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ORIGINAL PAPER

Determinants of rapid response success for alien invasive species in aquatic ecosystems

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Abstract Alien invasive species (AIS) have received much attention for their harmful effects on health, ecology and the global economy. In response to this threat, many countries have adopted the Convention on Biological Diversity, which requires prevention or eradication of AIS. The best management approach is prevention, however when this fails and AIS establish, it is imperative that cost-efficient, rapid-response (RR) countermeasures be available. We performed a meta-analysis of case studies involving successful and failed RR to AIS in temperate aquatic ecosystems. We examined eight variables including ecosystem type (freshwater vs. marine), method type (chemical vs. mechanical), number of methods (multiple vs. single), taxonomy (animal vs. plant), population abundance (number of organisms), infestation extent (surface area of infestation), habitat size (surface area of management site), and project duration (length of project in number of months). Eradication success was significantly greater for plant (89 %) versus animal AIS (64 %) while suppression of AIS was most successful for projects using chemical versus mechanical methods and when conducted in small habitats. Managers should expect that taxonomy will be highly influential to the success of eradication-based RR, while both method type and management surface area influence suppression outcomes.

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Introduction

Recent increases in the rate of biological invasions correspond with increasing global trade (Hulme 2009), with regions of high economic development and large landmasses being the most susceptible (Tatum et al. 2006). The threat of Alien Invasive Species (AIS) has been recognized globally, with 150 government leaders adopting the Convention on Biological Diversity (CBD) to address this growing concern (SCBD 2000). The CBD was approved December 1992 during the Rio Earth Summit and obliges signatory countries to prevent biological invasions and develop countermeasures in their territories (UNEP 1993). Many countries currently recognize rapid response (RR), which is the capacity to prevent or manage the establishment of AIS in a new location in a timely manner (McEnnulty et al. 2001), as a top priority in management plans (Waugh 2009). RR consists of eradication, controlling the spread or suppression of AIS, and is the second line of defence if prevention has failed (Locke and Hanson 2009; Dimond et al. 2010). A number of researchers have included RR when developing models or management support toolboxes. For example, Blackburn et al. (2011) highlighted prevention followed by RR measures. In addition, the Western Regional Panel (WANS 2003) proposed a methodology that relies on early detection and prevention, while having eradication plans as standby options. In many cases, however, management methods are too expensive, non-existent, or fail to eliminate the problem (WANS 2003; Hein et al. 2007). In the Great Lakes region, the U.S. government has invested more than $25 million over 25 years in attempted eradication of the gypsy moth (*Lymantria dispar*) (Tobin and Liebhold 2011), which eventually shifted to a 'slow the spread' strategy using pheromone traps and aerial spraying along the population's invasion front (Sadof et al. 2014).

RR to AIS incursions is particularly difficult in aquatic ecosystems, as pests are more difficult to detect until populations are large and/or effects more evident (WANS 2003; Reeves and Duncan 2009). The impacts of aquatic AIS can thus be paramount and success of their management not guaranteed. For instance, the macrophyte *Hydrilla verticillata* is capable of impeding water flow in canals; in Florida, infestations doubled in size over two years despite control measures that cost $6 million (WANS 2003). In the Great Lakes region and beyond, the zebra mussel (*Dreissena polymorpha*) is a biofouling nuisance and ecosystem engineer. Failsafe methods have yet to be developed for its effective removal and control is very costly (WANS 2003).

It is essential that RR strategies consider and plan for each of eradication, control-the-spread, and population suppression (Forrest et al. 2009). Development of RR strategies requires that key factors governing AIS management outcome be understood and information made readily available for end-users. However, development of robust support models for selecting different management countermeasures is a challenging problem given context dependency that includes the breadth of AIS life histories and environmental conditions where AIS may establish. In this paper, we aim to provide a quantitative foundation for the development of a general RR decision-support model that managers may consider when developing and implementing intervention programs.

