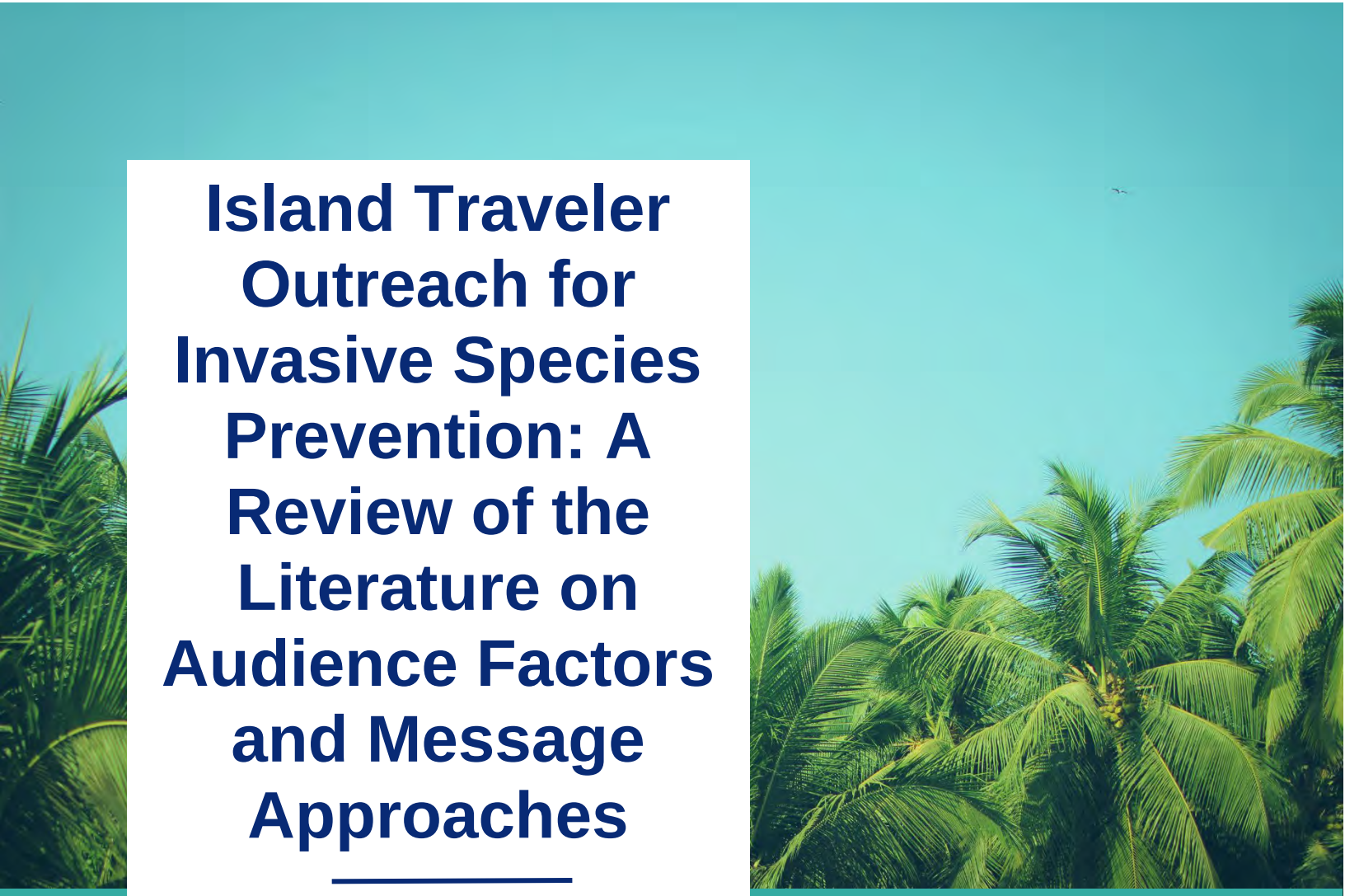


Island Traveler Outreach for Invasive Species Prevention: A Review of the Literature on Audience Factors and Message Approaches

May 2025

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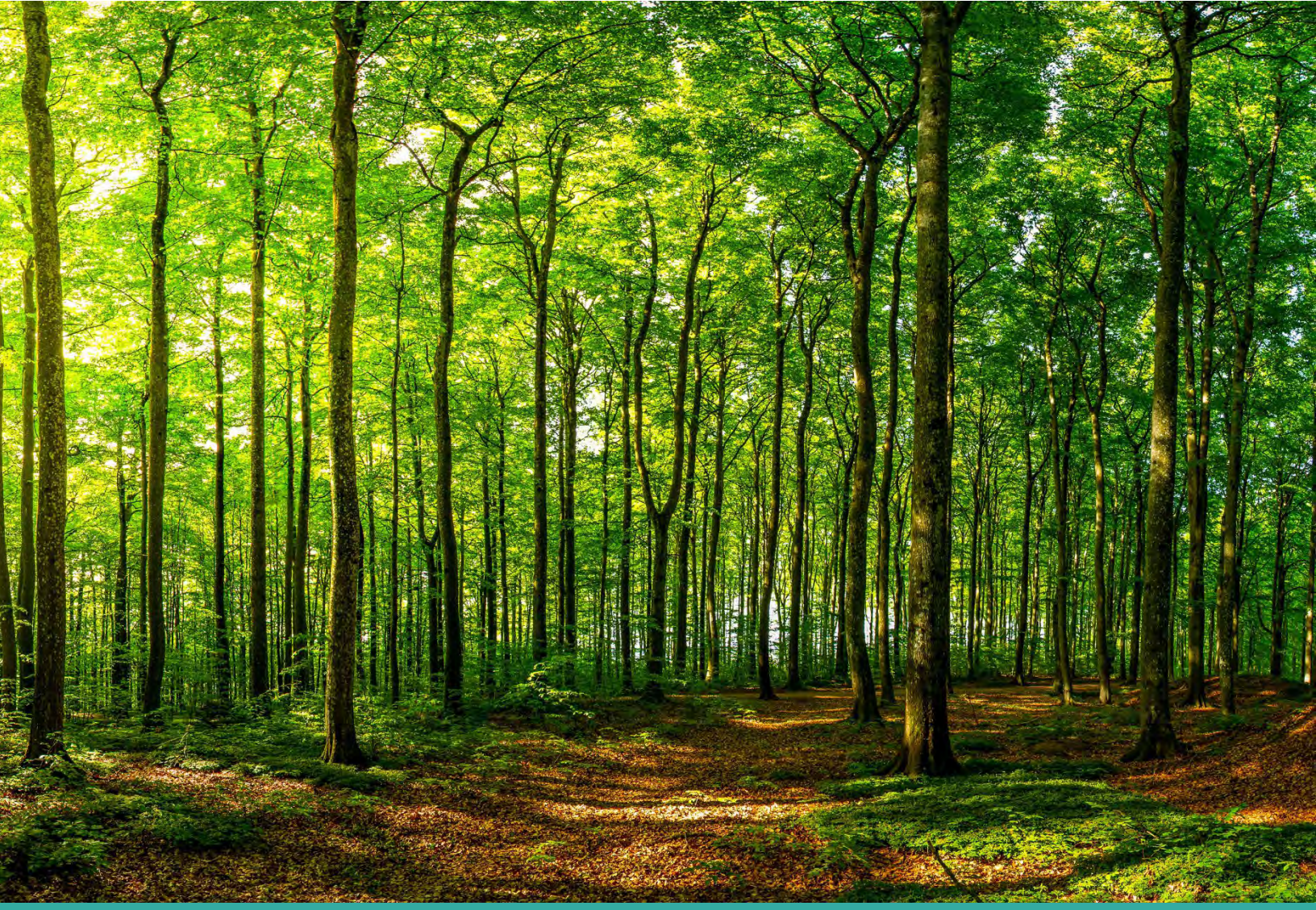
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Executive Summary

Executive Summary: Introduction

Report section: Introduction — Page reference: 4 - 10

The goal of this report is to provide a review of existing literature on behavior change interventions related to invasive species prevention, specifically in the context of island travelers.

