GuardIAS

GUARDING EUROPEAN WATERS FROM INVASIVE ALIEN SPECIES

Deliverable

D5.1 Indicators for measuring public awareness and engagement outcomes for improving management of biological invasions

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Executive Summary

Citizen and community engagement are instrumental for effective prevention, early detection and monitoring, and management of invasive alien species. This report presents the findings from a ***literature review*** across the ***social sciences and humanities (SSH)*** to better understand how public awareness and engagement can be understood and measured within the context of biological invasions. The main outcome is a ***framework*** that summarizes key information on suitable indicators for measuring changes in cognitive outcomes (the things people know), affective outcomes (how people feel), and behavioral outcomes (what people do).

The first chapter of this report describes how citizen and community engagement activities support effective management of biological invasions and identifies gaps in knowledge when it comes to evaluating their outcomes. The second chapter describes three SSH disciplines that were central in the literature review: environmental education, environmental psychology and environmental communication. Models and frameworks from these research disciplines have demonstrated that having certain knowledge about the environment is not a guarantee for displaying desired behavior. This '***knowledge-action gap***' also applies to citizen and community engagement in management of biological invasions.

To evaluate not only if efforts are increasing knowledge, but also leading to changes in attitudes or behavior, the third part of this report outlines six main ***indicators***:

Knowledge refers to the extent to which people are aware of biological invasions and their impacts (*system knowledge*), the possible solutions for mitigating these impacts (*action-oriented knowledge*), and to what extent one can contribute to part of the solution (*effectiveness knowledge*). Knowledge can be measured as either self-reported or factual knowledge.

Skills include identification skills, observational and reporting skills, and other specialized skills (e.g., trapping). Skill level can be measured as self-reported or actual levels.

Attitudes are evaluative responses to phenomena based on personal beliefs, for example whether people support management of invasive alien species, and which measures are deemed acceptable.

Risk perception encompasses the perceived severity of different types of impacts and perceived susceptibility to a threat.

Self-efficacy refers to a person's beliefs that they are able to effectively complete an action. This is especially relevant in promoting biosecurity behavior and identifying potential barriers for participation.

Behavior is typically measured as self-reported intended or past behavior. Objective behavior refers to actions that can be observed and measured in real life (independently of subjective interpretations).

The report concludes with a summary table that offers guidance for selecting suitable indicators and how to measure them. This ***framework*** and the concrete examples in Section 3.1-3.5 can aid researchers and practitioners with limited experience in developing and applying measurement scales in their project evaluations.

The report is complemented by a ***glossary*** of technical terms and ***references*** for further reading. The ***appendix*** contains relevant tables.

Abbreviations and acronyms

Table 1. Table of abbreviations and acronyms used in GuardIAS and the document

Abbreviation	Signification
AIS	aquatic invasive species
CDD	Check, Drain, Dry
GuardIAS	Guarding European Waters from Invasive Alien Species
IAS	invasive alien species
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
NGO	non-governmental organization
NIS	non-indigenous species
OneSTOP	OneBiosecurity Systems and Technology for People, Places and Pathways
KPI	key performance indicator
SSH	social sciences and humanities
WP	work package

1 Introduction

Globally, more than 37,000 species have been introduced by human activities to new regions and biomes where they did not previously occur. A subset of these introduced species becomes established, and another subset are ***invasive alien species*** that spread and have a negative impact on biodiversity and local ecosystems. Many invasive alien species also have impacts on nature's contributions to people and good quality of life (Roy et al., 2024). The Intergovernmental Platform on Biodiversity and Ecosystem Services published a comprehensive report about the status and trends of invasive alien species and their impacts (IPBES, 2023). In this report, experts also give advice on the best tools and policy measures for identifying and regulating pathways of introduction and for implementing effective control measures. One of the report's main conclusions was that ***public and stakeholder awareness and engagement*** contribute to effective management of biological invasions. The potential of this contribution depends on the invasion stage and the type of activities that are being implemented.

Preventing new introductions of species is generally heralded as the most cost-effective measure to minimize potential harmful impacts to biodiversity and society (IPBES, 2023; Katsanevakis et al., 2023). New introductions take place via human activities that transport animals, plants or micro-organisms, either deliberately (e.g., our pets) or unintentionally (e.g., as contaminants or hitchhikers) outside of their natural range (Hulme et al., 2008). For example, marine and freshwater recreational boaters can unintentionally spread invasive species while transporting boats and equipment from one body of water to another (Clarke Murray et al., 2011; Kelly et al., 2013; Rothlisberger et al., 2010). In this context, understanding and influencing boater behavior is central to management of aquatic invasive species (Cole et al., 2016, 2019). Authorities and non-governmental organizations (NGOs) use awareness campaigns to increase public knowledge about specific species or pathways and to advise on ways to minimize the risk of spread of invasive alien species. A recent survey of local and regional managers of invasive alien species in 41 European countries found that 93% of the respondents that were implementing preventive measures also engaged in activities for raising public awareness (Garcia-Lozano et al., 2025), making this a popular instrument.

Early detection and monitoring of invasive alien species is benefiting from the help of the general public, and especially from volunteer citizen scientists. Citizen science projects contribute to monitoring and early warning systems by expanding the spatial and temporal range of datasets in distribution mapping (e.g., Lehtiniemi et al., 2020) and obtaining first records of species (González-Moreno et al., 2025; Pocock et al., 2024). This contribution has advanced through both newly developed and existing monitoring programs, in some cases supported by the development and use of smartphone applications for reporting sightings (Howard et al., 2022). In addition to data outcomes, citizen science projects also lead to learning and other social outcomes, such as increased awareness of local issues, enjoyment of taking part in the activity itself, learning new subject-matter, and contributing to science in general (Anđelković et al., 2022; Bonney et al., 2016; Wehn et al., 2021). Adequate resources for outreach, communication and feedback activities are crucial to recruit and retain participants in citizen science activities.

Eradication and control (hereafter management[1]) of invasive plants, animals or microorganisms, for example via mechanical removal, is labor-intensive work that requires follow-up actions, such as monitoring and repeated treatments. Natural resource managers often get help from volunteers who wish to support nature conservation. Volunteers' motivations to engage in management of invasive species are diverse, ranging from general learning and development goals to a specific desire to protect native species and habitats (Anđelković et al., 2022). At the same time, managers and public authorities rely on cooperation of landowners and support of local communities, who may be less knowledgeable or have different attitudes towards invasive alien species management, to be able to carry out the work. Tailored communication at an early stage is instrumental for effective management campaigns, especially when there are multiple interests and values at play (Verbrugge et al., 2017). Community-driven eradication campaigns, citizen science platforms, and awareness campaigns have the potential to create a sense of shared responsibility for managing biological invasions, thus contributing to rapid response and long-term control (e.g., EASIN, n.d.; Jubase et al., 2021).

With the ***current rise in popularity of citizen and community engagement*** in prevention, early detection and monitoring, and management activities, it becomes increasingly important to evaluate their outcomes and learn how they can be improved. Thus far, ***only limited research has investigated if and how being exposed to information or being engaged in such activities influences people's awareness, attitudes, or behavior.*** Evaluation studies of awareness campaigns for invasive alien species are scarce, mainly conducted in North American and European countries, and often suffer from poor research design (Haley et al., 2023; Hall et al., 2020; Marzano et al., 2015).

> ***Box 1 Evaluation research*** Evaluation is a form of applied social research that systematically collects information to determine strengths and weaknesses of programs, projects, and products, aiming to improve their overall effectiveness. Various types of evaluation exist, including *front-end evaluation* for gathering baseline information, *formative evaluation* that is conducted during implementation, and *summative evaluation* that is implemented at the end of a project to identify its effectiveness.

Selecting ***suitable metrics for measuring success*** is a key aspect for obtaining useful and meaningful outcomes of evaluation studies. Within the context of biological invasions, evaluation research would ideally include at least two types of benchmarks: one that demonstrates how the campaign altered **human variables** (such as knowledge, attitudes, and behavior) and one that measures *a biological link* to human behavior (for example, a reduction in the rate of spread of an invasive species or increased trapping efforts). Two recent review studies, focusing on citizen science and public awareness campaigns, found that evaluation and impact studies often use simplistic approaches for assessing knowledge, attitudes and behavior (Haley et al., 2023; Wehn et al., 2021). The ***integration of measurement scales from established social science disciplines***, such as environmental psychology and environmental education, is instrumental for developing consistency in measuring the impact on human variables (Somerwill & Wehn, 2022). The human dimensions of biological invasions, while increasingly recognized (Novoa et al., 2018; Shackleton et al., 2019), remain understudied (Stevenson et al., 2023).