A number of studies have identified factors important to success of AIS interventions, but there exists scant evidence of universal determinants of RR outcome. For example, public support, logistics or budget availability all may play key roles in RR success (Twohey et al. 2003; Woodfield and Merkel 2006; ADFG 2011). Furthermore Locke and Hanson (2009) noted that eradication is less promising in marine versus freshwater ecosystems, with successes like eradication of green alga (*Caulerpa taxifolia*) in coastal embayments near San Diego, California a notable exception (Anderson 2005). Marine environments provide introduction pathways, such as hull-fouling and ballast water release, which are more potent than most of those common to freshwater systems. Another possible factor governing RR success is whether managers employ mechanical or chemical methods during intervention. In Imperial Country, California, fluridone was used as a chemical control agent against *Hydrilla* as a more reliable and cheaper alternative to manual removal (Akers 2012). In some cases, a combination of methods appears more effective than any single treatment alone. For instance, the addition of biological control methods to augment mechanical ones were key to the successful population reduction of rusty crayfish (*Orconectes rusticus*) from Sparkling Lake, Wisconsin (US LTER 2014), and of common carp (*Cyprinus carpio*) from Centennial Park, Sydney, Australia (Centennial Parklands 2013). Species taxonomy also may influence RR success. A critical difference between animal and plant AIS is whether the target can easily evade capture, or can leave persistent propagules (e.g. seeds) that may re-establish following treatment. During the removal of signal crayfish (*Pacifastacus leniusculus*) in Scotland, for example, trapping efforts were rendered more difficult by crayfish burrowing in muddy pits, and small individuals were more evasive than larger ones (Peay et al. 2006).

Many authors have also noted that population size of AIS may have a large impact on management actions employed, and on the resulting outcome (WANS 2003). In California, managers attempted to suppress the sabellid polychaete (*Terebrasabella heterouncinata*) below a critical patch size threshold (Culver and Kuris 2000). Finally eradication of AIS can also be influenced by the size of the recipient habitat that agencies are forced to manage and the length of time that an intervention persists. For example, managers quickly realized that spread of sea lamprey (*Petromyzon marinus*) in Lake Superior was inevitable due to difficulty in detecting and capturing the entire population across an 8,000,000 ha habitat (Twohey et al. 2003). Conversely, Ferguson (2000) noted that early detection and quick action facilitated eradication of black-striped mussel (*Mytilopsis sallei*) in Darwin, Australia.

In this study, we test eight null hypotheses regarding AIS eradication and suppression success in temperate aquatic ecosystems: (i) RR success is equally effective in marine and freshwater ecosystems; (ii) chemical methods are equally effective in RR as mechanical ones; (iii) single-method management approaches are equally effective as those undertaken with multiple-method strategies; (iv) RR applied to plants has an equal success rate as that applied to animals; (v) population abundance of AIS has no bearing on success of RR programs; (vi) extent of AIS infestation has no bearing on success of RR programs; (vii) size of treated habitat has no bearing on RR success; and (viii) the duration of projects has no bearing on RR success.

Methods

Data collection

We assessed RR successes and failures via meta-analysis of published papers in peer-reviewed journals and unpublished grey literature. In order to increase access to published, as well as 'grey' literature, and to reduce publication bias, we performed a combined literature search using Google, Google Scholar, Thomson Reuters Web of Science v5.11, and speaking with other scientists between May 1, 2011 and August 31, 2013. We searched Thomson Reuters Web of Science for papers published between 1965 and 2013, with the following keywords in the 'title' section: alien, invasive, exotic, nonnative, nonindigenous, introduced, pest; and combined this search with manage*, campaign, program, eradicat*, exterminat*, eliminat*, suppress*, mitigat*, remov*, reduc*, or restor*. This search yielded 467,275 publications. To narrow down the number of studies for review, we limited results to papers in the fields of agriculture, engineering, plant sciences, environmental sciences ecology, marine freshwater biology, public environmental occupational health, science technology other topics, operations research management science, life sciences biomedicine other topics, forestry, rehabilitation, water resources, and fisheries. From our combined literature search, we screened a total of 393 published papers and reports and incorporated 89 papers (and 127 species cases), of which 70 studies (and 108 species cases) aimed at AIS eradication and a further 19 studies (with 19 species cases) at AIS population suppression. The remaining 304 studies were unsuitable as they involved survey-only, or technique trial-and-error tests, with no attempt at AIS removal.