Islands present a biosecurity challenge, as they contain unique and fragile ecosystems that are particularly vulnerable to invasive species. Native species located on islands often cannot cope with introduction of new species; 75% of known extinctions were island species [1]. At the same time, islands are popular destinations for travelers, including both tourists and residents traveling between islands. These travelers have the potential to carry species with them, introducing new invasive species to an island or carrying existing invasive species from one island or area to another.

In order to design effective materials and campaigns to promote behavior change among island travelers, two frameworks are useful: social marketing and the COM-B model (capability, opportunity, motivation) [2]. These frameworks encourage consideration of the specifics of a given site (audience, current behaviors, perceived benefits/barriers, and desired behaviors) before selecting appropriate interventions. These interventions might target capability (physical or psychological ability), opportunity (external factors that encourage or discourage the behavior), motivation (both conscious and automatic decision-making), or a combination of these three. After interventions are put in place, their success should be evaluated and changes made as needed.

Report section: Review of Existing Literature — Page reference: 11 - 40

We conducted a thorough review of existing literature related to invasive species prevention and behavior change. The resulting list includes evaluations of behavior change interventions or campaigns as well as survey or interview studies describing current behaviors and motivations related to prevention. In addition, we conducted interviews with invasive species specialists at islands across the United States and incorporated their perspectives to provide context and depth to our findings. In our findings, we emphasize causal conclusions where possible, but as there are relatively few of these studies in the realm of invasive species behavior change, we also draw on correlational studies as well as meta-analyses to add robustness to our results. Our review showed that there is no perfect answer to inspire behavior change across contexts. Instead, it is important to consider the audience and their current behaviors, the perceived benefits and barriers, and the desired behavior you are trying to promote. Our review provides several contexts that are useful to informing the decided upon direction.

B1: Audience and Current Behaviors

- Travelers' knowledge about invasive species varies, but solely increasing knowledge or awareness is unlikely to change behavior.

- Capturing travelers' attention is similarly important but again is not sufficient to change behavior.
- Avid travelers or recreationalists are likely already aware of invasive species and engage in some prevention steps, but it can be difficult to persuade them to take more arduous steps (e.g., asking boaters to pressure wash their boats) or to take every step every time.
    - Messages highlighting self-efficacy or procedural knowledge are helpful here.
    - Repeated messaging and stage-of-travel messaging are also important to help already knowledgeable travelers remember to take prevention steps.
- Social norms messages are effective, particularly among less-engaged travelers.

B2: Benefits and Barriers

- Opportunity: External factors such as infrastructure, incentives, and message timing can incentivize behavior; their lack can provide barriers that less-motivated travelers are unlikely to overcome.
- Motivation: Environmental values and personal relevance/susceptibility motivate travelers to take prevention steps, while the perceptions of invasive species as attractive or not harmful makes them less likely to do so.
- Capability: Self-efficacy or procedural knowledge messages can help overcome barriers related to travelers' inability or perceived inability to take prevention steps,

B3: Desired Behaviors

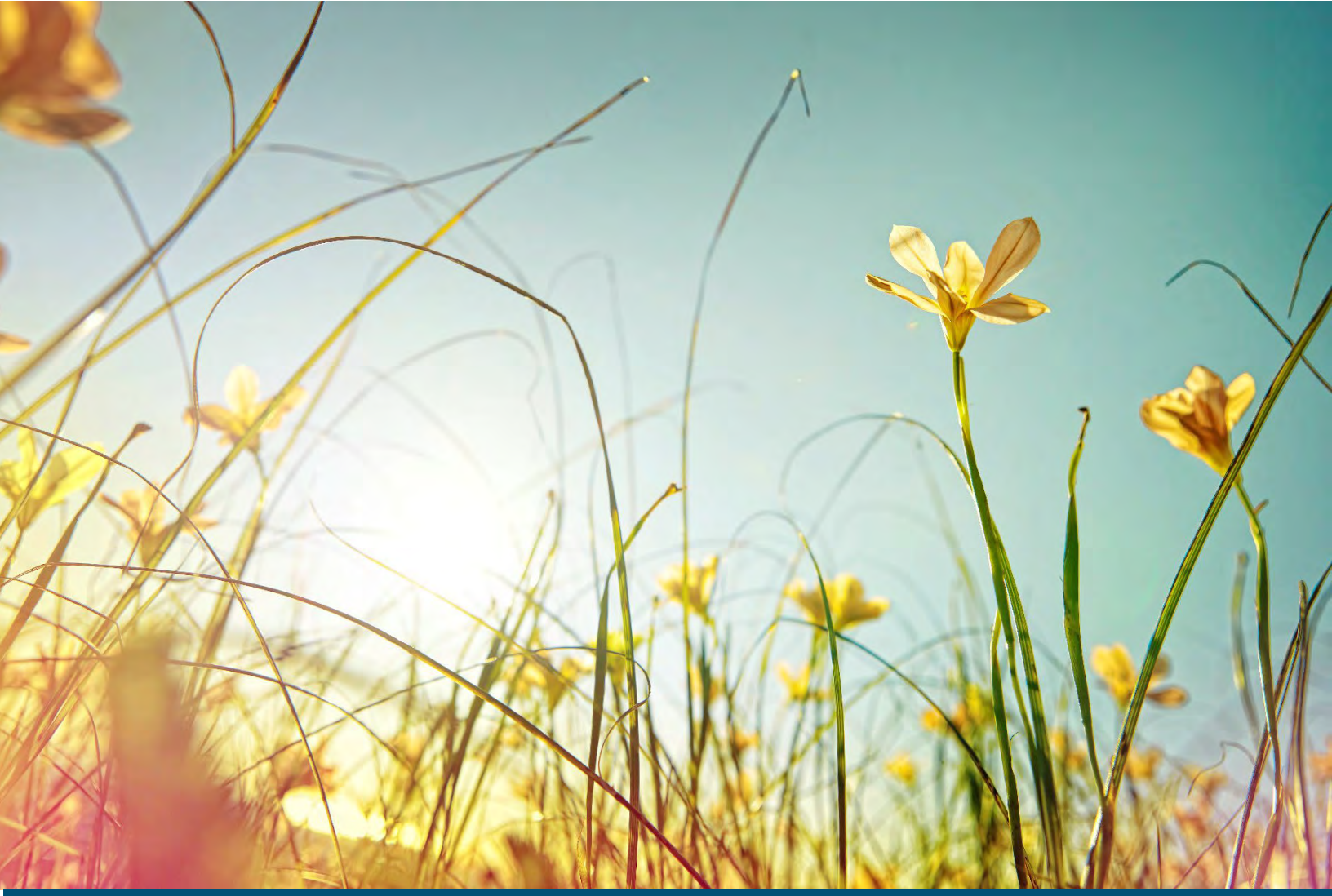
- For behaviors with low complexity but high importance, "nudge" interventions may help.
- Repeated messaging and social norms messaging are useful for repeated behaviors.
- Fear appeals or loss messaging are effective, particularly for one-time behaviors or for initial messaging to a new audience.
    - Fear/loss messaging should also include efficacy information, though.