[1] 'management' means any lethal or non-lethal action aimed at the eradication, population control or containment of a population of an invasive alien species, while also minimising the impact on non-targeted species and their habitats (following the EU Regulation No 1143/2014 on the prevention and management of the introduction and spread).

Box 2 Interdisciplinarity in invasion science Originating from invasion ecology, research on biological invasions has mostly been conducted within the natural and environmental science realms, with limited contributions from the *social sciences and humanities (SSH)*. Interdisciplinarity has become more prominent as the field matured, however, collaborations between disciplines remain largely confined within subdisciplines of ecology and environmental sciences (Vaz et al., 2017). Potential barriers for knowledge exchange between disciplines are a lack of collaboration between natural and social scientists as well as limited understanding of specific terminology, concepts and approaches (Fox et al., 2006).

1.1 Aim and intended outcomes

This ***Task 5.5*** report presents the findings from a ***literature review*** across the social sciences and humanities (SSH) to better understand how public awareness and engagement can be understood and measured within the context of biological invasions. The literature review focused on (i) defining key concepts, (ii) documenting best practices for operationalizing and measuring public awareness and engagement, and (iii) better understanding how these outcomes support effective prevention and management actions. The main findings are summarized in a ***guiding framework*** with ***indicators*** for measuring social outcomes from citizen and community engagement activities that aim to raise awareness on invasive alien species issues. The report includes concrete examples to support researchers and practitioners with limited experience in developing questionnaires and applying measurement scales in their project evaluations.

Task 5.5 results contribute to reaching ***Objective 5 in the GuardIAS project*** which is to use innovative approaches to engage with a diverse range of stakeholders, enhance literacy and awareness about invasive alien species, and bolster support of management actions.

Work Package 5 (Stakeholder engagement and social-ecological interactions), ***Work Package 2*** (Early detection and monitoring) and ***Work Package 4*** (Building capacity in support of management actions) will implement and evaluate a range of methodological approaches and tools for public and stakeholder engagement (Table 2). The indicators identified in this report provide a starting point for developing tailor-made questionnaires for evaluating the outcomes of these GuardIAS activities.

Table 2. Planned GuardIAS activities for public and stakeholder engagement (Katsanevakis et al., 2024).

eDNA sampling [WP2 / WP5]: Citizen science engagement events to collect high-quality eDNA samples. [KPI: Engage >100 citizens for eDNA sampling].
Citizen science platform iNaturalist [WP2]: Citizen science engagement through the iNaturalist platform to support with detection and monitoring [KPIs: >100 people active in a dedicated iNaturalist project for aquatic species of EU concern]
Eradication and control [WP4]: Engage citizens in eradication and control actions that will take place during 11 case studies (e.g., recreational fishers participating in lionfish culling campaigns).

BioArtBlitz events [WP5]: Organizing performances and field activities, co-designed by biologists, artists, and humanities researchers, which aim to engage citizens in both creative and scientific ways to actively participate in better understanding and managing IAS. [KPI: 20 BioArtBlitz events].
Marina events [WP5]: A citizen science initiative that will engage boaters and marina staff through educational banners, habitat collectors for studying biofouling, open-lab activities, and Zooniverse project activities to encourage active participation in monitoring and managing biofouling as a vector for alien species introduction. [KPI: Engagement activities in >20 marinas in Italy].
Zooniverse project [WP5]: In Zooniverse project "Sounds invasive to you?" people can directly assist scientists to analyze video/audio recordings. [KPI: Engage >1,000 citizens in the Zooniverse project].
Innovative applied games [WP5]: Development of two types of applied games for stakeholder engagement and development of species-specific management strategies (type 1) and raising public awareness and literacy about the impacts of aquatic IAS and management options (type 2). [KPI: applied games created for at least four case studies].

1.2 Literature review

Task 5.5 conducted a two-step literature review of research published in ***social sciences and humanities (SSH)*** disciplines. To define key concepts and disciplinary practices, the author first read introductory textbooks and standard works in relevant SSH disciplines. The second step consisted of a *scoping literature review* on the use and application of these concepts in research about biological invasions published in SSH journals. Unlike systematic reviews, which focus on answering a specific research question, scoping reviews are more exploratory and act as a precursor to a systematic review. This type of knowledge synthesis is appropriate as it aims to explore the breadth and scope of emerging literature related to a new topic. Its main purpose is to provide an understanding of key concepts and to identify knowledge gaps and inform future research agendas. Here, the focus was on documenting best practices for operationalizing and measuring key concepts as well as evidence to support effective prevention and management actions.

The scoping literature review consisted of four steps which are briefly summarized here. A full description of the methods for the literature review, including the search string, inclusion criteria, and list of initial and selected results per journal is provided in ***Appendix 1***. First, six leading SSH journals were selected to represent three main research disciplines (Step 1 – see section 2.1). Next, an identical search string was used to search each journal which provided a list of initial results (Step 2). These records were screened to select only those articles with relevant information, i.e., where invasive alien species were an object of study (Step 3). The selected articles were read by the main author and included in the review, as well as relevant citations withing these articles (Step 4).

Not all selected research articles are cited in this report. Articles that included invasive alien species only as a minor element of a broader study were not included (e.g., van Riper et al., 2020 who included only one item in a questionnaire that measured values and proenvironmental behavior). Moreover, studies that did not adequately report the measurement items and/or answering categories were not included in the examples given in this report.

1.3 Reading guide

Chapter 1 presents an overview of the potential of citizen and community engagement activities for strengthening management of biological invasions and identifies gaps in knowledge when it comes to evaluating their outcomes. It also briefly explained the literature review methodology. Next, *Chapter 2* describes the SSH disciplines that were considered in the literature review and what we can learn from them. *Chapter 3* outlines relevant indicators for measuring the social outcomes of engagement and outreach activities, culminating in a guiding framework that summarizes key information. The sub sections in this chapter provide concrete examples of measurement items and survey questions that can be considered when designing questionnaires. *Chapter 4* gives the main conclusions and an outlook for future research and applications.

While the GuardIAS project focuses on aquatic species, this report is intended to be a useful resource for researchers, policymakers and other professionals engaging in management of biological invasions across biomes. The examples were chosen to cover all biomes, however, there may be a bias towards freshwater and marine environments due to the nature of the GuardIAS project and its researchers and due to biases in the available literature itself.

This report focuses on individual learning outcomes and behavior of the general public and specific target groups within the context of biological invasions. When evaluating impact, one should also consider other relevant outcomes, such as ecological outcomes and data-related outcomes. Other guides and resources that have been developed provide complementary guidance, e.g., for evaluating the outcomes of citizen science projects[2], and have not been repeated in this report.

[2] Users Guide for Evaluating Learning Outcomes from Citizen Science - https://participatorysciences.org/resources/research-evaluation/

2 Social sciences and humanities

Rather than reinventing the wheel, we can learn from other disciplines that study human-environment interactions using social science theories and methods. This report draws on three main SSH research disciplines that can aid in understanding the human dimensions of biological invasions, namely the established field of *environmental education, environmental psychology* focusing on pro-environmental behavior, and *environmental communication* studies that deal with with disseminating ecological and environmental information and communicating environmental risks.

These three SSH fields were chosen because of their focus on research linked to the environment while at the same time being strongly rooted in SSH disciplines. As such, they are more distant to, and therefore less familiar and less read among the research community typically working on biological invasions, when compared to other interdisciplinary fields such conservation biology or environmental management. As an illustration, the review by Haley et al. (2023) included 24 studies, of which only two were published in social science journals (i.e., *Environmental Sociology* and *Journal of Environmental Education*).

Another communality among these research fields is that they generate knowledge that helps to understand how people think about, experience, and interact with nature, which is crucial for promoting biodiversity, environmental sustainability and human well-being goals (Clayton & Myers, 2009). As such, these SSH disciplines have untapped potential for maturing and further strengthening the broadening field of invasion science (Heger et al., 2021; McLeod et al., 2015; Walker-Springett et al., 2016). Social theories of human action are particularly helpful for studying complex social-ecological systems and provide conceptual structures for understanding what drives, changes, creates, or inhibits human action, either as individuals or collectives (Eyster et al., 2022; McLeod et al., 2015).