Case studies that were categorized as involving mechanical treatment methods included any combination of dredging, drawdown, electrofishing, manual removal, raking, pond/canal lining, and/or trapping. Those involving chemical methods involved the application of herbicides, pesticides, piscicides, or other toxic substances used to eliminate AIS. We catalogued case studies as employing a single or multiple method approach based on whether the study used only mechanical or only chemical methods, or both methods. When multiple AIS were present during treatment at the same site, or when study sites were physically connected, we considered cases as independent only if the authors demonstrated that populations were physically isolated from one another or that treatments of one population had no effect on the other. We defined project duration as the length of time, in months, between the reported launch date of a management program and either the end of the final confirmation survey or the project's termination date, whichever was later. In cases where projects were still ongoing by the time that we retrieved data, we used the most recent date of project activity (surveying or removal efforts) as the end date. In cases where reports had not disclosed either dependent or independent variables, we conducted an additional Google search for the specific data, attempted to contact the authors directly, or, in cases of missing continuous variables, estimated them using Image J v1.47$^{(R)}$ software. Image J allows end-users to upload a digital image file and measure area and/or distance within plots by calibrating the software's internal pixel scale with that of a known measurement unit. This software was specifically used in instances where papers provided graphical images of data without accompanying text or numerical tables, such as bar plots of population counts, and when estimates of surface area or stream length were made, using maps.

Statistical analyses

We catalogued values for all eight factors as either discrete or continuous depending on their nature. For each of the 127 species case studies, we recorded the ecosystem type as freshwater or marine, the method type as chemical or mechanical, the number of methods used as multiple or single, and taxonomy as animal or plant. In addition, we recorded AIS population abundance in number of organisms, the infestation extent in hectares of surface area colonized by AIS, habitat size in hectares of the management site, and project duration in months. For the 108 eradication-based cases, we recorded success or failure with respect to project outcome. For the 19 suppression-based cases, we recorded the log-response ratio, R, as a measure of suppression 'effect size' for these cases (Paolucci et al. 2013). This value was defined as:

$$R = \log\left(\left[\frac{X_{final}}{X_{initial}}\right] + 1\right)$$

where X_{final} and $X_{initial}$ were population sizes (abundance or hectares affected) after and before intervention, respectively. Smaller R values indicate more successful suppression.

In turn, we performed 16 separate statistical analyses, one for each hypothesis and outcome, to assess whether or not each factor statistically influenced eradication and/or suppression success. In assessing hypotheses (i) through (iv) with respect to the 108 eradication studies, we performed either a Chi square test of independence or Fisher's Exact test if sample size was below five expected cases in any group using SPSS v.20 (Field 2009). We tested whether the proportion of successful eradications varied between groups in each of four discrete factors. The four categorical predictor variables used for hypotheses (i) through (iv) were ecosystem type (freshwater or marine), method type (chemical or mechanical), number of methods (multiple or single), and species taxonomy (animal or plant). To evaluate eradication in hypotheses (v) through (viii), we employed binary logistic regression on the same 108 cases, but we assessed the goodness-of-fit of continuous data to the logistic model using the same discrete outcome. For these hypotheses we used population abundance, infestation extent, habitat surface area, and project duration as continuous variables predicting eradication success.

For the remaining 19 of 127 species cases, where the goal was suppression of AIS populations, we used parametric tests to evaluate the same eight null hypotheses. To test hypotheses (i) through (iv) with respect to suppression success, we conducted an independent *t* test and determined whether or not the mean R values differed between groups of each discrete predictor variable. Predictor variables used were identical to those described above for eradication-based case studies. In cases where groups contained only a single case study, a one-sample *t* test was conducted, otherwise a two-sample *t* test was used. We tested hypotheses (vi) through (viii) with respect to suppression success using linear regression, and observed whether there was a relationship between suppression success rate and each continuous independent variable. Continuous independent variables used were identical to those used for aforementioned eradication-based case studies. In instances where parametric test assumptions were not met, data was transformed using a log (square root) and/or (sin) function prior to analysis. Post-hoc power analyses were performed to supplement statistical analyses, as some sample sizes were small (G-Power v.3 software; Faul et al. 2007). A summary of the factors catalogued, hypotheses tested, and tests employed is provided in Table 1.

