**Low-probability, high-impact vector risk: behaviour and motivation for bait release by anglers**

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**Abstract – 1st order head**

Managing low-probability, high-impact (LOPHIC) risks, such as unauthorized stocking or the release of pets to the wild, is difficult because the rationale for risky behaviour is often unknown. We investigate attitudes and motivation for bait-bucket release by anglers, which is fundamentally LOPHIC due to the potential for invasions resulting from bycatch during bait harvest, and inadvertent release of non-target fishes by anglers. Using social surveys and multivariate analyses, we investigate factors contributing to bait release through perceptions about aquatic invasive species, baitfish, bait disposal, and other factors, such as social norms, convenience, public outreach, and management. Generally, angler perceptions about the risk of bait release varied, likely due to management influence, general misunderstanding about the appearance and impact of introduced species and the role of bait activity in species introductions, and the context-dependent nature of risk for a given angling event. A predictive model to classify risky vs. benign disposal behaviour was based on two variables: 1) the convenience of bait release; and, 2) the perception of released bait as a forage resource for fishes in recipient waterbodies. Results indicate that vector management will be enhanced by targeting social perceptions (i.e., the convenience and forage rationale for 70.5% of risk-takers). For a subset of vectors (29.5% of risk-takers), behaviours lacked obvious rationale; therefore, regime shifts in pathway management, such as bycatch reduction during harvest, modified commercial distribution networks, and increased reliance on self-harvested fishes at point-of-use, remains justified to offset the actions of individuals whose behaviour may never be understood with certainty and for which targeted outreach strategies are likely ineffective.

Keywords: prevention management, theory of planned behaviour, classification and regression trees, model, bycatch, fishes

**Introduction – 1st order head**

One of the most challenging aspects of vector management is accounting for rare and haphazard human activities, such as unauthorized stocking or the release of pets to the wild, which have potentially strong ecological consequences. Preventing the undesirable consequences of low probability, high-impact events (hereafter, lophic risk) is difficult, because causal understanding of the behaviour leading to such events is often lacking. Many of the greatest lophic risks result from illegal and sporadic behaviour, providing little opportunity for formal, structured analyses (Eliason 1999). Despite these difficulties, understanding the incidence and motivation for risky behaviour is critical to design practical and effective management and enforcement strategies targeting individuals who routinely participate in risky activities. Alternatively, if no clear rationale for risky behaviour exists, this too has implications for vector management.

The use of live baitfishes for angling, and the release of left-over baitfishes, is a potential vector for the introduction and spread of aquatic invasive species (AIS), should invaders be inadvertently contained within bait catches as bycatch (Drake and Mandrak 2013). To reduce the risk of species invasions due to bait activity, the release of left-over baitfishes is illegal in most jurisdictions (with some exceptions for harvesting at point of use); however, release persists regardless of the intent or existence of regulations. Social surveys have documented baitfish release rates ranging from 20% to 40% in Ontario (Litvak and Mandrak 1993, Drake and Mandrak [in review, A]), 25% in Manitoba (Lindgren 2006), and 41% is Wisconsin and parts of Michigan (Kulwicki et al. 2003). Bait-bucket transfer (i.e., the release of bait buckets inadvertently containing bycatch) has been implicated in the spread of AIS in North America and beyond (Litvak and Mandrak 1993; Mills et al. 1993; Drake and Mandrak 2010; Kilian et al. 2012), representing a classic lophic risk; the activity occurs infrequently, has high ecological consequence, and a mechanistic understanding of the behavioural motivation for bait-bucket release is lacking. The ecological risk posed by bait-bucket release is dependent on the potential for bycatch to be contained in bait catches (Drake and Mandrak 2013), the movement potential of anglers (i.e., to uninvaded waterbodies; Drake and Mandrak 2010), and risky behaviour, such as the release of bait-buckets inadvertently containing AIS (Drake and Mandrak [in review, A]). Release may also lead to the introduction and spread of aquatic pathogens (e.g., Viral Hemorrhagic Septicemia (VHS) virus in the Great Lakes; Lumsden et al. 2007). In some cases, such as self-harvest by the angler, and use of bait at point of harvest, bait-bucket release poses little risk from an AIS perspective; therefore, risk is context specific, dependent on the degree of selective fishing, angler movement patterns, and specific behaviours during angling. Drake and Mandrak (2013) modeled the incidence of AIS bycatch during commercial bait harvest, estimating relatively high capture of the invasive Round Goby (*Neogobius melanostomus*) during harvest from invaded systems (i.e., a group of 7 and 208 harvest events would result in a median probability of capture of 0.95 in Laurentian Great Lakes nearshore and tributary harvests, respectively). Despite high probabilities as bycatch, the incidence of AIS within retail tanks and angler purchases was considerably lower (median occurrence *P* = 0.0294, and *P* = 0.0147 within retail tanks and purchases, respectively (Drake and Mandrak [in review, B]; per-trip probability of purchasing a single propagule, *P* = 0.0073; Drake and Mandrak [in review, B]), indicating strong selection for target species, and removal (i.e., physical sorting) of non-target species. Traveling to an uninvaded waterbody following the purchase of invasive propagules and releasing propagules within the destination waterbody was rarer still (median trip/year probability of AIS introduction, *P* = 0.00087; Drake and Mandrak [in review, B]; however, introduction risk was non-negligible given the estimated 4.24 million yearly live bait angling events in Ontario. Given potentially strong ecological, social, and economic impacts associated with AIS establishment, bait-bucket release as a potential vector for the introduction and spread of invasive propagules remains a lophic risk and urgent fisheries management priority.