2.1 What can we learn from SSH disciplines?

Environmental education is a multidisciplinary field that focuses on teaching how natural environments function and particularly how human beings can manage behavior and ecosystems to live sustainably. Environmental education facilitates connections between actionable research findings and on-the-ground practices, for example by developing and testing education materials (using different pedagogical approaches) and evaluating learning outcomes (Ardoin et al., 2020). For example, Haak and others (2022) designed and evaluated an immersive, experiential learning module centered around the question of how scientific information is used in invasive species policy and management. Their results, published in *Environmental Education Research*, showed that participating graduate students went through a transformative learning experience in which their initial science-centric views were changed to a view where science was just one of the many inputs responsible for shaping policy, and thus recognizing the value of co-management and collaboration in addressing problems caused by invasive species. Research in this field also points to potential dilemmas for education and communication on invasive alien species. Otieno and colleagues (2014), in the same journal, discovered that the use of a sensational style in brochures about the local effects of climate change and invasive alien species enhanced general learning outcomes, but at the same time, this could lead to quite negative and one-sided views about these topics. While environmental education has an important role to play by providing important learning outcomes and experiences for youth, students, and professionals in different sectors, its practice can thus be

challenging due to inconsistent and ambiguous terminology use and the complications arising from communicating about risk and uncertainty pertaining to biological invasions and their management (Probert et al., 2022; Verbrugge et al., 2021).

Environmental psychology is a research discipline that studies bi-directional human-environment interactions, i.e., (i) the influence of the environment on human experiences, behavior, and well-being, and (ii) the influence that humans exert on the environment (Steg et al., 2018). One important area of study is to identify and measure factors that impede or encourage pro-environmental behavior in different contexts. This research discipline has a close relation to ***social psychology,*** the basic science aimed at understanding human social behavior. The main research methods in environmental psychology include questionnaires, laboratory and simulation experiments, field studies, and case studies. Measuring instruments often take the form of psychological tests and scales for understanding psychological constructs, such as knowledge, beliefs, attitudes, values, or intentions (Loewenthal & Lewis, 2001). Within the context of biological invasions, psychological concepts and theories are useful for understanding and explaining i) the role of human behavior in introducing species, ii) how individuals or groups are harmed by or benefit from invasive alien species, and ii) how and why responses may be inadequate or sometimes impede opportunities for successful mitigation (McLeod et al., 2015; Walker-Springett et al., 2016).

Environmental communication research is concerned with how communication about the environment shapes people's perceptions of the natural world, what environmental behaviors they adopt, and how they develop policies for environmental management (Senda-Cook, 2017). Focal areas in this research field are specific kinds of communication, such as (social) media, risk communication, science communication, public participation, and negotiation and conflict. Scholars have studied, for example, how invasive alien species are portrayed to the public through media (Chinn et al., 2024; Hutchen et al., 2024; Mando & Stack, 2019; Moloney & Unnithan, 2019) and experimentally tested whether using the term 'invasive' influenced people's support for control efforts (Kohl et al., 2020).

2.2 From knowledge to action

Behavioral models and frameworks from the research disciplines presented above have demonstrated that knowledge transfer, by itself, is not enough to change behavior or engagement. In fact, knowledge is only one of several interrelated factors that influence whether and how people make decisions (Figure 1). This gap between possessing (environmental) knowledge and displaying behavior is often referred to as the ***knowledge-action gap*** (Kollmuss & Agyeman, 2002). Most educational campaigns and engagement activities targeting knowledge, attitudes and motivations of people are so-called *antecedent* strategies that target factors preceding and influencing behavior. Such strategies assume that increased knowledge or changed attitudes will result in a desired behavior.

Previous research found that the knowledge-action gap also plays a role in public engagement in management of biological invasions (see examples in Box 4). Even when outreach campaigns succeed in increasing knowledge and awareness, they may not be effective in increasing engagement or motivating behavioral change that contributes to preventive actions and minimizing impacts of invasive alien species. Consequently, the evaluation of citizen and community engagement activities needs to consider not only if their efforts are increasing knowledge, but also whether this changes attitudes or behavior.

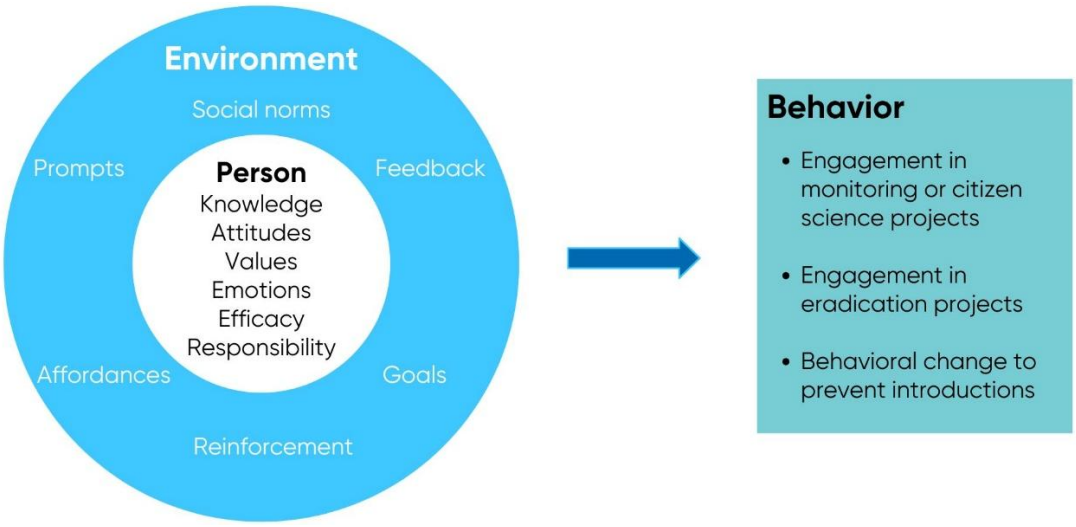


Figure 1. Internal and external factors affecting behavior (adapted from Clayton & Myers, 2009).

Box 4 The knowledge-action gap in public engagement in management of biological invasions. The following examples highlight how internal (e.g., specific beliefs) and external factors (e.g., prompts) can influence engagement in biosecurity behavior.

- Prinbeck and colleagues (2011) reported six barriers to changing leisure behaviors, including perceptions that: (i) the action taken may be worse for the environment than invasive species, and (ii) that invasive species management is a losing battle; normative beliefs that (iii) invasive species management is a low priority for many institutions and (iv) the general public does not know and does not care about invasive species; and behavioral control-beliefs that (v) one does not know enough about preventive behaviors to be effective, and (vi) that recommended preventive behaviors are too difficult to perform.
- For organizations, barriers for uptake of biosecurity measures range from perceived financial losses or benefits to fear of reputational damage or possible prosecutions for failing to act or being able to shift responsibilities to someone else (Sutcliffe et al., 2018). Normative beliefs also play a role, noting that invasive alien species are a problem that you cannot see (and therefore it does not exist?) and that everyone needs to act for it to be effective (a tragedy of the commons).
- Check, Clean, Dry (and similar campaigns) often combine *education* and *prompts* that appear on stickers or towels. *On-site training* in popular locations can contribute even further to actionable knowledge. Such communication efforts needs to be supported by visible infrastructure such as wash-down stations and other changes to the physical environment to 'nudge' recreational boaters into socially desirable behaviors, which can then encourage the behavior to become a social norm within a community (Shannon et al., 2020).
- Similarly, visitors to national parks must be exposed to, read, and comprehend educational messages (for example from the Leave No Trace education program). This message must have compelling arguments to change someone's attitude, causing them to accept the message, and retain it until they are in a situation where they need to behave in accordance with their new knowledge and attitude (Dolman & Marion, 2022).

3 Indicators

This chapter presents a guiding framework for selecting and applying relevant indicators for evaluating social outcomes from citizen and community engagement activities. Recognizing that human action is influenced by multiple factors (Figure 1), the framework includes indicators for measuring cognitive outcomes (the things people know), affective outcomes (how people feel), and behavioral outcomes (what people do).

Starting from the intended outcomes from an engagement activity (Table 3), Sections 3.1 – 3.5 focus on how these indicators can be operationalized using specific questions or scales for collecting data using questionnaires. Section 3.6 provides a summary of this information in a table form that serves a guiding framework with key questions.