Results

We found no relationship between the type of ecosystem (freshwater or marine) and eradication success rate ($P = 0.999$, N = 108, Power = 0.023; Fisher's Exact test). We also observed a nonsignificant relationship between method type and eradication success, although it appeared that chemical methods may be superior to mechanical ones ($P = 0.076$, N = 71, Power = 0.375; Fisher's Exact test, Fig. 1). There was no significant difference in eradication success for single versus multiple methods ($\chi^2 = 1.181$, $P = 0.277$, N = 108, Power = 0.165; Chi square test), though taxonomy was important, with eradication of plants more successful than that of animals ($\chi^2 = 9.366$, $P = 0.002$, N = 108,

Table 1 Summary of the factors, null hypotheses and statistical tests used for eradication-based and suppression-based management case studies in temperate aquatic ecosystems

Factor	Null hypothesis	Test (eradication)	Test (suppression)
Ecosystem type	Freshwater = marine	Fisher's Exact	One-sample *t* test
Method type	Chemical = mechanical	Fisher's Exact	One-sample *t* test
Number of methods	Multiple = single	Chi square	Two-sample *t* test
Taxonomy	Animals = plants	Chi square	Two-sample *t* test
Population abundance	High = low	Binary logistic regression	Linear regression
Infestation extent	High = low	Binary logistic regression	Linear regression
Habitat size	High = low	Binary logistic regression	Linear regression
Project duration	Long = short	Binary logistic regression	Linear regression

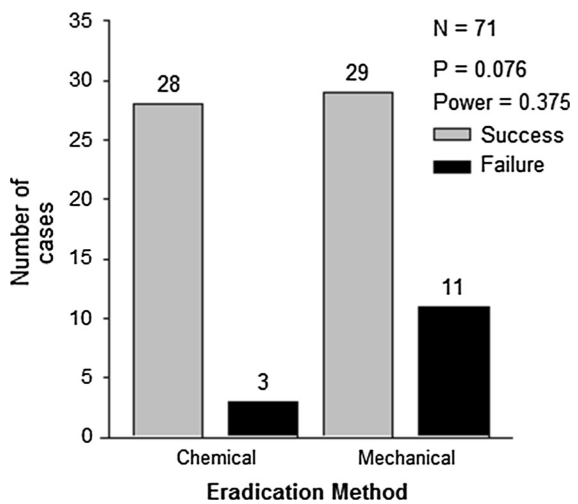

Fig. 1 Histogram of the number of successful and failed AIS eradication management case studies for chemical and mechanical methods in temperate aquatic systems

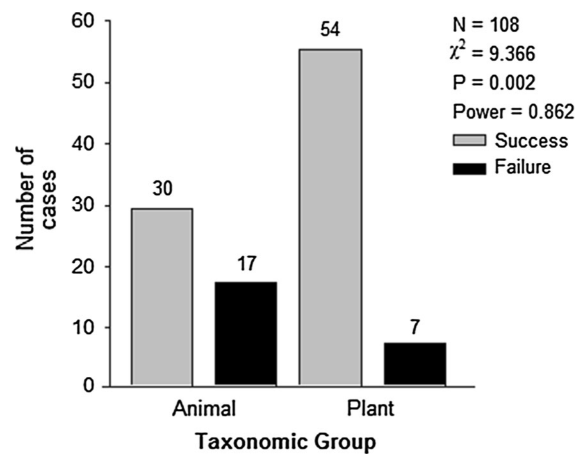

Fig. 2 Histogram of the number of successful and failed AIS eradication management case studies for animals and plants in temperate aquatic systems

Power = 0.862; Chi square test, Fig. 2). Surprisingly, eradication success was unrelated to population abundance, infestation extent, surface area or project duration based on binary logistic regression models ($\chi^2 = 1.236$, $P = 0.266$, N = 23, Power = 0.050; $\chi^2 = 1.939$, $P = 0.175$, N = 85, Power = 0.050; $\chi^2 = 0.671$, $P = 0.398$, N = 108, Power = 1.000; $\chi^2 = 1.523$, $P = 0.217$, N = 108, Power = 0.050; Binary logistic regression, respectively).

We observed no difference between mean suppression success in freshwater ($R_{freshwater} = 0.508$) and marine ($R_{freshwater} = 0.506$) ecosystems ($t_{17} = 0.019$, $P = 0.985$, N = 19, Power = 0.050; *t* test). However, suppression using chemical methods ($R_{chemical} = 0.000$) was more successful than that using mechanical ones ($R_{mechanical} = 0.462$) ($t_{17} = 4.877$, $P = 0.001$, N = 14, Power = 0.997; *t* test, Fig. 3). We also found that the number of methods that managers used had no significant effect on suppression success ($R_{multiple} = 0.943$, $R_{single} = 0.886$; $t_{16} = 1.728$, $P = 0.102$, N = 19, Power = 0.348; *t* test). Species taxonomy was not important to suppression success, as plant and animal AIS were equally suppressed ($R_{animal} = 0.507$, $R_{plant} = 0.511$; $t_{16} = -0.020$, $P = 0.984$, N = 19, Power = 0.050; *t* test).