Report section: Recommendations Page reference: 41 - 51

Every site will be different; it is important to consider your specific context when choosing interventions.

It is important to evaluate outreach campaigns in order to determine what works for your site and what doesn't.

Self-efficacy messages, stage-of-travel messages, nudges, social norms messages, and loss appeals (with efficacy information) can work; table 2 provides further details on context and audience for each appeal..



Section 1: Introduction and Background

SECTION 1.1: THE PROBLEM OF INVASIVE SPECIES

The National Park Service and Colorado State University are collaborating on a project that aims to use communication science to reduce the spread of invasive species to islands through travelers. This first part of the project included two pieces: 1) a review of existing literature on the spread of invasive species to islands, with a focus on experimental interventions that aim to change travelers' behaviors, and 2) interviews with park managers and other invasive species specialists with connections to U.S. islands. We believe that recommendations for designing outreach are best drawn from a synthesis of these methods, and so we combine insights from both parts of the project throughout this report rather than describing them separately.

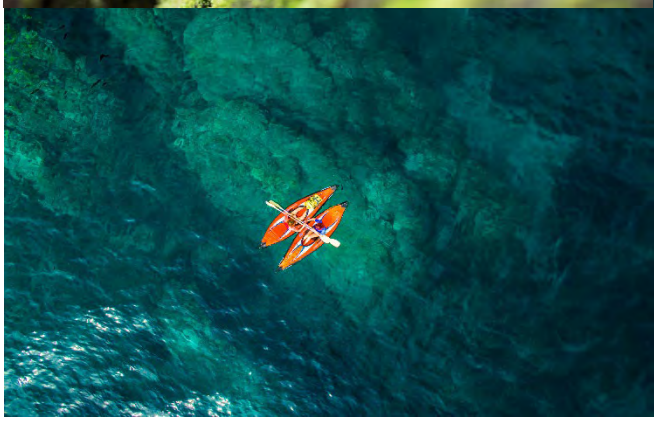
Look out your window, go to a park, or visit a natural area somewhere and chances are you'll find an invasive species of some kind. Invasive species are species that establish and spread in geographic locations where they are not native, and they are an increasing concern for natural resource managers [3]. Across the U.S., invasive species have a significant impact on ecosystems, and they were recently ranked fifth among direct drivers of change in nature [4]. These species can be introduced deliberately, such as intentional release for economic or aesthetic reasons [5], or inadvertently, such as introduction through the ballast water of vessels [6] or the movement of firewood [7]. Once they are introduced, invasive species are extremely difficult to eradicate. As a result, invasive species are now widespread in many geographic locations, leading to significant impacts. Economically, some estimates suggest they are as costly as natural disasters [8]. Ecologically, invasive species threaten native flora and fauna biodiversity [9], increase the risk of native species extinction [10], and altering the broader ecosystem [11].



Although invasive species are a threat across the U.S., islands are particularly vulnerable. There are over 23,000 islands under U.S. jurisdiction [12], and each island is an isolated and unique ecosystem. Islands contain 20% of Earth's biodiversity [1], in part because islands have a higher percentage of endemic species compared to mainland locations and outside species are less likely to be transported to islands naturally [13]. Endemic species on islands have limited experience with herbivores or predators and nowhere to escape to [10], [14]. This makes them vulnerable to non-native species; they generally can't adapt quickly enough to compete with introduced competition for resources or to avoid invasive predators. As a result, island native species have seen steep population declines. Approximately 50% of threatened species are endemic to islands, while 75% of known extinctions were island species [1]. A 2012 review concluded that the introduction of invasive species is far more likely to have a significant impact on the diversity of native plants or animals on islands than on mainlands [9].

Given the unique ecosystems of islands, and the cost of addressing risks posed by invasive species, it is important to examine how invasive species are first introduced to an island or how invasions spread. One pathway is travelers, including both visitors and island residents. Travelers are not the only or even the primary vector for invasive species spread [15], but they do offer a potentially cost-effective and feasible pathway that can help reduce the spread of invasive species on islands. Travelers to islands include tourists, who may engage in outdoor recreation to experience the island's biodiversity and natural beauty [16]. In a 2015 meta-analysis examining the impact of tourism in introducing invasive species, researchers found that non-native species were richer and more abundant in tourist locations than in control locations [17]. This tells us that travelers are likely transporting invasive species to new locations they visit, and popular vacation activities such as horseback riding, hiking, and boating provide opportunities for further spread by putting travelers in contact with natural environments [17]. This is problematic because islands are often desirable vacation spots; they attract visitors from all over the world, and those visitors have the potential to bring a variety of invasive species with them [18]. Biosecurity measures to protect against this may also be less supported by visitors than by residents [19], making them difficult to implement.





In addition, both tourists and residents move between islands, which can make it difficult to contain invasions or prevent secondary spread. For example, on the island of Hawai‘i, the annual Merrie Monarch festival draws in hundreds of visitors whose cultural practices warrant the transport of various plant materials. Each year, residents are reminded that at the conclusion of the event that all plant material must remain on Hawai‘i island to prevent the continued spread of an invasive fungal pathogen [20]. In this example, many travelers are not tourists from the mainland but residents of other islands, highlighting the importance of considering “travelers” as a broad category. Identifying and targeting specific traveler audiences is one component that can be addressed in a behavior change campaign.

SECTION 1.2: SOCIAL MARKETING FRAMEWORK

Since our goal is to change travelers’ behavior to prevent the spread of invasive species, social marketing is a helpful framework to apply to the eventual outreach campaign. Social marketing uses traditional marketing principles alongside behavioral economics, behavior change theory, and communication science to create initiatives that shape and influence behavior for individual and societal benefit [21]. While it is often seen as a tool for simple communication or social media campaigns, social marketing is a comprehensive framework for designing effective behavior change interventions.

The power of social marketing lies in its strategic integration of multiple approaches. In the context of visitor use management, implementation is most successful when it draws on the education, enforcement, and engineering approaches that will be familiar to federal agencies involved in natural resources management [22]. Not every initiative will equally leverage all three approaches, but beginning with a holistic consideration of how they work together to create conditions for behavior change ensures a cohesive strategy that effectively shapes visitor behavior.

Several established frameworks guide the social marketing process, with five key components:

- **Behavior Selection** - Identifying a single, discrete behavior that: 1) directly impacts desired outcomes, 2) can be clearly defined, 3) has potential to scale, and 4) can be effectively measured. This first step is critical to ensure that you focus the outreach campaign on the behaviors most likely to create meaningful change.
- **Audience Characterization** - Analyzing and segmenting potential audiences to pair each audience with the most needed behavior. This involves understanding demographic, psychographic, and behavioral characteristics to tailor approaches effectively.
- **Barrier and Benefit Analysis** - Examining both the motivations that drive desired behaviors and the barriers that prevent adoption. This deep understanding of behavioral drivers helps you select the best strategy.