 Reducing lophic risk through management intervention requires an understanding of how current management and outreach efforts influence an individual’s behavior. Public outreach programs have attempted to educate resource users about the risks associated with the release of live baitfishes, but release rates appear to have remained relatively constant (Dextrase and MacKay 1999). The lack of success of outreach programs is likely due to several factors, but is undoubtedly influenced by misunderstanding about the behavioural motivations for participating in bait release. Like many topical management scenarios involving risky actions, there has been little progress towards a mechanistic or causal understanding of why individuals engage in certain activities, especially those involving invasive species (Strayer 2009). While there has been progress determining the relationship between human attitudes and behaviors towards wildlife (Manfredo et al. 2003), little research has been conducted linking attitudes and behaviors relevant to the spread of AIS (Strayer 2009), especially regarding the role of risky behaviour. Most established research linking attitudes and behaviors toward wildlife is unsuitable as a foundation for research on AIS. Current approaches involving the wildlife attitudes and values scale (Purdy and Decker 1989) and wildlife value orientation (Fulton et al 1996) focus on recognized benefits of native wildlife, but have no measures for attitudes and risk perception towards AIS, the benefit of behaviors that prevent the spread of AIS, or assessments of the legal aspects involved in the spread of AIS. Here, we explore the theory of planned behavior (TOPB; Ajzen 1985) for examining lophic risk attributed to bait-bucket release by anglers. The theory of planned behaviour exhibits good predictive power for forecasting behaviors in many applications by assuming that individuals are rational and process available information before undertaking certain actions (Armitage and Conner 2001). Specific actions, such as the decision to participate in bait-bucket release, are influenced by perceived behavioural control (PBC), which involves individual attitudes, social norms, and any difficulties carrying out the behaviour (Ajzen 1985). Percieved behaviour control also incorporates the degree to which an individual perceives control over their specific actions, the influence of external conditions towards certain behaviors, and the individual's ability to carry out certain behaviours (Ajzen 1985). The TOPB framework is well suited to explore risky behaviour across resource management scenarios. We incorporate TOPB to provide perspective towards the lophic risks undertaken by anglers, which will provide heightened opportunity for risk reduction during vector management.

Understanding participation in risky behaviour requires an assessment of the specific ecological, social, and economic factors likely to influence an individual’s actions. We hypothesize that an individual’s risk perception strongly influences their participation in risky behaviour; therefore, the perception of the risk of live bait angling, and AIS in general, should be strongly related to an individual’s choice of bait disposal. Because bait disposal occurs once the fishing activity has been completed, most resource users are forced to participate in disposal; however, the choice of disposal method, such as releasing or participating in legal disposal methods (e.g., deposition on land, salting or freezing, giving left-over baitfishes to another angler), is less certain. Although anglers may be concerned with the consequences their actions have towards the spread of invasive species, many introduced species are perceived by anglers as beneficial, such as the recreational Pacific salmonid fishery in the Laurentian Great lakes (*Onchorynchus* spp.; Dettmers et al. 2012), or perceived improvements in water quality following Zebra Mussel (*Dreissena polynorpha*) colonization (Yu and Culver 2000). Should individuals perceive invasive species as beneficial, or fail to recognize an association between AIS and bait activity, they may be less likely to perceive bait-bucket release as risky and would be unlikely to take actions to reduce their ecological impact. Individuals may also be concerned with the impact the disposal method has upon the bait itself. Disposing bait on land (i.e., killing it) may be interpreted as cruel, wasteful, or inconvenient, because anglers must find an appropriate place to dispose of their bait. If no designated receptacle is available, or dumping or burying bait on the shore is unattractive or inconvenient, anglers may be more likely to release their bait into the water. Anglers are governed by fisheries regulations, and releasing bait into a waterbody is often illegal act, which may further influence disposal decisions. Additionally, because management agencies provide education to anglers about the risks associated with invasive species, the degree and effectiveness of public outreach may also influence decisions surrounding disposal. To incorporate these plausible factors towards a mechanistic understanding of risky behaviour, we expand upon traditional TOPB (Fig. 1A) by incorporating attitudes relevant to live bait, bait disposal, and AIS in general (i.e., what these species represent to the ecosystem and how they are interpreted by anglers). We also incorporate the influence of management (i.e., the intent, structure, and communication of regulations), social norms, public outreach, and perceptions of convenience (Fig. 1B). The objectives of this paper are threefold: 1) to explore the theory of planned behaviour for low-probability, high-impact risks that do not fit traditional social approaches involving wildlife valuation; 2) to examine risk perception and behavioural motivations of anglers participating in bait-bucket release (i.e., do specific attitudes emerge for releasers vs. non-releasers?); and, 3) to construct a predictive model of the incidence of risky behaviour to inform outreach and risk management.