We observed no significant relationship between suppression success and population abundance ($F_{1,12} = 1.006$, $P = 0.336$, N = 14, Power = 0.169; Linear regression), infestation extent ($F_{1,3} = 1.557$,

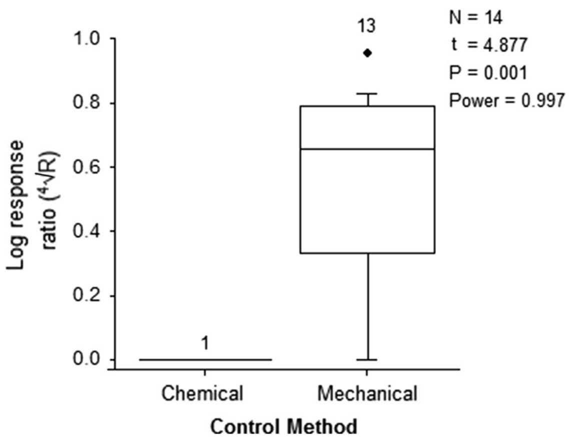

Fig. 3 *Box plot* comparing mean AIS suppression management success rate between case studies using chemical and mechanical methods in temperate aquatic systems. *Black diamond* indicates outlier value. *Lower values* of the log response ratio represent higher success

$P = 0.301$, N = 5, Power = 0.208; Linear regression), or project duration ($F_{1,17} = 0.036$, $P = 0.851$, N = 19, Power = 0.054; Linear regression). However, suppression success was inversely related to habitat surface area ($R^2 = 0.\ 243$, $F_{1,17} = 5.449$, $P = 0.032$, N = 19, Power = 0.644; Linear regression, Fig. 4), with invaders more suppressed in smaller areas.

Late in this study, we became aware of a case in Nevada County, California that originally involved suppression of *Hydrilla*, but whose objective later changed to eradication once managers recognized the opportunity to eliminate the species (see Akers 2012). Were we to repeat our statistical analysis by removing this suppression case study and adding it to the eradication database, only one of our original three results remained significant: that taxonomy significantly influenced eradication outcome (originally $P = 0.002$, now $P = 0.004$). The influence of method type on eradication also changed somewhat (from $P = 0.076$ to $P = 0.119$). In addition, the original negative relationship between habitat surface area and suppression success ($P = 0.032$) changed to non-significant ($P = 0.171$). These changes demonstrate that the suppression analyses were sensitive to low sample size.

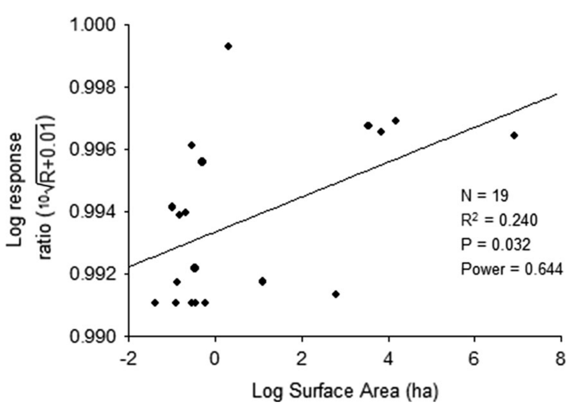

Fig. 4 Linear regression depicting the relationship between AIS suppression management success rate and habitat surface area in temperate aquatic systems. *Lower values* of log response ratio represent higher success

