pervasive negative effect on ecosystem health or biological diversity, then it seems reasonable that we shouldn't manage it at the detriment of other species or ecosystem elements. Management activities benefits should clearly outweigh the potential harms, and the harms should be minimized. While aquatic invasive plants can reduce ecosystem health (i.e., diminished ecosystem services), it appears that in Minnesota they mostly create nuisance conditions. We are unaware of any scientific studies confirming loss of ecosystem services due to an invasive aquatic plant in Minnesota; however, Heiskary and Valley (2012), in a review of Minnesota lakes with curly-leaf pondweed and lake ecology, note that it is possible that the control of curly-leaf pondweed in disturbed lakes may likely reduce ecosystem services.

An ethical foundation with a focus on consequence is in contrast that to one that has an emphasis on nativeness. In a review of literature, Simberloff et al. (2012) reported that non-native species have a greater propensity to become invasive than native species. But are ecologists just more likely to label an organism invasive because of its nativeness? Henri Tajfel, a social psychologist, found that the foundation of prejudice was the process of categorizing that lead to exaggerations of group differences (Tajfel 1970). Hansen et al. (2013) analyzed abundance data of native and non-native aquatic species. They found that nativeness was not a factor in the frequency of abundance and that the non-native species on average had higher densities than native species but the absolute difference in mean abundance was small, especially for aquatic plants. In addition, they noted that non-native

species have low abundance in most locations where they occur. Given subtle difference in abundance distributions of non-native and native aquatic plant species, it seems prudent to remove the category of nativeness as it may lead to prejudice and unethical treatment of non-native aquatic plant species and the ecosystems where they occur. We are following Switzer and Angeli (2016) in calling for an embrace of the pragmatic view of environmental ethics and abandoning the labeling of species based on nativeness and instead focusing on consequence to ecosystem health or minimizing the nuisances created by aquatic plants when appropriate.

OPERATIONAL PRINCIPLES

Clear management goals and evaluation of actions

Many AIS programs have a broad management objective to "hold back" non-indigenous species range expansions (e.g., MDNR 2009). This objective is reasonable, as it is consistent with the goal of reducing unwanted human-assisted migration. However, when this objective is applied to the strategy of killing offending organisms it often sounds heroic and inconsistent with ability or resources. With regard to many non-indigenous species, one needs to be skeptical based on known history or observations of other agency efforts. What is the probability of success of controlling a non-indigenous species? An *a priori* estimate of the probability of success may be that there is a low chance of controlling the species. In addition, the scale matters. Garrett Hardin (1985) stated: "The judgment of 'good' must be tied to scale". A plan to treat a site (a project plan) is different than a plan to eradicate a species at the scale of the state of Minnesota (a species management plan). Minnesota

manages at a project scale for new arrivals; it completes risk assessments for species, but it has not developed specific plans that are pragmatic at the state scale. Instead Minnesota requires local staff to make decisions about species at the site scale.

It is prudent for any conservation project to explicitly define the goals, objectives, and courses of action evaluated. The goals and objectives should be measurable, with success specifically defined and monitored. When ecosystem health is used in the goal or objective, an objective measure of ecological health should be used to assess that health along with sufficient monitoring to detect changes due to management. We should also measure any collateral damage our actions might produce, as it is reasonable to measure collateral damage to valuable fish and wildlife habitat and to determine if harms were minor or substantial. To be balanced, non-indigenous species goals, objectives, and intervention decisions will require a compromise with social values, costs of not intervening, costs of intervening, and benefits of each action.