**Methods – 1st order head**

To explore factors contributing to risky behaviour, we conducted a social assessment of anglers and their attitudes towards live bait and AIS. We focused on angling in Michigan, United States, and Ontario, Canada, because of a long history of live bait use (Litvak and Mandrak 1993), large angling populations (many of whom use live baitfishes for angling; Drake and Mandrak [in review, A]), and concerns regarding the introduction and spread of AIS through bait operations. The colonization of the Laurentian Great Lakes by invasive fishes (e.g., Round Goby), invertebrates (e.g., Spiny Water Flea *Bythotrephes longimanus*), and pathogens (e.g., the viral hemmorhagic septicemia (VHS) virus) has increased concern about the potential for bycatch during harvest operations within the Great Lakes, and inadvertent purchase and release by anglers, to beyond the Great Lakes basin. To quantify factors influencing risky behaviour, we conducted a three-part analysis: 1) development of survey instruments; 2) social surveying of anglers; and, 3) statistical analysis and predictive modeling of risky behaviour.

**Quantifying Vector Characteristics through Social Surveys – 2nd order head**

The survey instrument (i.e., content of social questionnaire) was designed based on *a priori* knowledge of angling, live bait, and AIS risk, and other latent variables fitting our theoretical framework (e.g., convenience, social norms, attitudes towards AIS; Fig. 1B). To ensure that all relevant factors were considered, we also conducted personal interviews from a diverse sample of live bait stakeholders and professionals, which included management, AIS, and bait-related personnel (e.g., Michigan Department of Natural Resources, Ontario Ministry of Natural Resources, Bait Association of Ontario), conservation officers, retail shop owners, and harvesters, in Michigan and Ontario from 2007 to 2009. These interviews confirmed the importance of latent variables and allowed us to structure indicator variables (i.e., questionnaire items) towards a mechanistic understanding of risky behaviour. The following latent variables emerged:

*Attitudes towards Live Bait.*  Previous studies (e.g., Litvak and Mandrak 1993) hypothesized that anglers’ misguided attitudes towards live bait led to the release of bait, causing biased perceptions. Therefore, we examined the degree of positive and negative value associated with bait and how this may lead to risky behaviour. For example, bait release may be positively associated with providing a foraging resource for large fishes in recipient ecosystems. Proper disposal of bait on land (i.e., into the trash) may be perceived negatively, such as by wasting a resource or killing fishes in a cruel or unnecessary manner.

*Attitudes towards AIS*. Non-native species have had positive socioeconomic benefits and may be valued by anglers (Dettmers et al. 2012). General attitudes towards AIS were evaluated by examining the value that individuals place on ecosystems lacking invasive species.

*Attitudes towards Bait Disposal.*  Individual attitudes towards an act determine whether the individual is likely to participate in a certain manner. We incorporated the perceived risks associated with live bait disposal and the perceived consequences bait disposal may have on the introduction and spread of AIS.

*Convenience.* Participating in risky behaviour is often influenced by perceptions of convenience. We examined whether anglers view bait release as more convenient than proper disposal methods, such as deposition on land. We also evaluated the extent to which providing a designated area for bait disposal may impact and direct perceptions of convenience.

*Social Norms.* Social norms typically involve the social pressures to behave in a certain manner. For anglers, this pressure may be attributed to the behaviour or characteristics of fellow anglers, such as the extent to which other anglers release their bait.

*Management*. Multiple aspects of management were identified by interviewees as factors likely to influence risky angler behaviour; primarily, the effectiveness and fairness of management regulations. We also incorporated the process by which regulations are created.

*Public Outreach*. Management agencies and conservation organizations engage in outreach to increase public awareness about the impact of risky behaviour to fisheries. We incorporated the availability, usefulness, and perception of outreach materials as potentially influencing risky behaviour.