Discussion

Developing effective RR capabilities is a formal goal of many governments to address the growing problem of AIS (e.g. Government of Canada 2004; Forrest et al. 2009; Waugh 2009). In this study, we formally assessed a series of factors that have, in one or more studies, been proposed as predictors of RR success (WANS 2003). Efficacy of eradication efforts based on use of chemical methods did not differ significantly versus mechanical ones (Fig. 1). However, this analysis suffered from low statistical power, indicating an inflated type II error possibility associated with limited sample size. Conversely, suppression of AIS via chemical methods was significantly greater than by mechanical approaches (Fig. 3). Toxicants applied to aquatic systems will typically diffuse throughout the system, and potentially expose and affect all individuals, including those in early growth stages and those that are hiding or otherwise difficult to detect. As a result, toxicants have the potential to eliminate all reproductive or pre-reproductive individuals without prior detection by managers. Moreover, chemical methods are unlikely to leave viable fragments of individuals that may later recolonize, a critical problem in aquatic plant control via mechanical methods (e.g. *Hydrilla* in Calaveras County, California) (Akers 2012). Of the chemical eradication-based case studies we reviewed, 10 involved aquatic plants, whereas there were 20 plant cases that used mechanical removal. Similarly, when evaluating suppression success, there was only a single case of chemical intervention involving a plant AIS, and only three others involving mechanical methods. Therefore, greater eradication and suppression success rates involving chemical versus mechanical methods might be due, in part, to the larger proportion of case studies in our dataset that involved mechanical removal of immobile plant AIS.

Eradication success rate of plant AIS surpassed that of animals (Fig. 2). Sample sizes for plants (N = 61) and animals (N = 47) were fairly large in this analysis, yet chemical treatment was used for only 10 cases involving plants but in 21 cases involving animals. The discrepancy in success rate could be due to mobility of animal versus plant AIS, where many of the latter cannot escape the toxicant. In some instances, however, eradication of plants may take longer to confirm as compared to animals, leading a higher false positive rate in plant interventions (WANS 2003). For instance, eradication of *Hydrilla* took more than 20 years to achieve in several regions including Yuba, Calaveras and Imperial counties, California (Akers 2012). In all cases, the plant reappeared on at least one occasion after it was thought to be completely eliminated.

We found a negative linear relationship between habitat surface area and suppression success rate (Fig. 4), suggesting that managers succeed more often when suppressing AIS populations in smaller versus larger management areas. While this relationship may have been expected, it could in fact be driven by simpler systems, easier access, or lower total budget demand for smaller systems. In addition, when AIS occupy isolated regions of a habitat, especially when they are also immobile, less management effort is required post-detection to remove the AIS. For example, authorities attempted unsuccessfully to chemically eradicate zebra mussel from four littoral areas in Lake Winnipeg, Manitoba, Canada, the 11th largest lake on earth. Conversely, zebra mussels were chemically eradicated from a much smaller (5 ha) system, Millbrook Quarry, Virginia (VDGIF 2005). Previous work illustrated the success of this approach with black-striped mussels in Australia (Ferguson 2000) and the green alga *Caulerpa* in California (Anderson 2005).

Project duration was not a significant predictor of either eradication or suppression success in our study. Assessing the importance of project duration is, however, difficult considering that short-term projects may be short either because they succeeded quickly or were abandoned when unsuccessful. On the other hand, long-duration eradication studies are lengthy precisely because they were unsuccessful over the short term. For example, complete removal of northern pike (*Esox lucius*) from Stormy Lake, Alaska was achieved in 1 year (ADFG 2011), whereas signal crayfish trapping in Catton Park Lake, U.K. lasted 4 years before being abandoned (Peay 2001). In Kruger National Park, South Africa, long-term treatment of water lettuce (*Pistia stratiotes*) was required as the species reappeared on an annual basis (Cilliers et al. 1996).

In addition to the factors investigated in this project, there exist others that may be vital to the successful eradication and/or suppression of AIS, but which are not as commonly addressed by authors, or are difficult to measure (WANS 2003). In some studies, management sites under investigation provided limited access due to geographic barriers, making capture and/or detection of AIS more difficult. Authors sometimes overcome this obstacle by employing chemical methods rather than manual removal, such as in the control of northern pike in Lake Davis, California where piscicide was employed (Borucki 2007). Additionally, in a workshop on signal crayfish management in the U.K., several elements of successful suppression were identified, such as short contractor preparation time, effective communication between stakeholders, and preparation of a clear mission statement (Peay 2001). Public cooperation was another important factor to the effective removal of northern pike from Lake Davis (Borucki 2007). However, the factors mentioned above are not universally agreed on by authors. Moreover, factors can interact and influence management success (WANS 2003; Anderson 2005). For example, knowledge of the green alga *Caulerpa's* invasion history in the Mediterranean Sea, combined with rapid detection and budget availability, led to an extremely efficient and effective eradication campaign in California.