Table 3. Indicators for evaluating cognitive, affective and behavioral outcomes of activities aimed at increasing awareness and improving management of invasive alien species.

Outcome	Indicators
Cognitive outcomes	Improved **knowledge and understanding** of, for example, (i) what native and non-native species are, (ii) impacts of invasive alien species, and (iii) management strategies. For biological invasions, knowledge is often *place-based*, meaning that invasive alien species and their impacts differ between and within countries or regions. Improved practical and procedural **skills** for carrying out monitoring and management of invasive alien species. Examples of relevant skills are species identification skills, observational skills, reporting skills, and trapping skills. New skills are formed by a combination of new knowledge and practical experience.
Affective outcomes	Boosting confidence levels that someone can participate in monitoring or successfully perform a preventative behavior (**self-efficacy**). Influencing **attitudes** towards and perceptions of invasives alien species and their impacts, including **risk perceptions**. Noting that invasive alien species can have positive and negative ecological, economic and socio-cultural impacts. Influencing **level of support** for invasive alien species management linked to specific species and pathways.
Behavioral outcomes	Stimulating and promoting **biosecurity behaviors** that prevent introductions and spread of invasive alien species. **Increased participation** in activities that monitor or manage invasive alien species.

3.1 Knowledge

Box 3 Definitions according to the online Cambridge Dictionary

- *Knowledge*: understanding of or information about a subject that you get by experience or study, either known by one person or by people generally:
- *Awareness*: knowing that something exists, or understanding of a situation or subject at the present time based on information or experience
- *Familiarity*: a good knowledge of something
- *Literacy*: knowledge of a particular subject, or a particular type of knowledge.

Source: https://dictionary.cambridge.org/ (Accessed: June 7, 2025)

What is knowledge? Knowledge, awareness, familiarity, and literacy are closely related concepts that are often used interchangeably. A useful typology of knowledge of the environment comes from Frick and colleagues (2004):

- ***System knowledge*** refers to understanding the basic structural and functional characteristics of an ecosystem. Within the context of biological invasions, it includes, for example, understanding the difference between native and non-native species, or general knowledge about invasive alien species and their impacts.
- ***Action-related knowledge*** refers to understanding solutions for environmental issues. Within the context of biological invasions, this could encompass knowledge of specific introduction pathways or knowledge of management strategies to mitigate impacts.
- ***Effectiveness knowledge*** refers to understanding the benefit of actions that can help the environment. Knowledge of targeted preventative measures such as cleaning your boots would be a good example here.

In their study, Frick and colleagues (2004) found that both action-related and effectiveness knowledge have a direct influence on people's conservation behavior, while systems knowledge is more distant and exerts only mediated influence.

Whether someone has knowledge or understanding can be measured in different ways. In fact, what a person factually knows about a topic (i.e., a correct understanding or in accordance with what is generally accepted) is not necessarily the same as their self-reported knowledge or understanding, which captures what people say they know or their own perception of how good this knowledge is (Ladwig et al., 2012). A recent study on knowledge and awareness of introduced species in marine environments revealed such a mismatch between perceived and actual knowledge, as only a small fraction of the respondents with self-declared knowledge of non-indigenous species (11-32%) could name correct examples of non-indigenous marine species (Martínez-Laiz et al., 2025).

Table 4 gives examples of how self-reported (or perceived) level of knowledge about biological invasions has been measured in previous studies, often using Likert-type scales. ***Table 5*** gives examples of how to measure factual knowledge of species (see Table 6 on identification skills for more examples).

Table 4. Self-reported knowledge: examples of measurement items and main findings.

Source	Measurement items and main findings
Self-reported – aquatic **(Golebie et al., 2024; Moore et al., 2024)**	**Method:** Respondents were asked to mark their level of familiarity with the items listed below. *Each item was measured on a 5-point scale with 'not at all familiar' (1), 'slightly familiar' (2), 'moderately familiar' (3), 'very familiar' (4), and 'extremely familiar' (5).* Question: "We would like to understand your familiarity with aquatic invasive species. How familiar are you with the following types of information?" • The biological characteristics that make a species "invasive" • Names of species that are considered invasive • Ways that invasive species affect the environment • How boaters and anglers can spread invasive species • Types of actions you can take to prevent invasive species from spreading • How to complete recommended preventative actions **Main finding:** Knowledge accounted for a substantial portion of the variance in biosecurity behavior, particularly through indirect relationships with self-efficacy and risk perceptions.
Self-reported – general **(Krasny & Lee, 2002)** **NIS: non-indigenous, invasive species**	**Method:** Pre- and post-written survey given to participants before and after a workshop. The questionnaire included 5-point Likert-type questions (*1-strongly disagree to 5-strongly agree*) for the following items on awareness and perceived knowledge: • NIS are a major environmental problem in my county • NIS are a major environmental problem in the US • I am very knowledgeable about NIS in natural areas • I am very knowledgeable about weeds in agriculture • I am very aware of the places where NIS grow in my county • I am very aware of the factors that cause NIS to spread in agriculture • There should be more efforts to control NIS in natural areas in my county • I can identify the NIS in my county • I am knowledgeable about skills or techniques to get rid of NIS **Main findings:** Participants reported enhanced knowledge following the program. Items showing significant increases from the pre- to post-test included knowledge about: NIS in natural areas, where NIS grow locally, NIS identification, skills needed to control NIS, and knowledge about the factors that cause NIS to spread. The participants had a high level of awareness of NIS problems prior to the program and showed no significant changes on these items.

Table 5. Factual knowledge: examples of measurement items and main findings.

Source	Measurement items and main findings
Factual + self-reported – terrestrial **(MacDonald et al., 2020)**	**Method:** Pest-specific objective (or factual) knowledge, based on (Sharp et al., 2011), was measured with four questions with *answering categories 1 (true), 2 (false) and 3 (don't know).* Individual scores were calculated as the number of correct answers. • Possums spread tuberculosis (Tb) to livestock • Trapping alone could rid New Zealand of all rats • Introduced pests are the primary threat to native birds • Wasps attack other insects **Method:** Subjective (or self-reported) pest-control knowledge was measured with five items with participants rating each statement from *1-strongly disagree to 5-strongly agree.* • I think I know enough about pest control to feel pretty confident about my view on the topic • Compared to most other people, I know less about pest control in New Zealand • Among my circle of friends, I'm one of the 'experts' on pest control • When it comes to pest control, I really don't know a lot • I do not feel very knowledgeable about pest control **Main finding:** In New Zealand, public attitudes towards gene drive technologies are influenced by a broad and interactive system of knowledge, attitudes, beliefs, and values. Relying exclusively on providing facts about the emerging technology is not sufficient to meaningfully empower society to participate in informed decision-making about if and how gene drive should be used.
Factual – terrestrial **(Dolman & Marion, 2022)**	**Method:** Long-distance hikers on the Appalachian Trail were asked to what extent they agree with the items listed below. *Each item was measured on a 5-point scale ranging from 1-strongly disagree to 5-strongly agree.* • Hikers can introduce invasive plant species via their clothing, shoes and gear • Hikers can spread invasive plant species via their clothing, shoes and gear **Main finding:** Most respondents agreed that hikers both introduce and spread "invasive plant species via their clothing, shoes and gear" (75% and 78% respectively). At the same time, they had very limited knowledge about invasive species and only few understood the impact that low-impact practices, such as boot brushing, have on preventing the spread of plants and seeds.

3.2 Skills

What are skills? Skills are formed by a combination of new knowledge and practical experience on how to apply this knowledge. It is about learning how to do something conforming to certain standards (e.g., in scientific reporting) or following best practices to obtain optimal results.

Species identification skills refer to one's ability to identify species and can be used as a proxy for species literacy, which is the knowledge that a person has about species (Hooykaas et al., 2019). Identifying species is an application of knowledge, therefore this indicator is included under 'skills' though it can also be considered more broadly as knowledge. ***Observational and reporting skills*** are important capabilities for citizen science participants in biodiversity monitoring. Volunteers who wish to participate in eradication of species, such as landowners, may also need to acquire ***specialized skills***, for example best practices in weed management or setting animal traps (and even euthanizing animals).

Table 6 gives examples of how identification skills can be measured as self-reported (perceived) skills or actual skills (by being asked to perform).

Table 6. Self-reported and actual skills: examples of measurement items and main findings.