Risky angler behaviour was documented through social questionnaires, which were designed to evaluate the relative importance of latent variables contributing to bait-bucket release. Surveying was separate for Michigan and Ontario anglers because of jurisdictional differences. Both questionnaires were composed of indicator variables (questionnaire items) that were evaluated by respondents using binary (0,1) and Likert scales (strongly disagree through strongly agree; Bollen 1989). For Michigan anglers, questionnaire mail-outs were distributed following Dillman (2007), but modified to include only three mailing cycles (see Table 1 for latent variables and corresponding indicator variables within the questionnaire). A random sample of 5,000 individuals, stratified by postal district and including all licence types (resident, non-resident, senior) was identified using the Michigan Department of Natural Resources and Environment's (MDNRE) database of licensed anglers. Survey distribution began in November 2009 and continued through January 2010. The first distribution cycle included an introductory letter describing the purpose of the survey, consent information, and a hardcopy of the questionnaire. Two weeks later, a postcard was sent out to remind individuals about their participation in the survey. The third mailing, which was conducted in January 2010, included another letter and a second copy of the questionnaire. The Ontario questionnaire was sent to a random sample of 5,000 resident, licenced anglers, stratified by postal district based on the Ontario Ministry of Natural Resources (OMNR) angler database. The Ontario survey involved two mailings; the initial mailing, which included an explanation of the survey and the paper copy of the questionnaire; and, the second mailing, which included a follow-up reminder about survey participation. Content of questionnaires differed slightly because of jurisdictional requirements (see Table 1 A,B for latent and indicator variables assessed in each jurisdiction). To investigate factors influencing risky behaviour, we analyzed only those surveys with anglers indicating live bait use. We also excluded surveys containing large portions of unanswered questions, because of concerns surrounding data quality. An additional survey was conducted for members of Michigan’s Bait Industry in February 2010, also using the Dillman (2007) format. The survey was distributed to all members of the industry (less than 700 individuals) who held a license for harvesting or selling baitfishes in Michigan. The content of this survey was designed primarily to assess specific activities undertaken by licence holders to prevent the spread of AIS. Responses were open (i.e., allowed for free-form responses), but were subsequently coded on a binary scale representing the existence of preventative practices with respect to AIS. However, because the industry survey had only 163 responses with many missing response variables, we excluded industry surveys from subsequent analysis because of concerns about sample size and data quality.

**Statistical Analysis and Predictive Modeling – 2nd order head**

Following the collection of responses, we modeled the relationships between indicator variables (questionnaire items) and the smaller set of latent variables (i.e., factors identified in our modified Theory of Planned Behaviour, such as attitudes towards AIS or social norms). Relationships were modeled using confirmatory factor analysis, which is common in behavioural analysis for variable reduction and to confirm the importance and structure of latent variables (Thompson 2004). Factor analysis was conducted separately for Michigan and Ontario surveys due to different indicator and latent variables. For both surveys, responses were coded on numeric scales (-3 to + 3 for Likert variables; 0 to 1 for binary variables). Correlation matrices used maximum likelihood to fit both factor models; however, the Michigan model was forced to seven factors (representing the seven latent variables within the questionnaire), while the Ontario model was forced to five factors (due to the smaller set of latent variables). The performance of the best factor models was evaluated using Bayesian Information Criterion (BIC; Raftery 1995), a root mean squared error of approximation (RMSEA), and the non-normed fit index, which compares the final factor model with the null expectation. Following Heir et al. (1995), we assumed that factor loadings above 0.6 were ‘high’, and also documented communality and uniqueness of each indicator variable as measures of their fit. The final factor models for Michigan and Ontario anglers were plotted graphically.

To enhance the mechanistic understanding of risky behaviour, we also conducted predictive modeling of bait-bucket release using the full set of indicator variables for Michigan anglers. Michigan anglers were used for predictive modeling because of the large set of seven latent variables. Predictive models were generated using classification and regression trees (CART; De’eath and Fabricus 2000) with binary recursive partitioning. First, as a descriptive exercise, we fit a classification and regression tree to the full set of Michigan data to explore which indicator variables routinely led an angler to indicate bait release within the survey. Next, to generate a robust predictive model, we conducted a 10-fold cross-validation routine to select the most parsimonious classification tree from all possible alternatives, and the best model structure (fewest tree nodes with greatest deviance explained) was determined. To determine model specificity and sensitivity, the best predictive model (following the 10-fold routine) was forecast across the full survey set. Prediction error (predicted probability of release vs. actual release as indicated by respondents) was evaluated using overall classification rate and AUC (area under the receiver operator characteristic curve), based on a confusion matrix (true positive rate, true negative rate, false positive rate, false negative rate). Both the full classification model, and the best predictive model, were plotted graphically. All statistical analyses were conducted using the statistical language and software program R, version 2.12.1 (R Development Core Team 2008).