We believe that we need to change the social norm related to invasives, and the continued deferment of these issues to just the Program means only one value system dominates natural resource management decisions. AIS programs must guard against becoming ideological, with practitioners being non-indigenous species fundamentalists. We must seek out professional opinion from experts with other viewpoints. Some natural resource professionals working in the AIS field wish to see no changes to an ecosystem. The reality is ecosystems change. For some lakes, we must think about moving away from maintaining past conditions with control efforts against recent species arrivals that likely can't be won. For example, perhaps once we get past the current view of non-indigenous species being predominately bad, then we can acknowledge some of the benefits of curly-leaf

pondweed and go back to how the agency used to deal with this species (i.e., management of nuisance conditions in the nearshore for individual lakehome owners). Curly-leaf pondweed may be the best aquatic plant for fish habitat in some of Minnesota's altered, polluted lakes by providing valuable ecosystem services.

For ecosystem health and protecting indigenous assemblages, the greater good may be best achieved with management goals and objectives focused on managing nuisance conditions rather than labeling a species "invasive" or "non-native". The agency would allow the reasonable control of aquatic plants, whether new or old arrival, based on clear criteria of nuisance conditions rather than on when the species arrived. Nuisance conditions would be defined by aquatic plant growth that interferes with boating and swimming that creates a burden to those users. This not only makes for good resource management, but it is also a concept easily understood by the public.

Management Principles

Species management should be based on a suite of good natural resource management principles. Control efforts should be based on a review of those principles, and the merits should not be based solely on eliminating a species because of its arrival time or cause of range expansion. Just because control of a non-indigenous organism is commonly practiced elsewhere does not make it right, just as appealing to fear of the potential consequences of a new species to an ecosystem should not prejudice us towards controlling a recent arrival. The professional social norm has again become a strong bias against ecosystem change that may be destructive to good natural resource management.

Good natural resource management principles are many. With regard to management of new arrivals, a pragmatic and operational-based plan is required to ensure due diligence in the decisions of if, when, where, and how to intervene when a recent arrival is observed. These plans should be species-specific developed with a diversity of expertise. The main purpose of a plan is to limit emotion, politics and prejudices from determining agency actions. In Minnesota, there is no plan that identifies priorities for where the natural resource management agencies will re-create or maintain the native coevolved diversity. Other principles that also should be used include adaptive management, transparency, audits of the systems used, and accountability.

Some operational principles may not be appropriate. When an organism's propensity to spread appears mostly innocuous or its character is comparable to an indigenous organism, other principles have been used as an excuse to aggressively attempt to eradicate an organism. For example, the precautionary principle was explicitly cited in taking management action on starry stonewort (*Nitellopsis obtusa*). This example may also demonstrate the bias against ecosystem change or the degree of the agency's risk aversion. Starry stonewort is a submerged plant that is easily transported by humans from lake to lake, and this macroalgae is similar to Minnesota's native Characeae. It was easy for Minnesota to justify the control of this species with the public given the inherent biases against plants in water. However, while starry stonewort has been present in North America since 1974 (Karol and Sleith 2017), no evidence existed that this plant reduces biodiversity, degrades fish habitat, or alters ecosystem health (Larkin et al. 2018). Conversely, evidence does exist that the management activities used to control this plant (application of copper sulfate products, often in combination with broad spectrum non-copper herbicides, mechanical removal and/or

dredging) can negatively impact fish habitat and ecosystem health.

Conduct cost-benefit analysis

Efforts against a species should have goals and objectives, and the courses of action should be evaluated and ranked by cost effectiveness. A fair criticism on non-indigenous species science is that investigators have published thousands of articles on how these organisms may have altered ecosystems, but more work needs to be completed on assessing social attitudes, economic values, benefits, and cost effectiveness of agency management actions (Januchowski-Hartley et al 2017). Over 50,000 non-indigenous species are in the United States and about $100 million annually are spent on non-native aquatic plant control (Pimentel et al. 2005). In the analysis of benefit:cost, what portion of those funds could be spent on more productive and lasting lake conservation investments?