Source	Measurement items and main findings
Actual - identification **(Sosa et al., 2021)**	**Method:** Teachers were prompted to recognize native and introduced species from the Argentine environment using either photographs or written names (common and scientific) of the same species. Question 1: The following photographs correspond to a group of native and exotic species from the environments of our country (Argentina). Could you indicate which you think are NATIVE SPECIES? *(Photographs appeared at random in each questionnaire. For each set of two photos, one can be selected).* Questions 2: The following are common and scientific names of native and exotic species found in our country. Which are NATIVE SPECIES? *(Written names appear at random in each questionnaire. Tick boxes to be checked, or not)* **Main finding:** Respondents performed better in recognizing native species when they chose between written names rather than photographs of the same species.
Self-reported – sampling and identification **(Crall et al., 2013)**	**Method:** Prior to a training for citizen scientists, participants indicated their level of experience with the following skills (*measured on a 5-point scale: 1-no experience; 2-little experience; 3-some experience; 4-proficient; or 5-expert*): i) vegetation sampling design, ii) plant identification, iii) invasive plant identification, iv) vegetation monitoring. **Main findings:** Participation in an invasive plant citizen science training program resulted in content learning gains, an increase in process skills, and an increase in self-reported intention to engage in pro-environmental activities. Participant motivations for attending the training included an interest in learning plant identification skills (47%), environmental issues (42%), invasive species or invasive species monitoring (39%), and learning to use GPS units (39%).

3.3 Attitudes and risk perception

What are attitudes? Attitudes are evaluative responses to phenomena based on personal beliefs about these phenomena. Researchers also refer to *perceptions* or *opinions* when they study these evaluative reactions. ***Perceptions*** can be understood as the ways in which an individual observes, understands, interprets, and evaluates an object, action, experience, individual, policy, or outcome (Bennett, 2016). Public perceptions play an important role in the long-term success of environmental management and conservation, including the management of biological invasions (Bennett, 2016; Kapitza et al., 2019).

The reviewed publications focused primarily on ***risk perception*** and perceived threats of invasive alien species to people and nature. ***Table 7*** gives examples of how risk perception can be measured by asking about *perceived severity* of or *perceived susceptibility* to impacts.

Attitudes towards invasive alien species and their management is another relevant area of investigation. ***Table 8*** gives examples of items for measuring attitudes towards invasive alien species and their management, including specific management interventions.

Table 7. Risk perception: examples of measurement items and main findings.

Source	Measurement items and main findings
Perceived severity – ecological – aquatic **(Pradhananga et al., In press)** **AIS: aquatic invasive species**	**Method:** Residents were asked about their beliefs that aquatic invasive species pose a risk (*measured on a 5-point scale from 1-not at all to 5-extreme risk).* Question: How much of a risk do you believe aquatic invasive species pose to the following…? • Habitat for native fish and aquatic plants • Water quality in Minnesota's lakes, rivers and streams **Main finding:** Average scores indicated high levels of perceived risk of AIS. Risk perception was a positive predictor of intention to support AIS organizations. Residents who perceived greater ecological risks were more likely to donate money to or join an organization that works to control or prevent the spread of AIS.
Perceived severity – aquatic **(Golebie et al., 2024; Moore et al., 2024)**	**Question:** If invasive species spread to your local ecosystem, how severe would you expect the impacts to be? Please indicate the severity of potential harm to… *(measured on a 5-point scale with 1-no impacts, 2-mild impacts, 3-moderate impacts, 4-severe impacts and 5-very severe impacts)* *Environment* • Quality of habitat and natural environments Environmental processes (e.g., water cycle) • Survival of plants and animals *Personal* • Your appreciation of the beauty of the landscape • Your own enjoyment of recreational activities • Your own access to the waterbody *Social* • Your appreciation of the beauty of the landscape • Your own enjoyment of recreational activities • Your own access to the waterbody

	Main findings: This study investigated the role of belief systems in shaping intentions to engage in biosecurity behavior. Self-efficacy was the strongest driver, followed by perceived benefits and risk perception (Golebie et al., 2024).
Perceived severity + susceptibility – terrestrial **(Clarke et al., 2021)**	**Method:** Family forest owners were asked to what extent they agree with items listed below (*measured on a 5-point scale ranging from 1-strongly disagree to 5-strongly agree).* *Perceived severity* • Invasive plants decrease the beauty of my wooded land • Invasive plants are bad for wildlife on my wooded land • Invasive plants reduce the property value of my wooded land • Invasive plants prevent the growth of new trees on my wooded land • Invasive plants reduce the value of timber on my wooded land • Invasive plants negatively impact my use or enjoyment of my wooded land • Invasive plants negatively impact my ability to hunt on my wooded land • Invasive plants negatively impact my ability to recreate (other than hunt) on my wooded land *Perceived susceptibility* • Invasive plants from neighboring or nearby wooded lands will eventually spread onto my property. • If I don't remove invasive plants from my wooded land as soon as possible, they will become harder to remove later. **Main findings:** Two most severe threats (as perceived by the respondents) were i) invasive plants preventing the growth of new trees on their woodlands and ii) decreasing the beauty of their woodlands. Respondents were more likely to remove invasive plants if they perceived a higher level of threat from invasive plants.
Perceived susceptibility – aquatic **(Moore et al., 2024)** **AIS: aquatic invasive species**	**Method:** Recreational boaters were asked to estimate the likelihood that an aquatic invasive species would spread, using two different time frames - *measured on a 100-point scale representing likelihood of AIS spread (from 0 to 100%).* Question 1: How likely is it that invasive species will spread to your waterbody within the next year? Question 2: How likely is it that invasive species will spread to your waterbody within the next ten years? **Main findings:** Respondents who live closer to areas where invasive fish species occur were more likely to believe that there is a risk that AIS will invade their waterbody. While both risk severity and risk susceptibility positively influenced intended behaviors among boaters, risk severity had a higher impact.

Table 8. Attitudes towards management: examples of measurement items and main findings.

Source	Measurement items and main findings
Attitudes – general **(Cerri et al., 2024; Palmer et al., 2025)**	**Method:** Two studies assessed the validity of the Pest Management Attitude scale (that was developed in New Zealand) in Italy and the United Kingdom (UK). Questionnaires included the following items *(measured on a 5-point Likert-type scale from strongly disagree to strongly agree).* • Pest species are a significant conservation problem • Pest control interferes with nature • The benefits of pest control outweigh the risks to native species • Pest control has unknown side effects • Native species have greater rights than pest species • Today's pest control methods are NOT proven to be effective • Investment in pest control is beneficial for future generations • Pest control is less important than other conservation issues • NOT enough pest control is being done **Main findings:** Of the UK participants, many completed the survey with human rather than biodiversity pests in mind. Wording of the Pest Management Attitude scale needs to be carefully considered to ensure that concepts (such as 'pest') translate cross-culturally to retain meaningful comparisons (Palmer et al., 2025).
Attitudes – terrestrial **(Kurz & Baudains, 2012)**	**Method:** Gardener's attitudes toward native and exotic plants (nine items) were measured using specially constructed scales *(measured on a 5-point Likert-type scale ranging from 5-strongly agree to 1-strongly disagree). *Indicates Reversed Items.* • Native plants are often unsuitable for the spaces available in smaller gardens* • Residents should consider removing established plants from their garden if the plants are not native to the area • Residents should try to grow plants for their garden from locally sourced seed • I think gardens that contain exotic (rather than native) plants look more green and lush* • It is important for residents to try to choose plants for their garden that are native to their specific local area • The problem with native plants is that they often look scraggly and untidy* • It is best to plant native plants in the garden because they attract birds • Residents should plant native plants in their gardens because they require less watering • I think that exotic plants such as roses are prettier than native plants* **Main findings:** Attitudes toward native plants appeared to be highly related to both how residents respond to the aesthetics of habitat-providing front yard landscapes and also the types of gardening practices that they are engaged in.
Attitudes – terrestrial **(Dolman & Marion, 2022)**	**Method:** Long-distance hikers' were asked about their attitudes towards management actions *(measured on a 5-point scale from 1-strongly disagree to 5-strongly agree).* • All invasive plant species should be eradicated completely • Invasive plant species have as much right to exist (…) as native plants • Managing invasive plant species (…) is difficult • Chemical management is the best method of control • Manually pulling up invasive plants is not effective