**Results – 1st order head**

Response rates for questionnaires varied between Michigan (34%, *n* = 1709 total responses) and Ontario (27%, *n* = 1348). Responses indicated a high proportion of anglers fishing with live baitfishes (91% and 81%) and moderate release rates (27% and 19%) in Michigan and Ontario, respectively (Online Resource 1). A large number of missing values occurred for responses concerning age and education, but these variables did not appear to be significant drivers of risky behaviour. Given the relatively large sample sizes and random selection of respondents, the sample of respondents was assumed to be representative of Michigan and Ontario live bait angler populations, so responses were not weighted in subsequent analyses. Sociodemographic and recreational characteristics of responding anglers, response frequencies, and other surveying characteristics are summarized in Online Resource 1.

Factor analysis confirmed seven main factors for Michigan anglers, although most latent variables were mixed across pre-determined categories (e.g., Factor 2: Public Outreach, Bait Disposal; Factor 4: Aquatic Invasive Species, Management; Factor 5: Management, Public Outreach; Factor 6: Bait Disposal, Convenience; Factor 7: Convenience, Baitfish, Social Norms). Each of the seven factors held indicator variables with loadings above the 0.6 threshold, and the fifth factor (Management, Public Outreach) held the greatest number of indicator variables (Fig. 2A, Online Resource 2). Analyses confirmed five main factors for Ontario anglers, with Attitudes Towards Management and Risk and Perception of Live Bait and AIS occurring as single factors. Remaining latent variables were mixed across categories (e.g., Factor 1: Public Outreach, Baitfish; Factor 3: Public Outreach, Management; Factor 5: Restrictiveness of Management, Risk and Perception of Live Bait and AIS). Each factor held variable loadings above the 0.6 threshold (Fig. 2B, Online Resource 3). For Michigan respondents, the strongest factor correlations (i.e., those of 0.3 or greater) were found between: Management, Public Outreach and Public Outreach, Bait Disposal (0.55); Public Outreach, Bait Disposal and Bait Disposal, Convenience (0.35); Management, Public Outreach and Attitudes towards management (0.55); and, Convenience, Baitfish, Social Norms and Attitudes Towards Baitfish (0.43; see Online Resource 4 for full factor correlations). For Ontario anglers, strong factor correlations were found between: Management and Public Outreach, Management (0.37); Public Outreach and Management and Public Outreach and Baitfish (0.34); and, Risk and Perception of Live Bait and AIS, Restrictiveness of Management and Risk and Perception of AIS (-0.30; Fig. 2B). Although factors are not directly comparable between surveys due to different indicator variables, both Michigan and Ontario models exhibited strongest correlations between factors describing Management and Public Outreach. The best factor models for Michigan and Ontario anglers, respectively, exhibited chi-square values of 1856.97 (*p* = 0.003, 1553 observations), 688.86 (*p* = 0.00007; 1061 observations), BIC values of -479.68 and -467.65, RMSEA of 0.056 and 0.055 (90% CI: 0.053 to 0.058, 0.05 to 0.059; both below the 0.06 threshold proposed by Hu and Bentler (1995)) and non-normed fit indices of 0.868 and 0.872, which approached the 0.90 value of model acceptability proposed by Hu and Bentler (1995).

The full classification model (i.e., classification of bait release across the entire Michigan dataset) identified eight nodes and six primary indicator variables classifying the incidence of bait release: 1) “release is the most convenient way to release bait”; 2) “releasing bait provides a foraging resource”; 3) “it is uncommon for anglers to release their bait”; 4) “bait disposal has an impact on the spread of AIS”; 5) “I seek information regarding AIS”; and, 6) “I have found signs at bait shops about the risk of live bait”; Fig. 3; see Table 1A for global set of variables included in the full classification model). Based on cross-validation, the most parsimonious model contained only two nodes with primary indicator variables as: 1) “release is the most convenient way to release bait”; and, 2) “releasing bait provides a forage resource for other fishes” (Fig. 4). The cross-validated model exhibited an overall classification rate of 80.6% with relatively high true positive and negative rates (0.705, 0.846, respectively), relatively low false positive and false negative rates (0.154, 0.295), and a moderately high AUC value (0.81; Fig. 5).