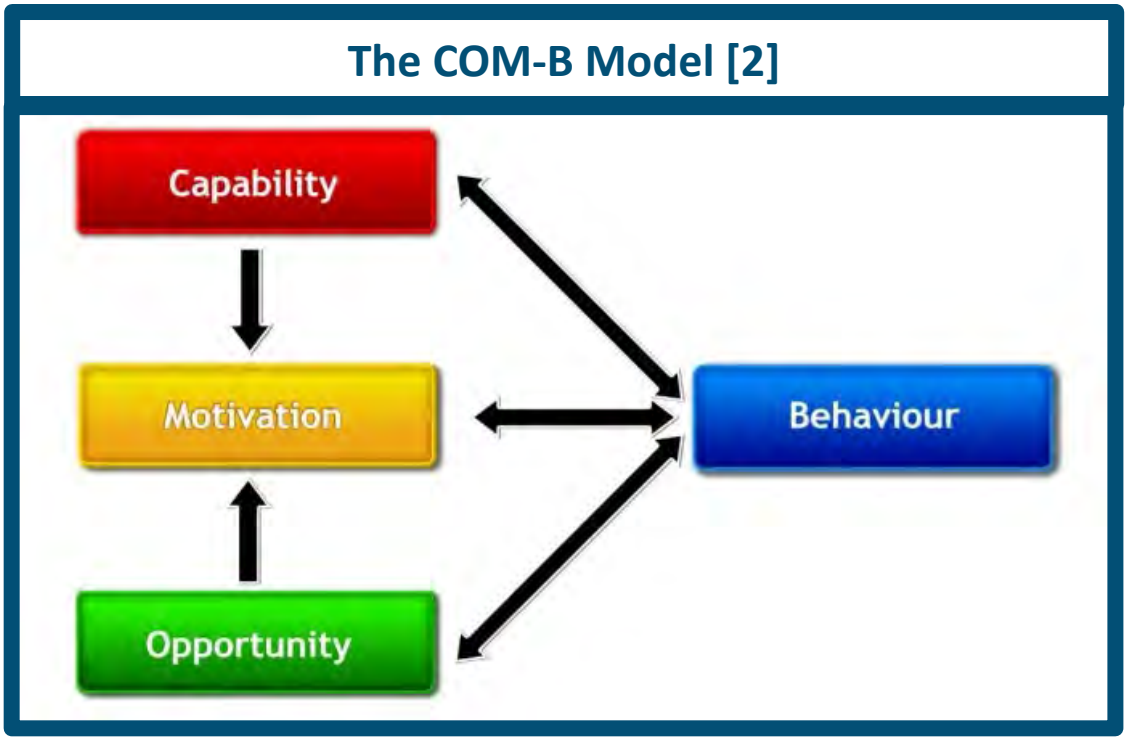
- **Strategy Development and Implementation** - Designing interventions based on audience insights that address identified barriers and leverage existing motivations. Interventions are then piloted before you progress to full-scale implementation.
- **Evaluation** - Systematically assessing both process and outcomes to determine the effectiveness of interventions, identify areas for improvement, and provide evidence for continued investment or expansion. Evaluation should be planned from the beginning and should be integrated throughout the campaign lifecycle.



SECTION 1.3: THE COM-B MODEL

While this framework provides a comprehensive approach to behavior change, the communication elements—particularly message framing and audience targeting—remain important. Communication strategies can amplify the effectiveness of a campaign when they are deployed strategically, and they are essential throughout the social marketing process. In the sections that follow, we focus specifically on these communication dimensions—examining evidence-based message framing techniques and audience characteristics that influence invasive species prevention behaviors. The research shows that how messages are crafted, which channels are selected, and when information is delivered can substantially impact adoption of preventative behaviors.

While our report concentrates on communication strategies, these elements function as part of the broader, integrated behavior change framework described above. Communication tactics form a critical subset of the intervention toolkit, but they do not operate in isolation. Multiple other factors that influence behavior came up in our review of existing literature, ranging from infrastructure availability to biosecurity laws and regulations. These factors are both a common theme in our review and an integral part of behavior change generally, and along with social marketing, the COM-B (Capability, Opportunity, Motivation – Behavior) model is useful for incorporating the literature on audience factors demonstrated to predict or relate to invasive species prevention behaviors. The COM-B model [2] is a practical framework that can help us examine audiences and behaviors as well as inspire ideas for behavior change strategies. COM-B draws on multiple foundational theories [23], [24] to provide a framework for systematically addressing behavior change dynamics.



The COM-B model identifies three essential components that must align for behavior change to occur: capability, opportunity, and motivation [2]. Capability refers to an individual's psychological and physical capacity to engage in a behavior. This includes knowledge, skills, and ability. In the context of invasive species prevention, capability would include travelers' knowledge of the threat and of necessary prevention steps along with their physical ability to take those steps. The second component is opportunity, which includes external factors that either help people engage in a particular behavior or discourage them from doing so. Both environmental and social influences are part of this category. For invasive species prevention, opportunity factors would include available infrastructure such as cleaning stations, message timing, and social norms encouraging invasive species prevention. Finally, motivation involves the cognitive and emotional processes driving an individual toward or away from a behavior. This includes travelers' habits, emotions, attitudes toward invasive species or the environment more broadly, and conscious choices. When considering the benefits and barriers to invasive species prevention behaviors and other audience factors, we categorize these based on Capability, Opportunity, and Motivation (section 2.2).

These three factors influence each other over time. For example, improving someone's capability through training can increase their motivation by making them feel more confident. Similarly, creating better opportunities in their environment can make it easier for them to act when they are motivated. On the other hand, a lack of capability or opportunity can lower motivation and reduce the chances of the behavior happening.

As an example of using communication approaches within the COM-B model, we offer Table 1 from Abrams and colleagues [25]. They used the COM-B model to guide messaging and strategy to encourage campers to avoid attracting wildlife.

Example of COM-B Model in a Communication-Driven Behavior Change Initiative Targeting Campers

	Type of	Involves…	Intervention Component(s)
Capability	**Physical**	**…a person's bodily or physical abilities (e.g., balance, strength, dexterity).**	• Provided packing tips sent by email before the trip and organization tips upon arrival to enhance ease of behavior in park (i.e., less physical and mental effort to gather and store attractants)
	Psychological	**… a person's mental functioning (e.g., understanding, memory, attention).**	• Relayed desired behaviors in three key messages • Used a rhyming summary message to enhance behavior recall • Used alliteration to enhance attention and recall to motivational message • Offered visual representations of desired behaviors and relevant items in all messaging
Opportunity	**Physical**	**…inanimate parts of the environmental system and time (e.g., infrastructure, financial and material resources).**	• Strategically placed signage reinforcing the most relevant behavioral messages at decision-making locations (entrance, campsites, shared use areas) • Bear boxes at two of the four parks
	Social	**…other people and organizations (e.g., culture, social norms, governance).**	• Used a normative message highlighting the trending behavior of campers working to change • Provided positive and negative feedback through campsite report cards left at unattended campsites
	Reflective	**…conscious thought processes (e.g., plans, evaluations, identity, attitudes).**	• Included a hook, "clean campsite, clear conscience," to align desired behavior with campers' experience goals and avoiding feelings of guilt • Focused on potential disruptions to campers' experience rather than harm to wildlife exclusively
Motivation	**Automatic**	**…habitual, instinctive, drive-related, and affective processes (e.g., desires and habits, biases).**	• Sought to reduce psychological distance of costs and benefits for campers to responsibly manage wildlife attractants • Salience of consequences and fear from bear incidents in one park allowed for comparison pre/post (unplanned, post-hoc analysis)