We must assess cost-effectiveness and conduct benefit:cost analyses as spending on AIS does come at a cost to long-term conservation efforts (e.g., lake water quality protection, sensitive shoreland protection, etc.). In Minnesota, cost benefit analysis has been required for AIS management activities since 2009 (MDNR 2009); however, no such analyses have been conducted even though millions of dollars have been spent. After spending about a million dollars on starry stonewort, the Program did not think such analysis would help management and thought cost benefit analyses couldn't be completed due to lack of clear understanding of the benefits of past control efforts. For non-indigenous species that don't have a high probability of producing measurable economic losses, the high cost of deciding to actively manage its population may be a poor decision. As with medical ethics where justice is one of

prima facie moral principles, the management of invasive species management in the context of other conservation efforts has a responsibility to strive for a fair distribution of the limited total conservation resources and to include a serious consideration of cost effectiveness of control efforts.

Iftekhar and Pannell (2015) note common human biases as they relate to natural resource management. They speak of the planning fallacy, that is a tendency to be excessively optimistic about a project or management strategy, and that natural resource managers may be more likely to take actions even when those actions are not worthwhile (due to an action bias). They note that better agency decisions might be made if managers are asked to justify their decisions. A strategy to reduce the planning fallacy related to AIS is to ask managers to forecast the completion costs and benefits for the whole effort rather than a single treatment to kill the offending organism.

In efforts on well-adapted non-indigenous species, do conservation priorities and other natural resource management principles go unchecked and unused? What are we willing to spend today in perpetuity on non-indigenous species control or the appearance of control? What will be the cumulative costs of the often poorly defined objectives and goals for non-indigenous species management? With AIS, who will be held accountable if the control efforts fail? In the past, it appears that we just moved on to fund new efforts against the latest unwanted arrival. For example, what is the probability of success of holding back common reed variety haplotype M, what will be the collateral damage, what will be the total cost, and what will be the benefits of aggressive actions against this variety?

Proper communication

AIS communication that uses hyperbolic and biased language could cheapen nature and lead to credibility concerns. Bold claims of grievous harm across large geographical areas and warring language or anti-immigrate rhetoric may create a system of untouchables. These approaches unfairly divide nature into forces of light and darkness, good and evil, beneficial and detrimental. A species in such a worldview either belongs or does not. Use of a binary classification of species may be a sign of ecological illiteracy and intellectual laziness. A species reduced to good or bad is cheapened, just as human value is reduced from prejudices created from categorization (Tajfel 1981). Zebra mussel, starry stonewort, curly-leaf pondweed can be both beneficial or a nuisance depending on conditions and their environment, which is also the case for any indigenous aquatic organism. A species can't be reduced to a single class; things are more complex in nature. Those who try to reduce species to good or bad do real injustice to nature and to natural resource management. The language used distracts and limits pragmatic management options, and it often breeds contempt for new arrivals.

Since lakeshore owners generally don't like plants in lakes, they are predisposed to favor efforts to remove lake plants whether non-native or native. Such predispositions have implications on AIS communications and actions. First, Sunstein and Zeckhauser (2014) state "vivid images can produce palpable overreactions." Therefore, describing conditions of weedy conditions or using images of dense lake plant stands will trigger fears in lakeshore owners. AIS program communications often consciously and inadvertently spread fear by such imagery. Second, the idea of stopping or slowing an invasion of lake weeds resonates with some lake users. Finally, another problem with some non-indigenous species

communication is that it often decreases the value of species and may reduce our commitment to protecting similar species. We worry that risk assessments are not inclusive of the ecological values of non-native species (e.g., common reed regardless of the varietal designation). The various actions related to promoting the perceived "evil" nature of an organism often decreases the perceived ecological value of the organism. We have seen government staff and the public denigrating native common reed because of the application of an "invasive" label to one non-native variety of the plant. The challenge is to raise public awareness of non-native species and prevent the spread of these species without hyperbole and without communications and actions that cheapens nature.

CONCLUSION

A set of AIS management policies should attempt to be principled and pragmatic, while recognizing multiple views on non-indigenous species. The first four policies are those listed by Woods and Moriarty (2001):

(1) Continue to focus on reducing human-assisted migration of unwanted species.