**Discussion – 1st order head**

To our knowledge, this study represents the first assessment of the motivation for risky human behaviour involving invasive species. This represents a major step towards understanding and mitigating vector activities that have previously been considered too haphazard or sporadic for assessment. We contribute to the scant knowledge of motivations for risky or illegal activities involving fish and wildlife (Eliason 1999) and demonstrate a novel approach for predictive modeling of lophic behaviours. Multivariate analyses revealed two main behavioural types. First, ‘pro-management’ behaviours. These individuals agree with management paradigms and generally understand and agree with the risks of AIS, and how these risks are portrayed by management. Individuals believe that regulations are effective and based on sound science, that agencies are active in education, that education improves their understanding of risks, and that live bait is a potential vector for AIS and fish diseases. These individuals also indicated that regulations are easy to follow, and believe that restrictions on baitfish use (i.e., to mitigate AIS and disease risk) are not overtly strict. These individuals are generally satisfied with management and agree with bait regulation approaches being taken by management agencies. The second behavioural type, ‘pro-release’, indicated that it is both wasteful and cruel to dispose of bait properly (i.e., by depositing it on land or in the trash), and that releasing bait into the water is convenient. Further emphasizing the importance of convenience and general perceptions of baitfish, the mechanistic model indicated that convenience and attitudes towards baitfish (i.e., forage resources) were the strongest factors predicting release as disposal behaviour. For example, individuals disagreeing that “release is the most convenient way to release bait”, were likely (*p* = 0.935) to dispose of bait properly; whereas, individuals whom identified release as convenient, and indicated that releasing provides a forage resource for other fishes, were likely (*p* = 0.635) to release. The global classification tree revealed additional factors beyond convenience and forage for classifying risky vs. benign behaviour, such as social norms (i.e., with releasers agreeing that bait release is common among anglers), attitudes towards disposal (i.e., with releasers indicating that bait disposal does not impact the spread of AIS), and public outreach (with releasers failing to seek information regarding AIS). Nonetheless, the simple structure of the best predictive model indicated that bait release can be determined *a priori* based almost entirely on individual perceptions of convenience and attitudes towards baitfish. Risk-takers indicated that bait release was convenient, and a subset of these individuals indicated that releasing baitfish provides a forage resource for fishes. These results are in contrast to other investigations of lophic risk involving wildlife poaching (Eliason 2003), where illegal and risky behaviours were attributed to denials of responsibility, perceived necessity for the behaviour, or disagreement with the law. Despite the success of our predictive model, no clear behavioural rationale existed for a subset of risk-takers (8% of live bait anglers, or 29.5% of releasers). This group of anglers indicated that bait disposal was not convenient and did not provide a forage resource for fishes, but released anyway.

How can these results be used to reduce risky behaviour and enhance management of AIS, baitfish, and recreational fisheries? Results indicate that risky anglers can be identified based on their attitudes about baitfish and convenience, so targeting known perceptions about convenience (or physically alleviating the inconvenience of disposal on land, such as through designated bait receptacles) and forage resources will inevitably help to modify behaviours of most (70%) risk-takers fitting the convenience and forage behavioural pattern. This provides a targeted approach to the management, outreach, and enforcement of risky vectors whose actions contribute to the introduction of AIS. Beyond convenience and forage, bait release is also undoubtedly influenced by perceptions of governance and the perceived risk tolerance of management by anglers. Management agencies permit bait use, so anglers may inherently believe bait activity to be benign solely because it is allowed by government (i.e., managers appear to be concerned about AIS, but if bait catches actually did contain AIS and bait use was risky, then the activity wouldn’t be permitted). Although not prominent within our most parsimonious model, the perception of AIS and the ecological impact of introducing non-native species differs greatly among anglers due to personal opinions about fisheries and the roles of stocking, which will further influence individual perceptions about the risk of release and AIS in general. During discussions with managers and anglers, it was evident that many anglers believe (often incorrectly) that purchased baitfishes were harvested in close proximity to the retail location (further emphasizing the misperception of a ‘clean’ resource validated by governments), believing that purchased baitfishes represent a local, benign source of fishes and further influencing the perception of risk during disposal decisions. Although local harvest and retail distribution may occur in some circumstances, in other cases the commercial distribution network revolves around widespread harvester and angler movement of fishes, especially as it relates to the movement of Great Lakes bait to inland areas. Many anglers are unable to discern invasive species from target catches (Drake and Mandrak [in review, B]), further contributing to perception bias and misinformed decisions during disposal. However, greatest perception bias is undoubtedly the result of a disconnect between release regulations and the context of bait trips, which vary wildly between jurisdictions. For instance, in Ontario, anglers are not permitted to release bait regardless of its origin (to enhance enforcement for purchased-released bait), so following self-harvesting at point of use, anglers are required to dispose of bait on land, which is undoubtedly perceived as wasteful and cruel by anglers who self-harvest at point of use. In New York, angler self-harvest is prominent; however, self-harvested fishes may not be moved overland, effectively negating overland species transport and AIS introduction risk; and, release (of self-harvested fishes) is encouraged for the sustainability of bait resources following use at point-of-harvest. Therefore, the risk posed during live bait angling is context dependent and based on bait management paradigms as they relate to the potential for AIS bycatch (commercial, angler self-harvest), movement of fishes (harvester, angler), and angler release rates (Drake and Mandrak [in review, B]).