Section 2: Review of Existing Literature

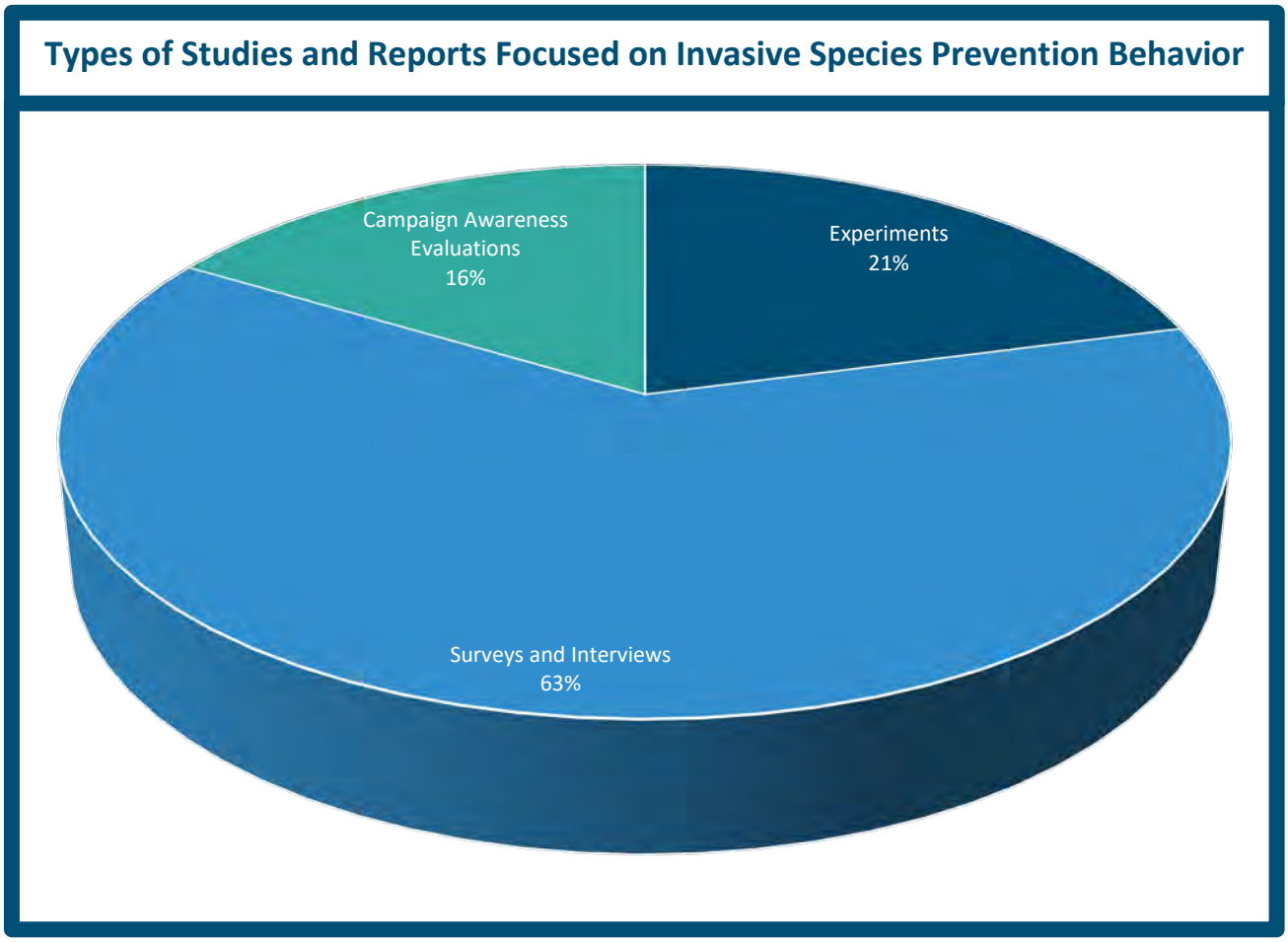
Visit a large park somewhere in the US and you might find a sign about preventing the spread of invasive species. Stop by a marina, boat launch, outdoor recreation store, or environmental tourism company and you might notice a sticker or brochure for a prevention campaign. Invasive species outreach campaigns have grown in number in recent years, but how effective are these outreach methods? Is a particular type of message more likely to persuade people to engage in invasive species prevention behavior? For example, is it better to use signs that provide knowledge about the impact of invasive species, teach people how to do prevention steps, appeal to people's love of nature, or something else entirely?

To explore these ideas, we reviewed existing research on invasive species prevention and behavior change. Our searches were conducted between November 2024 and April 2025, with multiple steps and repeated searches. In reviewing this body of research, we wanted to answer one primary question:

What does existing research tell us about audiences and communication campaigns or interventions to motivate invasive species prevention behavior change?

Answering questions like this is simpler with data from rigorous experiments, and in our review, we focused on these studies where possible. Given the lack of experimental research in the context of invasive species prevention behavior, though, we also drew conclusions from related qualitative and quantitative research that did not necessarily answer causal questions. In order to provide a complete picture, we also reviewed reports and studies that evaluated invasive species prevention campaigns by looking at the reach of the campaign or the public's awareness of the messaging. These studies emphasize awareness and education, often not measuring behavior change, but they provide useful insights. Our final review included 59 studies in the context of invasive species prevention. Since the number of experiments focused on invasive species behavior change is small (n = 13), we also included some particularly well-designed or robust experiments looking at environmental behaviors more broadly and applied them to the context of invasive species. Given the small body of experimental literature focused on invasive species behavior change, we rely more heavily on these broader studies.





Back to our question: what do we know about promoting behavior change in invasive species prevention?

Frustratingly, the answer is "it depends." However, there are some broad takeaways supported by scientific literature, so we'll start with those.

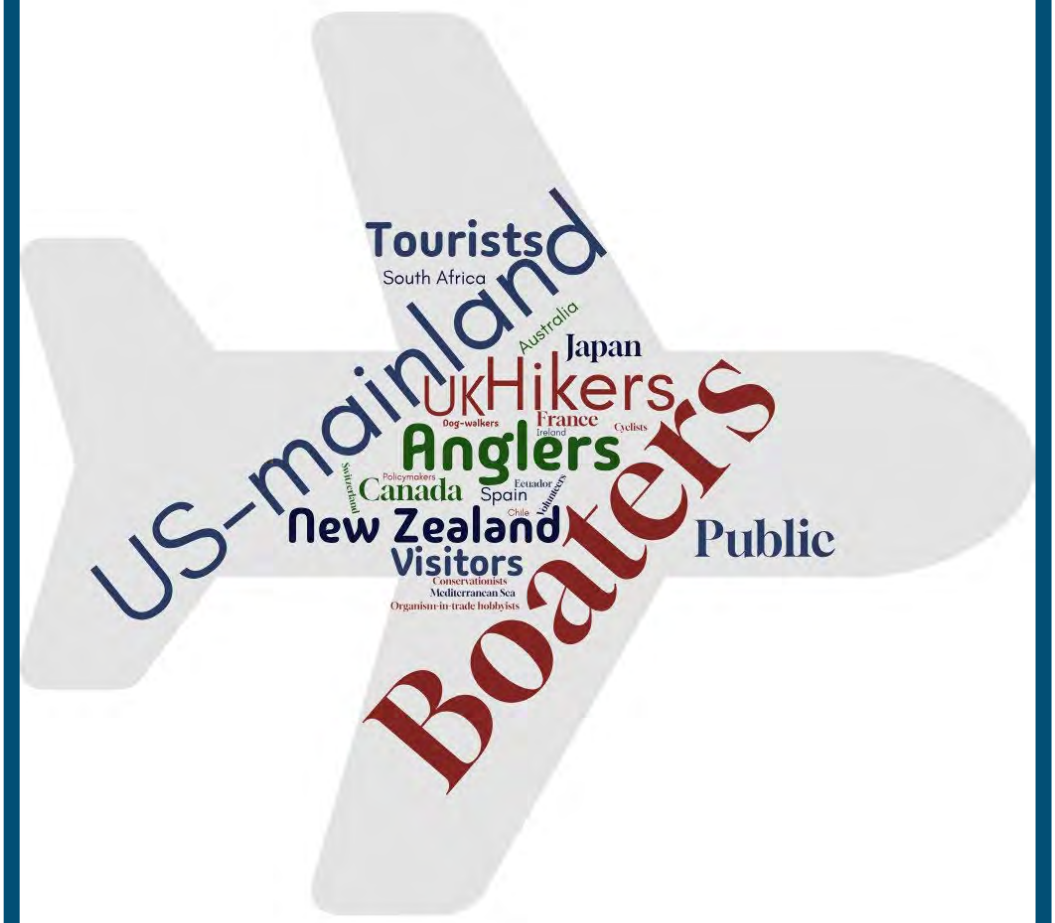
SECTION 2.1: AUDIENCE AND CURRENT BEHAVIORS

One factor "it depends" on is the audience.