	Main findings: General awareness that managing invasive plants within the trail corridor is difficult (70%). More than half (57%) did not believe that invasive plant species have as much right to exist (...) as native plants. For the three other statements 'Neither Agree nor Disagree' was the modal response.
Acceptability – aquatic **(Sharp et al., 2017)**	**Method:** Recreational boaters at two lakes were surveyed on their perceptions, knowledge of and attitudes towards AIS, mostly using Likert-type scales. Question: Do you support transport laws, which prevent watercraft from launching into or leaving navigable water bodies with visibly attached plants or animals on them? *7-point scale ranging from 1-strongly support to 7-strongly oppose.* Question targeting boater's attitudes towards management actions using the five items listed below (*measured on a 5-point scale ranging from 1-unacceptable in all cases to 5-acceptable).* • Provide boat cleaning stations at all launches • Inspect boats at all launching stations for AIS • Work with community volunteers to monitor AIS locations and movement in water bodies • Use regulated herbicides to manage invasive plants • Leave invasive species alone **Main findings:** Respondents were supportive of transport laws and more neutral about working with community volunteers to monitor AIS movement, inspecting boats for AIS at all launching stations, and providing boat cleaning stations at all public launches. Respondents were less certain about the use of herbicides to manage invasive plants and did not feel that leaving AIS alone was acceptable.
Perceived control – aquatic **(Kahler et al., 2020)**	***Method:*** A self-administered survey asked residents about their opinions regarding Asian carp and possible invasion response actions by fisheries managers in Michigan's lakes and streams. They were asked to respond to the items below *on a 7-point Likert-type scale ranging from 1-low and 7-high*. • I feel that I have control over the risks from invasive carp • If there is a problem with invasive carp, the fisheries management agencies responsible for management will respond accordingly • I trust the fisheries management agencies involved in invasive carp management to manage invasive carp appropriately • I believe that I have the opportunity to voice my opinions about invasive carp management in Michigan • Science is the best way to approach invasive carp management • Problems involving invasive carp are increased by human development, such as canals that connect rivers and lakes • Invasive carp management should be a top priority for fisheries managers in Michigan • Managing the risks from invasive carp in Michigan will be important in the future **Main finding:** Low level of agreement with the item about having control over risks from Asian carp. Moderate agreement that responsible agency for Asian carp management will respond accordingly and that they trust the agency to do so. Highest level of agreement related to the opinion that management of Asian carp in Michigan would be important in the future.

3.4 Self-efficacy

What is self-efficacy? Self-efficacy is a term to describe a person's beliefs that they are able to effectively complete an action. This concept, coined by the social scientist and psychologist Bandura (1977), postulates that if people feel confident in their ability to perform a behavior, they are more likely to do so. Self-efficacy is measured with psychological scales consisting of items on the same Likert-type scale for easy aggregation into a combined measure.

Table 9 shows that several studies have demonstrated that self-efficacy plays a key role in shaping behaviors that help prevent the introduction and spread of invasive alien species. In addition to self-efficacy, studies have also measured ***perceived behavioral barriers*** that may impede action (***Table 10***).

Table 9. Self-efficacy: examples of measurement items and main findings.

Type	Measurement items and main findings
Self-efficacy – aquatic **(Golebie et al., 2024)**	**Question:** We would like to understand how you view your ability to prevent the spread of aquatic invasive species (AIS). How strongly do you agree or disagree with the following statements? *Each item was measured on 5-point scale from 1-strongly disagree to 5 -strongly agree.* • I understand what I need to do in order to minimize the risk of AIS • I am capable of performing the tasks required to minimize the risk of AIS • I feel confident in performing the steps necessary to minimize the risk of AIS **Main finding:** Self-efficacy was the strongest psychological factor that explained the intended biosecurity behaviors of aquarium hobbyists. As confidence in one's abilities increased, so did their intended actions.
Self-efficacy – aquatic **(Moore et al., 2024)** **AIS: aquatic invasive species**	**Method:** Recreational boaters were asked to what extent they agree with items listed below *(5-point scale ranging from 1-strongly disagree to 5-strongly agree).* • I understand what I need to do in order to remove AIS from my boat or equipment • I am capable of performing the tasks required to remove possible AIS from my boat and equipment • I feel confident in performing procedures necessary to prevent AIS from spreading **Main finding:** Self-efficacy was the strongest predictor of intended behavior, highlighting the need to provide instructions on how to perform AIS preventative behaviors and instill a sense of confidence among boaters.
Self-efficacy – aquatic **(Howell et al., 2015)** **AIS: aquatic invasive species**	**Method:** Bait shop owners/employees were asked to what extent they agree with items listed below (*measured on a 5-point scale from 1-strongly disagree to 5-strongly agree).* • Bait shops can play an important role in educating customers about AIS • I consider myself to be well-qualified to inform customers about AIS prevention • I feel that I could do a good job helping my customers understand AIS prevention • I feel I could help my customers adopt behaviors that will help reduce the spread of AIS **Main finding:** Strong correlation between perceived behavioral control (self-efficacy and perceived knowledge) and engagement (communicating with customers). Raising awareness and self-efficacy among opinion leaders can make them feel more confident to share knowledge about AIS with their customers.

Self-efficacy – terrestrial **(Clarke et al., 2021)**	**Method:** Forest owners were asked to what extent they agree with items listed below (m*easured on a 4-point scale ranging from 1-strongly disagree to 4-strongly agree).* • I know what invasive plants to watch for on my wooded land • I have sufficient time to inspect my wooded land for invasive plants • I have sufficient money to remove invasive plants from my wooded land • I have sufficient knowledge to prevent and remove invasive plants from my wooded land • I have access to the mechanical equipment needed to remove invasive plants from my wooded land • I know how to apply herbicides to kill invasive plants on my wooded land • I feel comfortable with using controlled burn/prescribed fire to remove invasive plants from my wooded land • I know who to contact if I have a question about invasive plants • I know who to contact to report sightings of invasive plants • I know about county, state or federal programs that assist woodland owners like me in removing invasive plants **Main findings:** Intentions to manage invasive plants were greater for those who: (i) perceived the problem to be more severe, (ii) felt a stronger sense of self-efficacy to address the problem, and (iii) had previous invasive plant management experience.

Table 10. Perceived behavioral control: examples of measurement items and main findings.

Type	Measurement items and main findings
Perceived behavioral barrier – aquatic **(Wallen & Kyle, 2018)**	**Method:** Participants were asked to indicate their level of agreement with seven statements referencing reasons for not engaging in Check, Drain, Dry (CDD) behaviors *(measured on a 5-point scale ranging from 1-strongly disagree to 5-strongly agree).* • I do not think CDD will slow the spread of aquatic invasive species • Boat ramps are too crowded • There are no cleaning stations to do CDD • I do not know what aquatic invasive species to look for • I do not think CDD behaviors are effective • I am rushed, too tired, or have no time after boating • I do not have the ability to do CDD **Main findings:** Participants were segmented into two groups based on their reported level of agreement with these statements. The groups responded differently in an experiment testing different message frames.
Perceived behavioral barrier – aquatic **(Golebie et al., 2024)**	**Question:** There are many barriers that prevent people from following recommend-dations to prevent the spread of aquatic invasive species. Please rate your level of agreement or disagreement with the following barriers (*measured on a 5-point scale ranging from 1-strongly disagree to 5-strongly agree).* • I lack the necessary resources or equipment • I do not have enough time to follow recommended guidelines • My health or physical abilities make following recommended guidelines difficult **Main findings:** Barriers were a non-significant predictor of intended behavior for aquarium hobbyists. The role of knowledge in minimizing barriers is nevertheless important and may be a useful outreach tool in other contexts.

3.5 Behavioral change

What is behavior? Human behavior is a complex phenomenon influenced by internal and external factors (Figure 1). Many theories attempt to explain environmental and conservation behavior (Eyster et al., 2022). Behavior can be performed by different actors, for example individuals or organizations, and take place in both public and private spheres (Steg et al., 2008).

It is important to note that there are different ways to measure behavior:

Self-reported behavior is a measure based on perceptions of behavior, which reflects subjective judgments about performance rather than the actual (real) behavior itself. Self-reported measures can ask about past, present or intended behavior. Sometimes they are referred to as stated behavior.

Objective behavior refers to actions or reactions that can be observed and measured independently of subjective interpretations, for example via observations made by trained observers or using devices. Other commonly used terms for objective behavior are actual, observed, or measured behavior.