For a sub-set of vectors (29.5% of releasers), no clear rationale for risk-taking exists, confirming the incidence of haphazard and unpredictable behaviour common within lophic scenarios beyond invasive species (e.g., financial systems, narcotics use); however, unlike these scenarios where clear benefits of risk-taking exist, the rewards of risk-taking for vectors not fitting the convenience-forage pattern are unclear (i.e., why release if it is not convenient and does not provide a forage resource?). Although these individuals may seek the thrill of not adhering to fishery regulations, this seems unlikely. Regardless of the rationale, for this subset of live bait anglers, vector outreach and education is likely to be less effective because specific rationale for participating in bait release is unknown. Reducing the ecological impact of these vectors (for which release may never be effectively prevented) will require bait management to focus on ecological factors, such as modified commercial distribution networks, increases in selective fishing (i.e., to reduce bycatch during commercial harvest), stronger controls on angler and fish movement, or greater reliance on angler self-harvest at point of use. Like many before us (Ludwig and Leitch (1996), Keller et al. (2007), Killian et al. (2012), Drake and Mandrak [in review, A], we emphasize that bait release is risky business. We demonstrate clear rationale for risk-taking behaviour that may be effectively managed with targeted strategies, and, for individuals whose behaviour lacks clear rationale, emphasize that regime shifts in bait management may be necessary to reduce the ecological, social, and economic impacts of risky behaviour.

**Acknowledgements – 1st order head**

 [Sentence to thank reviewers] We thank the many individuals who were interviewed or responded to our questionnaire. Funding for this study was provided by the Great Lakes Fisheries Trust. Additional funding to D.A.R. Drake was provided by a Natural Sciences and Engineering Research Council (NSERC) Post-Graduate Scholarship. Funding to N. E. Mandrak was provided by an NSERC Canadian Aquatic Invasive Species Network Grant and the Fisheries and Oceans Canada Aquatic Invasive Species programme.

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 **Figure Captions.**

**Fig. 1** Conceptual model representing the structure of the Theory of Planned Behaviour (A), and the modified form of the model used in this study to assess risky behaviour (B). The modified conceptual model in this study incorporates convenience in lieu of perceived behavioural controls, multiple aspects of attitudes, and the influence of management and public outreach on risky behaviour

**Fig. 2** Results of confirmatory factor analysis for Michigan (2A) and Ontario (2B) live bait anglers using maximum-likelihood fitting. Models were fitted with 7 factors (Michigan model) and 5 factors (Ontario model) to conform with specific latent and indicator variables from social surveys. Only indicator variables with loadings greater than 0.6 are shown; likewise, only factor correlations of 0.3 or stronger are shown. See Online Resource 2, 3 for full factor tables

**Fig. 3** Classification tree derived using binary recursive partitioning for the global set of surveys for Michigan live bait anglers, with disposal behaviour (bait release vs. legal disposal methods, such as deposition on land) as the response variable. Branch lengths were chosen for ease of interpretation and do not represent deviance explained

**Fig. 4** Classification tree derived using binary recursive partitioning and a 10-fold cross-validation fitting and evaluation procedure for surveys from Michigan live bait anglers. The classification tree structure represents the best predictive model of bait disposal behaviour based on parsimony and deviance explained. Tree branch length represents the relative proportion of explained deviance for each step

**Fig. 5** Confusion matrix of predicted vs. actual outcomes following application of the cross-validated predictive model of live bait angler disposal behaviour

**Tables.**

Table 1. Latent and indicator variables to assess social perceptions of fisheries, live bait, and aquatic invasive species by anglers in Michigan, USA (1A) and Ontario, Canada (1B). Latent variables represent broad categories of inquiry, whereas indicator variables represent measured attributes related to latent categories. Scales and rankings were either binary (0,1 representing the success or failure of an activity) or categorical (ranked using a Likert scale (Bollen 1989), strongly disagree to strongly agree; numerically as -3 to +3).