When effectively targeted, these efforts minimize issues with unwanted species. Cost effectiveness analysis should occur to focus on approaches that are most effective, while consistent with citizen rights and state rules.

(2) Control efforts will only be conducted where the prospects for removal are high and the costs are low.

It is pragmatic to target species control when the statewide distribution is isolated and the individual population is very low and spatially constrained; it may be folly when it is not. If a new population is discovered where the species is observed at several locations, the unknown locations may be many. Successful reductions of individual populations have been short-lived if the target species has already become widely distributed (e.g., attempts to eradicate or control Eurasian watermilfoil from some Minnesota lakes failed when the plant recolonized, presumably from new introductions by watercraft).

(3) Actions on well-established species will be cautious and taking no action is a required consideration for all projects and a reasonable approach for naturalized species.

If a species is not substantially negatively impacting ecosystem health or things that are valued, then it is reasonable to treat the organism like a native species.

(4) There will be cases where there will be hard ethical and moral dilemmas.

Wood and Moriarty (2001) encourage exploration of multiple values to avoid the trap of oversimplifying the issue down to only one value system. If a species isn't threatening something the public values, then we shouldn't manage it at the expense of other species.

(5) We will develop species-specific management plans and a list of locations where we will attempt to maintain coevolved diversity.

The management of an unwanted non-indigenous species will be consistent with management

plans. The management plan will have goals and objectives, and the courses of action should be evaluated by benefit:cost analysis and ranked by cost effectiveness. Managers will forecast the potential completion costs and benefits for a range of likely comprehensive efforts targeting a specific organism prior to site-scale management projects. Lakes with little human disturbance will be the best places to conserve biological integrity.

(6) Site-scale management projects will conduct a local benefit:cost analysis, measure collateral damage, and minimize harms to other resources.

Control efforts will focus on nuisance conditions consistent with rules and regulations. Citizens may manage an AIS plant if it is creating a nuisance. Management actions beyond the scale of the littoral area adjacent to personal property will be dependent on consistency with other policies on aquatic plant management.

(7) Words matter, so agency staff will not use language that degrades or label species. Images matter, so agency staff will use appropriate representations of aquatic plant communities.

The language used will be neutral and science-based, which recognizes that AIS issues are really about human values that vary by individual and across time. The types of images shown will not be used to trigger fears in lakeshore owners.

We continue to advocate for the reduction of human-assisted migration of unwanted species and the recognition of the nuances and complexity of this issue that other ecologists have articulated (Davis et al. 2011). We suggested inclusion of several additional goals and principles be applied to new arrivals. We should focus on reducing the movement of

unwanted species; however, we must have the courage to challenge our actions on species that have recently arrived. And finally, we should have the wisdom to see the beauty of nature, no matter when it arrived or how it got here.

Acknowledgments

We thank Ian Chisholm for a discussion on the application of the 'First, Do No Harm' principle to non-native species management. This manuscript was improved by the reviews of two anonymous reviewers. Recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Minnesota Department of Natural Resources.

REFERENCES

Bach, T. M. and B. M. H. Larson. 2017. Speaking about weeds: indigenous elders' metaphors for invasive species and their management. *Environmental Values* **26**(5):561-581.

Bazzaz, F. A. 1979. The physiological ecology of plant succession. *Annual Review of Ecology and Systematics* **10**(1):351-371.

Beauchamp, T. L., and J. F. Childress. 2012. *Principles of Biomedical Ethics*. New York: Oxford University Press.

Birks, H. H., M. C. Whiteside, D. M. Stark, and R. C. Bright. 1976. Recent paleolimnology of three lakes in Northwestern Minnesota. *Quaternary Research* **6**(2):249-272.

Blossey, B., K. Saltonstall, and H. E. Castillo. 2014. Confirmed field hybridization of native and introduced Phragmites australis (Poaceae) in North America. *American Journal of Botany* **101**(1):211-215.