Although managers are mainly interested in factors that increase success rate of their projects, those that contribute to failure are also worthy of study. In all cases involving eradication of aquatic AIS that were reviewed in this study, authors made the assumption that populations were completely eliminated due to lack of detection. The post-intervention survey period was lengthy in some projects, such as in the eradication of *Hydrilla* from California (Akers 2012), where monitoring persisted over eight years in some cases.

In other cases, such as the removal of topmouth gudgeon (*Pseudorasbora parva*) from Clawford Lakes Fishery in the U.K., the outcome was deemed successful within months of intervention (Angling Times 2012). The assumption that an eradication attempt has succeeded may be erroneous if the source of propagules is unknown, as intervention may have eliminated the original population but this success could be masked by introduction of new individuals if the transmitting pathway remains operable.

Our study was limited primarily to studies published in the primary literature. Our findings could be biased if researchers are more likely to publish results when eradication or suppression studies are successful. We attempted to address this issue by incorporating as many cases from the 'grey' literature (58 species cases) as possible and from including personal communications (five species cases). Just as we may learn from factors that contribute to unsuccessful invasion events, we may benefit from a closer examination of eradication or suppression case studies that failed. Thus, there is a need for managers to officially report both successful and unsuccessful campaigns.

In conclusion, we discovered certain factors may be responsible for determining the outcome of AIS RR campaigns. Plants were more likely to be eradicated than animals and suppression of AIS was most successful when using chemical methods and in small habitats. We advise managers to expect that different factors will impact eradication and suppression efforts depending on the species involved, habitat characteristics, and the type of control method employed.

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References

Akers P (2012) The California Department of Food and Agriculture (CDFA) Hydrilla eradication program annual progress report 2012. California Department of Food and Agriculture, Sacramento

Alaska Department of Fish and Game (2011) Stormy Lake restoration project: environmental assessment. Soldotna

Anderson LWJ (2005) California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. Biol Invasions 7:1003–1016

Angling Times (2012) Fishery fined for keeping invasive species in angling lakes. http://www.gofishing.co.uk/Angling-Times/Section/News–Catches/General-News/Fishery-fined-35K-for-having-invasive-species/. Accessed 27 Mar 2014

Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP, Jarošík V, Wilson JRU, Richardson DM (2011) A proposed unified framework for biological invasions. Trends Ecol Evol 26:333–339

Borucki S (2007) Lake Davis 2007 pike eradication project. California Department of Fish and Game Pesticide Investigations Unit. http://www.cdpr.ca.gov/docs/dept/prec/2008/update_lake_davis.pdf. Accessed 18 Mar 2014

Centennial Parklands (2013) Carp eradication program. http://www.centennialparklands.com/au/__data/assets/pdf_file/0008/54548/FACT_SHEET_-_Carp_Eradication_Program.pdf. Accessed 25 Feb 2014

Cilliers CJ, Zeller D, Strydom G (1996) Short- and long-term control of water lettuce (*Pistia stratiotes*) on seasonal water bodies and on a river system in the Kruger National Park, South Africa. Hydrobiologia 340:173–179

Culver CS, Kuris AM (2000) The apparent eradication of a locally established introduced marine pest. Biol Invasions 2:245–253

Dimond PE, Mandrak NE, Brownson B (2010) Summary of the rapid response to round goby (*Neogobius melanostomus*) in Pefferlaw Brook with an evaluation of the national rapid response framework based on the Pefferlaw Brook experience. Canadian Science Advisory Secretariat Research Document 2010/036. Fisheries and Oceans Canada

Faul F, Erdfelder E, Lang A-G, Buchner A (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39:175–191

Ferguson R (2000) The effectiveness of Australia's response to the Black Striped Mussel incursion in Darwin, Australia. Department of Environment and Heritage, Canberra

Field A (2009) Discovering statistics using SPSS, 3rd edn. Sage, London

Forrest BM, Gardner JPA, Taylor MD (2009) Internal borders for managing invasive marine species. J Appl Ecol 46:46–54