 Table 1A.

|  |  |  |
| --- | --- | --- |
| **Latent Variable** | **Indicator Variable**  | **Scales and Ranking Method** |
| **Disposal Behavior** | I dispose of my bait by releasing it into the water  | Binary  |
| **Attitude Towards Disposal** | How I dispose of live bait can have an impact on the spread of AIS | Categorical |
|   | Live bait is a potential route for the spread of AIS  | Categorical |
|   | Disposing of baitfish properly can help stop the spread of AIS  | Categorical |
|  | I worry about the presence of AIS within my live bait | Categorical |
| **Social Norms** | The people I fish with care about how I dispose of my live bait  | Categorical |
|  | The people I fish with dispose of their live bait in the same manner I do  | Categorical |
|  | It is uncommon for anglers to release their live bait | Categorical |
|  | Conservation group membership  | Binary  |
| **Convenience** | If there were a convenient place to dispose of live bait, I would be more likely to not release  | Categorical |
|  | Release is the most convenient way to dispose of bait  | Categorical |
|  | There is no other convenient way to dispose of bait  | Categorical |
| **Attitudes Towards Baitfish** | Releasing live bait provides a forage resource for other fishes  | Categorical |
|  | It is wasteful to dispose of bait by dumping on land  | Categorical |
|  | It is cruel to dispose of bait by dumping on land  | Categorical |
| **Attitudes Towards AIS** | Important to prevent introduction and spread of AIS  | Categorical |
|  | Important to experience an ecosystem free of AIS  | Categorical |
|  | Healthy ecosystems do not have AIS | Categorical |
| **Management** | MDNR places a high priority on prevention of AIS  | Categorical |
|  | MDNR makes regulations easy to follow  | Categorical |
|  | MDNR makes information easy to find  | Categorical |
|  | Regulations use sound science  | Categorical |
|  | Regulations are effective at preventing AIS  | Categorical |
|  | Regulations are appropriately restrictive given the risks of AIS  | Categorical |
|  | MDNR conducts sufficient consultation  | Categorical |
|  | Politics play a role in creating fisheries regulations  | Categorical |
|  | Fisheries regulations are created fairly  | Categorical |
| **Public Outreach** | MDNR is actively involved in education regarding risks  | Categorical |
|  | MDNR is actively involved in education regarding ways to prevent threats of AIS and diseases  | Categorical |
|  | Information used by MDNR improves my understanding  | Categorical |
|  | Information used by MDNR changes my behavior  | Categorical |
|  | Information used by MDNR is accurate  | Categorical |
|  | I actively seek information regarding AIS  | Categorical |

Table 1B.

|  |  |  |
| --- | --- | --- |
| **Latent Variable** | **Indicator Variable**  | **Scales and Ranking Method** |
| **Disposal Behavior** | How do you dispose of your live bait? [Release into water] | Binary  |
| **Risk and Perception of Live Bait and AIS** | Live baitfish are a potentially important route for the spread of invasive species | Categorical |
|  | Live baitfish are a potentially important route for the spread of the fish disease viral hemorrhagic septicemia (VHS)  | Categorical |
|  | Releasing live fish into a waterbody provides forage resources for other fishes  | Categorical |
|  | It is important to prevent the spread of invasive species at any cost | Categorical |
|  | I do not like to kill live fish  | Categorical |
|  | The costs and benefits of regulations must be considered when preventing the spread of invasive species and diseases | Categorical |
|  | Individual anglers play an important role in the management of fishery resources | Categorical |
|  | Please list any groups that you belong to that are involved in conservation or angling  | Interpreted as Binary  |
| **Management and Fishery Regulations** | Regulations regarding fishery resources in the province are created fairly |  |
|  | Fishery resources in the province are well managed | Categorical |
|  | OMNR uses sound science when creating fisheries regulations  | Categorical |
|  | Fisheries regulations do enough to protect fisheries | Categorical |
| **Management and Restrictiveness of Fishery Regulations** | Current live bait regulations place too many restrictions on my angling activities  | Categorical |
|  | Restrictions on live bait movement are too strict given the amount of risk of movement of non-native species and diseases by live bait | Categorical |
|  | I believe there is a high potential for conservation officers to catch individuals who are not complying with live baitfish regulations | Categorical |
| **Public Outreach** | It is easy for anglers to find information about the current live bait regulations  | Categorical |
|  | It is easy to find information regarding threats to fishery resources | Categorical |
|  | The educational information I see improves my understanding of the risks associated with the movement of live bait |   |
| **Angler Response to Public Outreach** | The educational information I see regarding live bait, non-native species and diseases has influenced me to change how I dispose of live bait | Categorical |
|   | I actively seek out information regarding live bait regulations | Categorical |
|  | I actively seek out information about the status of non-native species and fish diseases in Ontario | Categorical |

**Figures**

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**Fig. 1**

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**Fig. 2A**

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**Fig. 2B**

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**Fig. 3**

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**Fig. 4**

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**Fig. 5**