In practice, it is more convenient and cost-effective to study self-reported behavior using surveys or questionnaires rather than objective (or actual) behavior using observations or monitoring and recording of real time actions. On-site, observational data collection is logistically taxing (particularly when seeking a large sample size) which explains the preferred use of self-reports over objective measures (Wallen & Kyle, 2018). Self-reporting can also be used to investigate behaviors that may not otherwise be observable. The extent to which a self-reported measure of behavior translates into real behavior is being debated and caution is warranted for potential 'intention-behavior' gaps (Kormos & Gifford, 2014; Sheeran & Webb, 2016). The accuracy of self-reports can be reduced by limited memory or knowledge of participants, or the different interpretation of descriptors uses (e.g., how many times is 'often'?).

The growing body of literature investigating people's adoption of behaviors to prevent new introductions or spread of invasive alien species is based on self-reports investigating ***intended*** biosecurity behaviors ***(Table 11)***, or ***past*** and ***present*** behaviors ***(Table 12)***.

Table 11. Self-reported intended behavior: examples of measurement items.

Source	Measurement items
Intended – aquatic **(Moore et al., 2024)**	**Method:** Intended behavior was measured using a six-item scale that was modified to resemble the goals of regional awareness campaigns *(measured on a 5-point scale from 1-never to 5-every time I go fishing).* • Drain all standing water from the boat • Conduct visual inspections of boats for invasive species • Remove plants, animals, and mud from boat • Rinse boat and trailer • Wipe down hull with a towel • Allow boat to dry before entering a different body of water

Intended – aquatic **(Seekamp et al., 2016)**	**Question:** Before moving from one lake or river to another, how often do you do the following? *Respondents could choose between "never", "frequently", "always", or "does not apply".* • "Dispose" of unwanted bait and fish parts in the trash • "Drain" all water from bait buckets, livewell, motor, or bilge • "Inspect and Remove" plants, animals, and mud from all equipment • Rinse boat and equipment with "high pressure" water • Rinse boat and equipment with "hot water" • "Dry" everything for at least 5 days
Intended – aquatic **(Wallen & Kyle, 2018)**	**Question:** Based on the message you have just read, if you saw this message on signs or billboards around the Texas lakes and reservoirs, how likely are you to do the following Clean, Drain, Dry™ behaviors the next time you boat? (m*easured on a four-point scale from 1-extremely unlikely to 5-extremely likely).* • Drain all water from my livewell, bilge, motor, and other receptacles that have been in contact with public waters before leaving that same waterbody • Clean my boat, gear, and trailer; removed any mud, plants, and animals before transporting my boat to another public waterbody • Dry my boat and trailer for at least 7–10 days before launching into other public waters • Washed my boat and trailer before traveling to another public waterbody
Intended – aquatic **(Howell et al., 2015)** **AIS: aquatic invasive species**	**Method:** Questions probed bait shop owners and employees about their willingness to do the following *(measured on a 5-point scale ranging from 1-not at all to 5-very):* • Remind customers of the AIS prevention steps required in Wisconsin • Put signs or posters in their shops • Hand out AIS publications to customers • Hand out stickers for bait containers, tackle boxes, boas, and trailers • Be a part of community efforts to stop the spread of AIS Questions asked owners and employees how often during their busiest month they perform specific outreach activities related to AIS prevention (*measured on a 5-point scale from 1-never to 5-always).* • Talking one-on-one to customers • Hand out informational materials • Display signs or posters
Intended – general **(Pradhananga et al., In press)**	**Question:** How likely are you to take the following actions in the next 12 months? *(measured on a 5-point scale from 1-very unlikely to 5-very likely).* • Donate money to an organization that aims to control or prevent AIS • Join an organization that works to control or prevent the spread of AIS • Advocate for an organization that helps to manage AIS

Table 12. Self-reported past and present behavior: examples of measurement items.

Type	Measurement items
Past – aquatic **(Wallen & Kyle, 2018)**	**Method:** Past behavior was measured by asking participants to self-report on the frequency of performing four different biosecurity behaviors *(measured on a 5-point scale with 1-never, 2-sometimes, 3-about half the time, 4-most of the time, and 5-always).* Question: Over the past 12 months, I … • Drained all water from my livewell, bilge, motor, and other receptacles that have been in contact with public waters before leaving that same waterbody • Cleaned my boat, gear, and trailer; removed any mud, plants, and animals before transporting my boat to another public waterbody • Dried my boat and trailer for at least 7–10 days before launching into other public waters • Washed my boat and trailer before traveling to another public waterbody
Past – aquatic **(Golebie et al., 2021; Shin et al., 2022)** **AIS: aquatic invasive species**	**Method:** Past behavior was measured by asking participants to self-report on the frequency of performing eight different behaviors (*measured on a 5-point scale from 1-never to 5-very often).* *Private sphere behaviors* • Looked up information about AIS • Avoided purchasing products that contribute to the spread of AIS • Took measures (e.g., washed boat or equipment) to personally reduce the spread of AIS • Talked to other people in my community about AIS *Public sphere behaviors* • Participated in a policy process (e.g., voting) related to AIS • Donated money with the intention of reducing impacts from AIS • Wrote a letter, sent an email, or signed a petition about AIS • Encouraged other people to attend an event related to AIS
Present – aquatic **(Sharp et al., 2017)**	**Method:** Recreational boaters were asked the following question *(measured on a seven-point scale from 1-every time to 7-never*). Question: How often do you or your fellow users check for hitchhiker plants and animals before entering or exiting a body of water?
Present – terrestrial **(Dolman & Marion, 2022)**	**Method:** Long-distance hikers were asked how often they do the following *(measured on a 3-point scale: "never", "sometimes" or "always")* • Remove objects from the area, even a small item like a rock, plant, stick or feather • Brush all vegetation and dirt off boots at trailheads before getting off the trail • Brush all vegetation and dirt off boots at trailheads before getting back on the trail

3.6 Summary

Table 13. Framework for selecting suitable indicators and guidance on how to measure them.

What do you want to know?	Which indicator?	What can I measure?	How to measure?	Reference table(s)[3]
Are people (more) aware of invasive alien species?	Knowledge	- System knowledge - Action-oriented knowledge - Effectiveness knowledge	Self-reported knowledge Factual knowledge	Table 4 Table 5
Can people recognize target species? Have they learned new skills?	Skills	- Identification skills - Other skills	Self-reported skills Actual skills	Table 6
How do people perceive risks posed by invasive alien species?	Risk perception	- Perceived severity - Perceived susceptibility	Typically Likert-type scales	Table 7
Do people support management? Do people think management actions are effective?	Attitudes	- Acceptability of management - Perceived control / response efficacy	Typically Likert-type scales	Table 8
Do people feel (more) confident in performing an activity? Do they perceive any barriers for doing so?	Self-efficacy	- Perceived self-efficacy - Perceived behavioral barrier	Typically Likert-type scales	Table 9 Table 10
Do people intend to change their behavior? Are people actually changing their behavior?	Behavior	- Intended behavior - Past behavior - Present behavior - Objective behavior	Typically Likert-type scales (e.g., frequency) for self-reported behavior	Table 11 Table 12

[3] Reference tables refer to tables in this report. They include specific examples of measurement items.

4 Conclusion and outlook

Knowing how to prevent and manage the impacts of invasive alien species is a complex question that requires understanding of social-ecological interactions and factors that drive human behaviors. Questionnaires and interviews are often-used instruments to measure knowledge, awareness, perceptions or attitudes regarding an environmental problem, but it requires skill to design them.

Table 13 summarizes key information on suitable indicators and how to measure them. Together with the examples and references in Section 3, it is intended to serve as guidance for researchers and practitioners with limited evaluation experience in developing and applying measurement scales in their project evaluations.

The most appropriate evaluation method depends on a project's goals, available timeline and resources. To maximize its value, evaluation needs to be considered as an integral and ongoing part of a project. If evaluation is implemented as an afterthought, it will substantially limit capabilities for conducting a proper intervention study. The inclusion of social scientists in (research) teams is recommended to improve study design and implementation.

The scoping literature review in this study was limited to selected journals and therefore does not constitute a comprehensive overview of the literature available on this topic. The findings presented in this report can provide a starting point for future work that aims to:

(i) ***evaluate outcomes of communication and engagement activities*** that aim to improve management of biological invasions. GuardIAS (focusing on aquatic ecosystems) and sister project OneSTOP[4] (focusing on terrestrial ecosystems) are obvious starting points for this line of work and provide opportunities to consider potential biases between aquatic and terrestrial ecosystems.