Callicott, J. B., L. B. Crowder, and K. Mumford. 1999. Current normative concepts in conservation. *Conservation Biology* **13**(1):22-35.

Colautti, R. I., and H. J. MacIsaac. 2004. A neutral terminology to define 'invasive' species. *Diversity and Distributions* **10**:135-141.

Cordell, S., R. Ostertag, J. Michaud, and L. Warman. 2016. Quandaries of a decade-long

restoration experiment trying to reduce invasive species: beat them, join them, give up, or start over? *Restoration Ecology* **24**(2):139-144.

Cronin, J. T., E. Kiviat, L. A. Meyerson, G. P. Bhattarai, and W. J. Allen. 2016. Biological control of invasive *Phragmites australis* will be detrimental to native P. australis. *Biological Invasions* **18**(9):2749-2752.

Davis, M. A. 2009. Invasion Biology. New York: Oxford University Press.

Davis, M. A., and M. K. Chew. 2017. The denialists are coming!' Well, not exactly: a response to Russell and Blackburn. *Trends in Ecology & Evolution* **2221**:229-230.

Davis, M. A., M. K. Chew, R. J. Hobbs, A. E. Lugo, J. J. Ewel, G. J.Vermeij, J. H. Brown, M. L. Rosenzweig, M. R. Gardener, S. P. Carroll, K. Thompson, S. T. A. Pickett, J. C. Stromberg, P. Del Tredici, K. N. Suding, J. G. Ehrenfeld, J. P. Grime, J. Mascaro, and J. C. Briggs. 2011. Don't judge species on their origins. *Nature* **474**(7350):153-154.

Edge, R. S., and J. R. Groves. 2006. *Ethics of Health Care: A Guide for Clinical Practice*. Clifton Park, NJ: Thomson Delmar Learning.

Enger, S. M., and M. Jorgenson. 2016. Management of rooted aquatic plants, algae, leeches, swimmer's Itch, 2015. Minnesota Department of Natural Resources Staff Report. St. Paul, MN. https://files.dnr.state.mn.us/fish_wildlife/fisheries/apm/annual_report.pdf (assessed 18 August 2018).

Fall, J. J. 2014. Governing mobile species in a climate-changed world. In J. Stripple and H. Bulkeley (eds.), *Governing the Climate: New Approaches to Rationality, Power and Politics*. New York: Cambridge Press.

Fischer, A., S. Selge, R. Van der Wal, and B.M.H. Larson. 2014. The public and professionals reason similarly about the management of non-native invasive species: a quantitative investigation of the relationship between beliefs and attitudes. *PLoS ONE* **9**(8):e105495.

Grime, J. P. 1966. Shade avoidance and shade tolerance in flowering plants. In R. Bainbridge, G. C. Evans, and O. Rackham (eds.), *Light as an Ecological Factor*, pp 187-207. Sympium of the British Ecological Society, Cambridge 1965. Oxford, U.K.: Blackwell Scientific Publisher.

Gucker, C. L. 2008. *Phragmites australis*. In: Fire Effects Information System, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, https://www.fs.fed.us/database/feis/plants/graminoid/phraus/all.html (assessed 23 October 2017).

Hansen G. J. A., M. J. Vander Zanden, M. J. Blum, M. K. Clayton, E. F. Hain, J. Hauxwell, M. Izzo, M. S. Kornis, P. B. McIntyre, A. Mikulyuk, E. Nilsson, J. D. Olden, M. Papes, and S. Sharma. 2013. Commonly rare and rarely common: comparing population abundance of invasive and native aquatic species. *Plos One* **8**:e77415.

Harari, Y. N. 2015. *A Brief History of Humankind*. New York: HarperCollins.

Hardin, G. 1985. *Filters Against Folly: How to Survive Despite Economists, Ecologists, and the Merely Eloquent*. New York: Penguin Books.