This can mean many, many things. Social marketing highlights the importance of audience segmentation, or understanding different groups within your audience and tailoring outreach to each group's needs. This can include comparisons by demographic groups (age [26], gender, education level, or domestic versus international travelers [27]), but more importantly, it can also include deeper comparisons: travelers' experience with invasive species prevention, perception of invasive species, engagement in outdoor activities, and more. The research we reviewed included a broad range of audiences – too broad to cover here. (We provide a visual word cloud summary below,

where larger words indicate higher frequency. Appendices A, B, and C also include audience information where available.)

Word Cloud of Audience Segments in Reviewed Studies



SECTION 2.1.1: KNOWLEDGE

One often-mentioned audience factor is knowledge of invasive species, and increased knowledge or awareness is sometimes measured as a desired outcome. In our interviews, many invasive species specialists focused on the goal of increasing awareness or knowledge about the threat of invasive species, and similarly, some studies in our review highlighted correlations between increased knowledge and prevention behaviors or behavioral intentions [26], [28]. It makes logical sense; we

would expect that more knowledgeable travelers would be more likely to take prevention steps, suggesting that campaigns focused on education and outreach are likely to be effective.

However, experimental research tells a different story. Of the invasive species experiments we reviewed, perhaps the best designed study focused on this question. Does increasing travelers' knowledge of invasive species cause behavior change? This study was conducted at a hiking trailhead at Mt. Myoko and Mt. Hiuchi in Japan [29], where the researchers compared four different message conditions by posting one of four signs just before the boot brush station located near the entry. One sign provided factual knowledge ("Please clean your footwear to prevent introduction of invasive plant seeds. Seed introduction into natural areas causes problems"), and another provided the same factual knowledge but added a note of procedural knowledge ("Please remove soil from your footwear sole using the mat/brush"). The researchers also included a blank sign as a control condition[1]. They then observed whether hikers cleaned their shoes as they passed the boot brush station.

What did they find? The factual knowledge condition had no effect [29]; participants who saw just the factual knowledge message were no more likely to stop and clean their boots than participants who saw a blank sign.

Despite these results, it is difficult to draw firm conclusions based on a single study. While we did not find any other invasive species prevention studies specifically examining whether knowledge causes behavior change, there are many studies examining outreach efforts to encourage behavior change in a wide variety of other contexts. Some of those look at interventions that are similarly useful in the world of biosecurity. This allows us to draw on that vast body of research, including meta-analyses, to provide valuable insights.

So, what do meta-analyses say about the importance of audience knowledge? Do they support the results of the Mt. Myoko study? To answer these questions, we can look at a 2019 meta-analysis by Nisa and colleagues, which included 83 studies examining behavior change interventions in the context of climate change [30]. This was a particularly well-designed meta-analysis because the authors employed a strict inclusion criteria and limited their analysis to only randomized controlled trials. Moreover, the Nisa meta-analysis exclusively included field experiments, demonstrating that these interventions work not only in the lab but also in real-world contexts. The authors found five types of interventions across the 83 studies: providing knowledge or information, social responsibility and values appeals, encouraging engagement (e.g., goal-setting or commitment), social comparison, and choice architecture or nudges. Examining results across all those studies, the authors concluded

[1] The fourth condition in the Mt. Myoko study employed a nudge intervention [29], which is discussed in more detail in section 2.3.

that interventions solely providing knowledge or information had little impact. Participants who received this type of intervention increased their probability of behavior change by only 3.4%.

This may seem like a surprising result; a link between knowledge and behavior seems so intuitive that it's strange to realize this link isn't as reliable as we may have thought. However, these results and others [29], [30], [31], [32], [33], [34], [35] show a disconnect between knowledge and behavior, indicating that just providing knowledge isn't enough. That is, increased knowledge may be related to prevention behavior but, by itself, is unlikely to cause people to engage in prevention steps. Supporting this idea is another 2019 meta-analysis, this time focusing on conservation campaigns conducted by the nonprofit Rare [36]. This meta-analysis looked at the results of 84 social marketing campaigns that Rare conducted around the world and concluded that knowledge is not directly linked to behavior change; rather, the authors wrote, certain kinds of knowledge change people's attitudes about the benefits of the proposed action and their beliefs about whether such behavior is commonly accepted by others or is the right thing to do. Then, as a second step, changed attitudes and beliefs lead to changed behavioral intentions and eventually to changed behavior. This meta-analysis was not as well-designed as the Nisa meta-analysis [30], though. For example, it exclusively included studies from the Rare organization, and other researchers have reported that Rare studies may not include enough of their results to allow others to replicate their conclusions [37]. Since the Rare meta-analysis did not provide a list of included studies, it is particularly difficult to verify their findings. These studies are also quasi-experiments using pre- and post-tests rather than randomized controlled trials as in the Nisa meta-analysis. Even so, the results are grounded in many theories of behavior change, which emphasize that knowledge by itself is unlikely to change behavior.

Knowledge by itself is unlikely to change behavior.

SECTION 2.1.2: ENGAGEMENT AND FREQUENCY OF TRAVEL

Another audience factor relates to traveler engagement and frequency of travel. In our review and in our interviews with invasive species specialists, we noted differences in behavioral interventions based on travelers' degree of engagement with invasive species or with outdoor recreation as well as their frequency of travel to islands or affected areas. As these are often related to one another, we discuss them here in combination. Engagement referred to participation in recreational activities [38], [39], particularly boating, fishing, and hiking. Frequency of travel was typically discussed in research related to boaters and anglers traveling between bodies of water [40], [41], but our interviews also highlighted the differences between one-time visitors and island residents—who are more likely to travel frequently to the mainland or to other nearby islands.

Based on these distinctions, we might expect that frequent travelers who are highly engaged in outdoor recreation would be likely to engage in prevention behaviors, and that is somewhat true. Avid recreationists are more likely to report that they take prevention steps [42], although they may not always do so or may not do every step every time. Unfortunately, invasive species spread can happen in those instances of 'not always' or 'not every time' [40], indicating a need to continue reaching out to this audience.

However, highly engaged travelers appear to be some of the most difficult to persuade using typical methods. For example, one experiment with over 3,500 boaters across western US states [39] tested 19 different message frames (e.g., highlighting the ecological losses from invasive species, focusing on the participant's identity as an angler, etc.) against the messaging used in the standard Clean, Drain, Dry campaign that has been widely adopted [43]. The authors found that the message boaters saw had no impact on their willingness to take prevention steps. Given the design of this experiment, though, the results could mean several different things. The authors' control condition was the Clean, Drain, Dry message, and while survey data shows that biosecurity behaviors have improved since this campaign began [43], we were unable to find any experimental research evaluating Clean, Drain, Dry. The results of the Western States boater study indicate that none of the other messages were more effective than Clean, Drain, Dry but don't necessarily prove that the baseline message is more effective than no message.