Government of Canada (2004) An invasive alien species strategy for Canada. Ottawa, Ontario. 40 p. http://ec.gc.ca/eee-ias/default.asp?lang=En&n=1A81B051-1. Accessed 21 May 2014

Hein CL, Vander Zanden MJ, Magnuson JJ (2007) Intensive trapping and increased fish predation cause massive population decline of an invasive crayfish. Freshw Biol 52:1134–1146

Hulme PE (2009) Trade, transport and trouble: managing invasive species pathways in an era of globalization. J Appl Ecol 46:10–18

Locke A, Hanson JM (2009) Rapid response to non-indigenous species. 1. Goals and history of rapid response in the marine environment. Aquat Invasions 4:237–247

McEnnulty FR, Bax NJ, Schaffelke B, Campbell ML (2001) A review of rapid response options for the control of

ABWMAC listed introduced marine pest species and related taxa in Australian waters. Centre for Research on Introduced Marine Pests Tech. Rep. 23. CSIRO Marine Research, Hobart, Australia

Paolucci EM, MacIsaac HJ, Ricciardi A (2013) Origin matters: alien consumers inflict greater damage on prey populations than do native consumers. Divers Distrib 19:988–995

Peay S (2001) Eradication of alien crayfish populations. R&D Technical Report W1-037/TR1. Environment Agency, Bristol

Peay S, Hiley PD, Collen P, Martin I (2006) Biocide treatment of ponds in Scotland to eradicate signal crayfish. Bull Fr Pêche Piscic 380–381:1363–1379

Reeves GH, Duncan SL (2009) Ecological history vs. social expectations: managing aquatic ecosystems. Ecol Soc 14:8

Sadof CS, Jansen GR, Marshall P (2014) Gypsy moth in Indiana. Purdue University Department of Entomology. http://extension.entm.purdue.edu/publications/gm-1.pdf. Accessed 21 May 2014

Secretariat of the Convention on Biological Diversity (2000) Sustaining life on Earth. Montreal, Quebec. 21 p. https://www.cbd.int/doc/publications/cbd-sustain-en.pdf. Accessed 18 July 2015

Tatum AJ, Hay SI, Rogers DJ (2006) Global traffic and disease vector dispersal. Proc Natl Acad Sci USA 103:6242–6247

Tobin PC, Liebhold AM (2011) Gypsy moth. Encyclopedia of Biological Invasions. University of California, California, pp 298–304

Twohey MB, Heinrich JW, Seelye JG, Fredricks KT, Bergstedt RA, Kaye CA, Scholefield RJ, McDonald RB, Christie GC (2003) The sterile-male-release technique in Great Lakes sea lamprey management. Int Assoc Gt Lakes Res 29: 410–423

United Nations Environment Program (1993) Convention on biological diversity. Concluded on 5 June1999, 29 December 1993. UNEP vol. 1760 I–30619

U.S. North Temperate Lakes Long Term Ecological Research network (2014) Management of aquatic invasive species: rusty crayfish removal in Sparkling Lake. University of Wisconsin Board of Regents https://lter.limnology.wisc.edu/researchhighlight/management-aquatic-invasives-rusty-crayfish-removal-sparkling-lake. Accessed 15 May 2014

Virginia Department of Game and Inland Fisheries (2005) Final Environmental Assessment Millbrook Quarry Zebra Mussel and Quagga Mussel Eradication. U.S. Fish and Wildlife Service. http://www.dgif.virginia.gov/wildlife/final_zm_ea.pdf. Accessed 7 Aug 2015

Waugh JD (2009) Neighborhood watch. Early detection and rapid response to biological invasion along US trade pathways. IUCN, Gland, Switzerland 90 pp

Western Aquatic Nuisance Species Panel (WANS) (2003) Model rapid response plan for aquatic nuisance species. Prepared for the Western Regional Panel on Aquatic Nuisance Species by California Department of Food and Agriculture. http://www.fws.gov/answest/Docs/WRP%20RRP%20Final,%20Part%20II.pdf. Accessed 5 July 2015

Woodfield R, Merkel K (2006) Final report on eradication of the invasive seaweed *Caulerpa taxifolia* from Agua Hedionda Lagoon and Huntington Harbour, California. http://www.globalrestorationnetwork.org/uploads/files/CaseStudyAttachments/71_c.-taxifolia-eradication.pdf. Accessed 27 Mar 2014