Heiskary, S., and R. D. Valley. 2012. Curly-leaf pondweed trends and interrelationships with water quality. Minnesota Department of Natural Resources Investigational Report 558. St. Paul, MN.

Iftekhar, M. S., and D. J. Pannell. 2015. Biases in adaptive natural resource management. *Conservation Letters* **8**:388-396.

Januchowski-Hartley, S. R., V. M. Adams, and V. Hermosa. 2017. The need for spatially explicit quantification of benefits in invasive-species management. *Conservation Biology* **32**(2):287-293.

Karol, K.G. and R. S. Sleith. 2017. Discovery of the oldest record of *Nitellopsis obtusa* (Charophyceae, Charophyta) in North America. Journal of Phycology **53**:1106-1108.

Keulartz, J., and C. van der Weele. 2009. Between nativism and cosmopolitanism: framing and reframing in invasion biology. In M. Drenthen, J. Keulartz, and J. Proctor (eds.), *New visions of nature: complexity and authenticity*, pp. 237-256. Dordrecht: Springer.

Larkin, D. J., A. K. Monfils, A. Boissezon, R. S. Sleith, P. M. Skawinksi, C. H. Welling, B. C. Cahill, and K. G. Karol. 2018. Biology, ecology, and management of starry stonewort

(*Nitellopsis obtusa*; Characeae): A Red-listed Eurasian green alga invasion in North America. Aquatic Botany **148**:15-24.

Larson, B. M. H. 2005. The war of the roses: demilitarizing invasion biology. *Frontiers in Ecology and the Environment* **3**(9):495-500.

Leopold A. [1943] 1999. What is a weed? In J. B. Callicott and E. T. Freyfogle (eds.), *Aldo Leopold: for the health of the land*, pp. 207-212. Washington D.C.: Island Press/Sherwater Books.

MacArthur, R., and E. O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton, NJ: Princeton University Press.

Madsen, J. 1999. A Quantitative Approach to Predict Potential Nonindigenous Aquatic Plant Species Problems. *ANS Update: News from the Great Lakes Panel on Aquatic Nuisance Species* **5**(4):1.

Marris E. 2013. The end of the invasion? *Nature* **459**(7245):327-328.

Martin, L. J., and B. Blossey. 2013. The runaway weed: costs and failures of *Phragmites australis* management in the USA. *Estuaries and Coasts* **36**:626-626.

Minnesota Department of Natural Resources. 2009. A Minnesota state management plan for invasive species. St. Paul, MN.

http://files.dnr.state.mn.us/natural_resources/invasives/state_invasive_species_plan.pdf (assessed 18 August 2018).

Moles A. T., H. Flores-Moreno, S. P. Bonser, D. I. Warton, A. Helm, L. Warman, D. J. Eldridge, E. Jurado, F. A. Hemmings, P. B. Reich, J. Cavender-Bares, E. W. Seabloom, M. M. Mayfield, D. Sheil, J. C. Djietror, P. L. Peri, L. Enrico, M. R. Cabido, S. A. Setterfield, C. E. R. Lehmann, and F. J. Thomson. 2012. Invasions: the trail behind, the path ahead, and a test of a disturbing idea. *Journal of Ecology* **100**:116–127.

Moyle, J.B. 1937. Recommendations for planting aquatic vegetation in Minnesota lakes and streams. Minnesota Department of Conservation, Division of Game, St. Paul, MN.

Nault, M. 2016. The science behind the "so-called" super weed. *Wisconsin Natural Resources Magazine* August:10-12.

Norgaard, R. B. 2016. Watch your language: power words at the human-nature interface. *Earth's Future* **4**(2):1-5.

Qvenild, M. 2014. Wanted and unwanted nature: landscape development for Fornebu, Norway. *Journal of Environmental Policy & Planning* **16**(2):1-18.