Another interpretation of this study involves the engagement of its audience. Participants in the Western States boater study [15] were experienced recreationists who already knew about aquatic invasive species and were already taking many steps to prevent their spread. Given that, the results don't necessarily mean that none of the message frames were more effective than others at promoting behavior change; they tell us that when highly-engaged travelers are already taking some prevention steps, their behavior doesn't change regardless of whether they're shown a Clean, Drain, Dry message or one of the other message frames tested. Similarly, another experiment [44] with wading anglers found that the message they were shown made no difference in their willingness to take prevention steps, but again, the study participants tended to be avid anglers who fished more frequently than the general population. Given these individuals' prior knowledge and experience, as well as their existing commitment to actions such as allowing their boats or fishing gear to dry between uses, it's not surprising that exposure to a single message in a single experiment accomplished little.

Highly engaged travelers appear to be some of the most difficult to persuade using typical methods…when they are already taking some prevention steps, their behavior doesn't change when they're shown a prevention message.



In contrast, an experiment in Texas [45] looked at people on the opposite end of the spectrum: high perceived barriers to taking prevention steps or little previous commitment to taking such steps. They examined the effect of several message frames on boaters' biosecurity intentions. Like the Western States boater experiment [39], the Texas boater experiment used standard language from the Clean, Drain, Dry campaign ("Don't be a carrier for aquatic invasives") as the control condition and compared it with three experimental messages emphasizing regulation ("It's the law"), descriptive norms ("Most Texans clean, drain, and dry"), or injunctive norms ("Texans expect you to clean, drain, and dry") [45].

Control and Regulation Messages [45]





They conducted an analysis where they segmented their participants into groups: low or high past behavior and low or high perceived barriers to implementing the prevention steps. With this approach, they found that the messages focusing on regulation or on injunctive norms (what others expect of them) were particularly effective among participants who were less likely to already be taking prevention steps and who reported high barriers to doing so. This suggests that messages appealing to social norms might be a useful approach for reaching audiences with low motivation to engage in invasive species prevention.

Messages appealing to social norms might be a useful approach for reaching audiences with low motivation to engage in invasive species prevention.

For highly motivated audiences, the wading angler study [44] and Western States boater study [39] offer some additional insights. In the wading angler study [44], the authors conducted additional analyses showing that participants with a strong sense of self-efficacy (the perception that the participant is able to do the recommended action) were more likely to take prevention steps and less likely to view the message as manipulative. Similarly, the Western States boater study [39] and others [46] found that boaters were generally motivated to take prevention steps but that they were less likely to commit to more difficult steps such as pressure washing their boats than to easier steps such as cleaning and draining their boats. Other studies in our review similarly highlighted self-efficacy messages as a useful approach and as one of the best predictors of prevention behavior [47]. A 2016 meta-analysis of 204 experiments confirms this; the researchers found that improving self-efficacy consistently led to behavior change [48]. The experiments included in this meta-analysis were focused on health behaviors rather than invasive species prevention, but the results still provide useful insights that can be applied to our context. Self-efficacy messages related to invasive species could include providing procedural knowledge about how to take prevention steps as in the Mt. Myoko study [29], highlighting the ease of certain prevention steps while focusing less on more arduous steps that people may not be willing to take [39], or addressing common barriers [28].



Self-efficacy messages could also be tailored to a particular stage of travel, another aspect of audience segmentation and another factor that contributes to "it depends." In our interviews, many invasive species specialists highlighted this lack in existing messaging, noting the need for consistent messages that target traveler behaviors at each stage: during packing and planning, prior to departure, upon arrival at the island, and upon departure from the island. Several studies in our review similarly noted that single-exposure messaging is relatively ineffective and highlighted the importance of repeated exposure [44], [49]. For example, the invasive species specialists in our interviews noted that travelers departing from the mainland or arriving at the island may be asked if they are carrying certain items, such as fruit or other plants. However, travelers may be reluctant to

surrender their items at that point. In contrast, messages including self-efficacy steps specific to each stage could discourage travelers from packing these items in the first place.

So, where does this leave us? For less motivated audiences, injunctive norms messages (what others expect you to do) are likely to work well. For more engaged audiences who are already knowledgeable about invasive species, though, messaging is probably not enough. Our review of the literature shows that this audience is already highly motivated to take prevention steps, and so targeting motivation through messaging alone may have diminishing returns. Yes, self-efficacy messaging shows promise by addressing perceived barriers. But even self-efficacy messages won't be enough if the perceived barriers are real barriers. For example, if boaters don't pressure wash their boats because they don't have access to a pressure washer, messaging won't change that. Instead, a comprehensive strategy for avid recreationalists might combine targeted normative and efficacy-focused messaging with investments in infrastructure and systems that make prevention behaviors easier to perform, addressing the barriers and benefits in each of the COM-B categories (Capability, Opportunity, Motivation - Behavior) that we cover next.

SELF-EFFICACY MESSAGING SHOWS PROMISE BY ADDRESSING PERCEIVED BARRIERS...BUT EVEN SELF-EFFICACY MESSAGES WON'T BE ENOUGH IF THE PERCEIVED BARRIERS ARE REAL BARRIERS.

SECTION 2.2: PERCEIVED BARRIERS AND BENEFITS

Invasive species prevention behavior depends on the audience and their current behaviors, but it also depends on the audiences' perceptions of the desired prevention behaviors. Do they see significant barriers? What about benefits? When perceived barriers are high and perceived benefits are low, it's hardly surprising that travelers are unlikely to change their behavior. What does existing research tell us about the barriers to biosecurity behaviors and travelers' perceptions of the related benefits? Our review suggested that research in this area broadly fits into the categories of the COM-B model (capability, opportunity, and motivation), so we will discuss each of those in turn.

SECTION 2.2.1: CAPABILITY

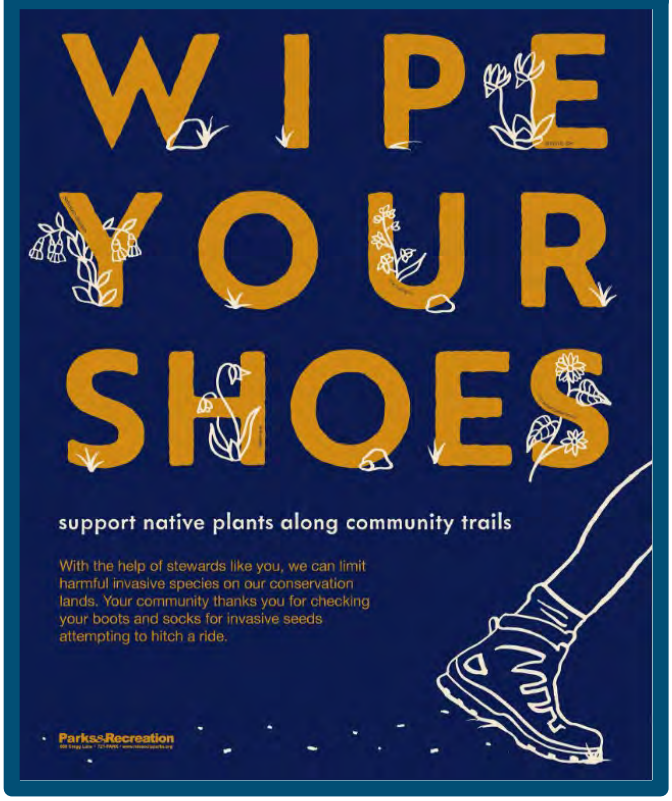
Capability refers to travelers' ability to actually do a behavior. This includes their knowledge of what to do (I should wipe my shoes when I start or finish hiking), how to do it (I should wipe all sides of my shoes, including the laces, and spray with rubbing alcohol), and their physical ability to do it (I can balance on one foot while I spray my shoe with rubbing alcohol). In our review of the research and interviews with invasive species specialists, we found that capability-related barriers frequently

emerged. Several of these were barriers we've already discussed – knowledge/awareness about invasive species, procedural knowledge about the recommended action, and self-efficacy related to prevention steps.