(ii) ***conduct systematic reviews*** to address specific research questions in relation to the topic presented in this report. Future reviews could focus on, for example, trends in research on this topic, geographical distribution of studies, or in which types of journals this type of research is published. The preliminary results from this report (based on the author's view) seem to suggest a potential bias towards studies from North America and with a focus on aquatic species. Also, studies are published in a wide range of journals, thus pointing out the importance of reading beyond one's own disciplinary boundaries. Future studies can shed lights on these, and other, important questions.

(iii) ***advance methods for measuring of knowledge and engagement*** within the context of biological invasions. The use of tested or validated measurement scales helps to build on and connect to previous studies, which increases knowledge development in invasion science. For example, while knowledge is often place-based, meaning that invasive alien species and their impacts differ between and within countries, efforts in developing or using consistent measurement scales can aid in more rigorous and systematic investigation of different types of knowledge across groups and countries.

[4] Project OneSTOP: OneBiosecurity Systems and Technology for People, Places and Pathways. More information at https://onestop-project.eu/.

5 Glossary

Action-oriented knowledge—Knowledge of behavioral options and possible courses of action ("knowing how").

Alien species—A species whose presence in a region is attributable to human activities that have enabled it to overcome the barriers that define its natural range. Also referred to as *non-native species*, *exotic species* or *non-indigenous species*. The subset of alien species that have produced a viable, self-sustaining population and may have spread are called *established* alien species.

Attitudes—Attitudes integrate beliefs, emotions, and judgments about an object (or species) or a behavior (such as conserving wildlife). It reflects concern for (e.g., the environment) or caring about something (e.g., environmental issues).

Awareness—Having information of, being conscious of a fact or something, or being informed about its existence. It can be either something tangible or a piece of information. Sometimes used as synonym of knowledge.

Barriers—Beliefs about external factors that may impede behavior.

Beliefs—What we think but may or may not be factually true.

Benefits—Beliefs that a behavior will have a positive impact.

Biological invasion—A process that transports (moves) and introduces a species outside of its natural range, intentionally or unintentionally, by human activities to new regions where it may become established and spread.

Capability—Whether we have the knowledge, skills, and abilities to engage in a behavior. This comprises psychological capability, including mental states, knowledge, and skills, as well as physical capability.

Construct—A psychological attribute or latent variable that cannot be measured directly, such as concern or interest, but only through a set of measurable indicator variables.

Drivers— (within the context of biological invasions): Factors that directly or indirectly cause changes to nature and may facilitate biological invasion.

Drivers— (within the context of predicting human behavior): Behavioral drivers refer to internal and external factors that motivate and facilitate action, as well as the barriers that can deter action.

Effectiveness knowledge—Knowledge about the relative gain or benefit associated with a certain behavior (also sometimes referred to as *relational knowledge* or *impact knowledge*).

Engagement—The process of engaging individuals or group for a clear purpose to achieve agreed outcomes. It can target different groups (e.g., stakeholders, citizens or communities) and take different forms, such as identification, analysis, planning, communication, relationship building, participation, feedback, and reporting.

Environmental education—Organized efforts to teach how natural environments function, and particularly, how human beings can manage behavior and ecosystems to live sustainably.

Evaluation—The systematic collection of information to determine strengths and weaknesses of programs, projects, and products to improve their overall effectiveness.

Familiarity—The extent of having knowledge or being aware of something. You can be a little or very familiar with something. Sometimes used as a synonym for *knowledge*.

Indicators—Specific criteria for measuring success. Indicators should articulate how you define and measure success in reaching your outcomes.

Instrument—In evaluation research, a tool used to collect and organize information either through self-reports or observation. Examples include survey questionnaires, behavioral rating scales, tests, checklists and inventories, psychometric instruments, and rating scales.

Intended behavior—Self-reported likelihood of engaging in a behavior.

Intervention—A coordinated sets of activities designed to influence or change something, for example a specific behavior.

Introduction pathways—The many ways in which species are moved from one location to another by human activities that give rise to an intentional or unintentional introduction.

Invasive alien species—A subset of established alien species that spread and have a negative impact on biodiversity, local ecosystems and species. Many invasive alien species also have impacts on nature's contributions to people (embodying different concepts, such as ecosystem goods and services and nature's gifts) and good quality of life.

Knowledge-action gap—A disconnect between what people think and do.

Likert-type scale—A type of psychometric response scale commonly used in surveys to obtain a participant's preferences or degree of agreement with a statement or set of statements.

Literacy—Having an understanding of essential principles and fundamental concepts (for example, *species literacy*).

Motivation—Internal processes that influence decision-making and behavior, both consciously (reflective motivation) and unconsciously (automatic motivation).

Native species—A species (animal, plant or other organism) within its natural range, including shifting its range, without human involvement.

Objective behavior—Actions or reactions that can be observed and measured independently of subjective experiences or interpretations.

Opportunity—External factors that make the execution of a behavior possible. This can include physical and social opportunity.

Outcomes—The changes that a project is intended to produce in individuals, groups, or communities as a result of participation.

Perception—The way an individual observes, understands, interprets and evaluates a given object, action, experience individual, policy, or outcome.

Risk perception—A subjective assessment of a threat. Risk perceptions encompass both the perceived susceptibility to, and severity of harm caused by a particular hazard.

Scale—In survey research, a set of questions that attempt to measure different levels of a single construct (or in the case of subscales, multiple related con- structs) within a population.

Self-efficacy—Beliefs about one's ability to effectively complete a behavior.

Self-reported behavior—A measure based on perceptions of behavior, which reflects subjective judgments about performance rather than the actual behavior itself.

Social norms—Informal rules that govern behavior in groups and societies.

Social psychology—Scientific discipline aimed at understanding human social behavior and the motivations, cognitions and emotions related to such behavior.

Survey—A methodological process that involves sample design, data collection, and data analysis and interpretation that is aimed at gathering systematic information about a defined population, typically through interviews or questionnaires.

System knowledge—Knowledge about environmental problems and how ecosystems work ("knowing-what").

Note: sources that were used to collate the glossary: (Clayton & Myers, 2009; IPBES, 2023; Phillips et al., 2014).

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Appendix 1 Search terms and strategy

Step 1: Selection of leading journals in the following three SSH fields: environmental education: *Journal of Environmental Education* and *Environmental Education Research*, environmental communication: *Environmental Communication* and *Public Understanding of Science*, and environmental psychology: *Journal of Environmental Psychology* and *Environment and Behavior* – as described in section 2.1.

Step 2: Initial search query. The author searched for journal articles in the selected SSH journals using the 'search anywhere' option on the journal publisher's website. The search query was formulated to account for the different synonyms used to describe invasive alien species.

List of search terms: [All: "invasive species"] OR [All: "invasive alien species"] OR [All: "introduced species"] OR [All: "non-native species"] OR [All: "alien species"] OR [All: "non-indigenous species"] OR [All: "exotic species"] OR [All: "biological invasion"] OR [All: biosecurity)] OR [All: "invasive weeds"] OR [All: "invasive alien plants"] OR [All: "introduced plants"] OR [All: "non-native plants"] OR [All: "alien plants"] OR [All: "non-indigenous plants"] OR [All: "exotic plants"]

Step 3: Screening of initial results. The author screened the titles and abstract of the initial search results for each journal search. In case no abstract was available, the full pdf was opened and screened. At this stage, the following results were excluded: (i) article types other than research articles were excluded (e.g., commentaries and book reviews) and (ii) articles that mentioned invasive species (or another search term) in the text (e.g., in the introduction or discussion) but did not study it as a topic.

Step 4: Screening and reporting of selected results. The author read the selected articles and extracted the following information: (i) empirical study (y/n), (ii) main findings, and (iii) cited papers of interest to the review. Steps 3 and 4 were repeated for the cited papers until saturation was reached. Selected papers were compiled in an Endnote library.

Table 14. List of selected journals and search results.

Journal name	ISSN	Initial search result	Selected result
Environmental Education Research	1940-1892	90	8
Journal of Environmental Education	1469-5871	41	8
Environmental Communication	1752-4040	27	6
Public Understanding of Science	0963-6625	37	2
Journal of Environmental Psychology	1522-9610	16	6
Environment and Behavior	0013-9165	14	3