Payton, M. A., and D. C. Fulton. 2004. A study of landowner perception and opinions of aquatic plant management in Minnesota lakes. Minnesota Department of Natural Resources Project Report. St. Paul, MN. http://files.dnr.state.mn.us/eco/apm/review_reports/05a..pdf (assessed 18 August 2018).

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. *Bioscience* **50**(1): 53-56.

Plut, K., J. Paul, C. Ciotir, M. Major, and J. R. Freeland. 2011. Origin of non-native *Phragmites australis* in North America, a common wetland invader. *Fundamental and Applied Limnology* **179**(2):121-129.

Radomski, P. 2006. Historical changes in abundance of floating-leaf and emergent vegetation in Minnesota lakes. *North American Journal of Fisheries Management* **26**:932-940.

Radomski, P. J., and T. J. Goeman. 1995. The homogenizing of Minnesota lake fish assemblages. *Fisheries* **20**(7):20-23.

Radomski, P. J., and K. Van Assche. 2014. *Lakeshore Living: Designing Lake Places and Communities in the Footprints of Environmental Writers*. East Lansing, MI: Michigan State University Press.

Richardson, D. M. and A. Ricciardi 2013. Misleading criticisms of invasion science: a field guide. *Diversity and Distributions* **19**:1461-1467.

Russell, J. C., and T. M. Blackburn. 2017. The rise of invasive species denialism. *Trends Ecology & Evolution* **32**:3-6

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. *Proceedings of the National Academy of Sciences* **99**(4):2445-2449.

Schlaepfer M. A., D. F. Sax and J. D. Olden. 2011. The Potential Conservation Value of Non-Native Species. *Conservation Biology* **25**(3):428–437

Schlaepfer, M. A., D. F. Sax, and J. D. Olden. 2012. Toward a more balanced view of non-native species. *Conservation Biology* **26**(6):428-437.

Schroeder, S. A., and D. C. Fulton. 2013. Public lakes, private lakeshore: modeling protection of native aquatic plants. *Environmental Management* **52**:99-112.

Simberloff, D., L. Souza, M. A. Nunez, M. N. Barrios-Garcia, and W. Bunn. 2012. The natives are restless, but not often and mostly when disturbed. *Ecology* **93**:598–607.

Smith, M. C. 2005. Origin and uses of *Primum No Nocere* – above all, do no harm! *Journal of Clinical Pharmacology* **45**(4):371-377.

Stuckey, R. L. 1979. Distributional history of *Potamogeton crispus* (curly pondweed) in North America. *Bartonia* **46**:22-42.

Stuckey, R. L. 1984. Distributional history of *Najas flexilis, N. gracillima*, and *N. marina* (Najadaceae) in eastern North America. *The Ohio Journal of Science* **84**(2):4-5.

Sunstein, C. R., and R. J. Zeckhauser. 2014. Overreaction to fearsome risks. *Environmental and Resource Economics* **48**(3):435–449.

Swearingen, J., and K. Saltonstall. 2012. *Phragmites* field guide: distinguishing native and exotic forms of common reed (*Phragmites australis*) in the United States. United States Department of Agriculture Technical Note Plant Materials 56. Boise, ID.

Switzer, D., and N. F. Angeli. 2016. Human and non-human migration: Understanding species introductions and translocation through migration ethics. *Environmental Values* **25**:443-463.

Tajfel, H. 1970. Experiments in intergroup discrimination. *Scientific American* **223**:96-102.

Tajfel, H. 1981. *Human Groups and Social Categories*. Cambridge: Cambridge University Press.

Van de Wal, R., A. Fischer, S. Selge, and B. M. H. Larson. 2015. Neither the public nor experts judge species primarily on their origins. *Environmental Conservation* **42**(4):349-355.

Vaughn, L. 2016. *Bioethics: Principles, Issues, and Cases*. New York: Oxford University Press.

Woods, M., and P. V. Moriarty. 2001. Strangers in a strange land: the problem of exotic species. *Environmental Values* **10**:163-191.