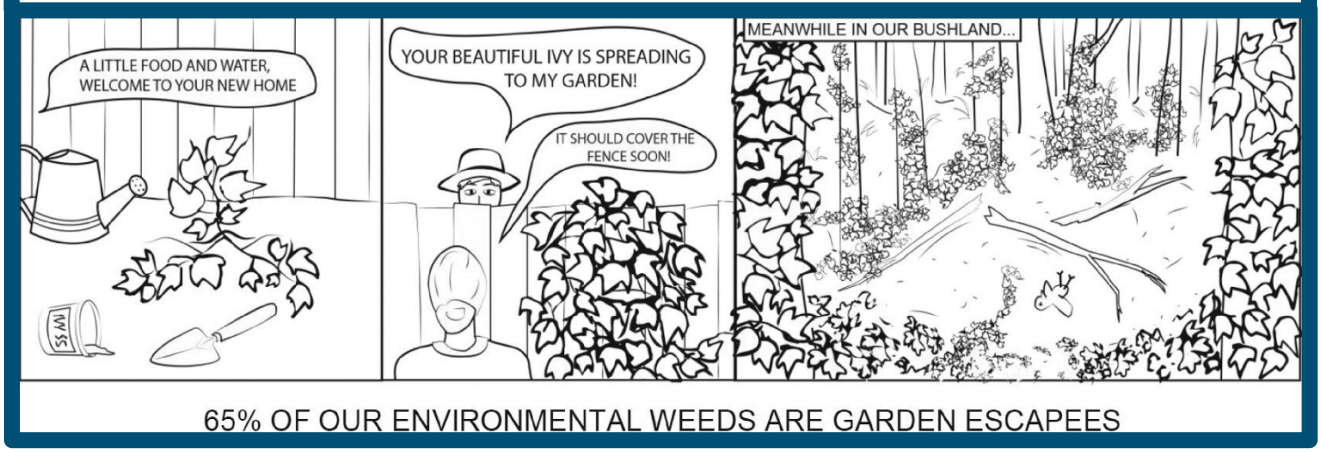
An additional capability factor is attention; do travelers notice and engage with the messaging, or do they simply ignore it? In one study in Montana [50], researchers observed hikers' use of boot brush stations and found, predictably, that the presence of any signage about invasive species was better than no signage. More than that, they also observed whether hikers ignored the sign, briefly glanced at the sign, or stopped and read the sign; their results showed that a brief glance made hikers 85 times more likely to clean their shoes than ignoring it, while stopping to read the sign made them 405 times more likely. Similarly, prevention campaigns such as Don't Pack a Pest and Clean, Drain, Dry have been very effective at reaching audiences and gaining their attention [43]. So yes, getting travelers' attention matters.

While any messaging is better than no messaging [50], other elements matter too. Several studies highlighted the importance of ensuring that signs [51] and cleaning stations or supplies [26], [29], [52] are obvious and easy to spot. This can include changes to the signage itself, such as using graphic design elements to draw travelers' attention or employing modalities other than text [53]. Two studies even explored the use of virtual reality [54] or comics [55] as a medium.

Graphic Design Example [50]



Invasive Species Prevention Comic [55]



But these design features aren't helpful if the messaging isn't visible, so it's important to consider the need for structural changes such as moving signs or cleaning stations to locations that are hard to miss. A social marketing campaign at two lakes in New Zealand, for example, noted in their audience analysis that travelers often came to kayak but did not always perform prevention behaviors when arriving at or departing from the lakes [52]. To address this, the campaign provided a kayak cleaning station and placed both the station and the signage in locations where kayakers had to walk right past them to reach the lake or the parking lot.

In our interviews with invasive species specialists, they also brought up the difficulty of holding travelers' attention, especially when several pieces of information needed to be conveyed to a particular audience. For example, travelers such as researchers or contractors who are visiting an area that is closed to the public may need to follow multiple specific rules when packing or traveling to the island. The creative messaging techniques mentioned above (comics [55] or virtual reality [54]) could be useful here as well. Similarly, another study tested the use of an e-learning training designed to teach biosecurity practices and found that it led to improved behavior [56].

Although capturing travelers' attention matters…it does not necessarily lead to behavior change by itself.

Yet although capturing travelers' attention matters, experimental evidence shows us that it does not necessarily lead to behavior change by itself. In the Mt. Myoko experiment [29], for example, researchers measured use of the boot brush station, but they also met hikers further down the trail and requested they complete a questionnaire. This included a question asking simply if the hikers had even noticed the boot brush station. The researchers then conducted an additional analysis incorporating the variables from the questionnaire. Surprisingly, hikers in the procedural knowledge, factual knowledge, and control conditions who noticed the boot

brush station were no more likely to stop and clean their shoes than hikers who didn't notice it in the first place. In other words, even when the signs caught their attention, they didn't necessarily stop. As this study and others [57] have shown, some types of messaging attract travelers' attention and still don't change their behavior.

Addressing travelers' capability is integral for effective behavior change interventions, but successful approaches must go beyond simply removing capability barriers. Attention and knowledge matter, but they are best addressed in combination with other factors related to capability (e.g., self-efficacy) as well as opportunity and motivation.

SECTION 2.2.2: OPPORTUNITY

Along with capability, our review found barriers and benefits related to opportunity. In the COM-B model, opportunity refers to external factors that facilitate or hinder prevention behavior [58]. This includes both physical factors (infrastructure, finances, etc.) and social factors (culture, governance, etc.). In the context of invasive species, we found opportunity barriers and benefits fell into four categories: infrastructure or lack thereof, external incentives, message timing, and social norms.

Study findings related to infrastructure barriers both make perfect sense and are difficult to implement in the real world. For example, tools such as boot brush stations or boat-cleaning stations must first exist before travelers can use them. One study surveyed thru-hikers on the Appalachian Trail about their invasive species prevention behaviors, and they found that approximately half were not able to name a single place where they had seen a boot brush station along the trail [26]. Other studies similarly noted that there was not enough infrastructure to meet the demand [51], particularly when travelers are unwilling to wait in line for the few stations that do exist [51]. In our interviews, invasive species specialists also highlighted the need for the necessary supplies to be available at such stations, ranging from hoses and brushes at boat-cleaning stations to isopropyl alcohol spray bottles at boot brush stations. Similarly, an informal evaluation of the PlayCleanGo campaign noted that travelers don't tend to use boot brush stations that are dirty, covered with weeds, or not maintained [59]. When the stations were maintained, however, they appeared to be used; the evaluation found 39 species growing beneath the boot brush stations they examined, including 14 invasive species.

Infrastructure is an important barrier to address, and once the infrastructure exists to help travelers engage in prevention behaviors, incentives can encourage or discourage use. Charging fees for cleaning stations [60] or for inspections [61], for example, tends to

ONCE THE INFRASTRUCTURE EXISTS TO HELP TRAVELERS ENGAGE IN PREVENTION BEHAVIORS, INCENTIVES CAN ENCOURAGE OR DISCOURAGE THEIR USE.

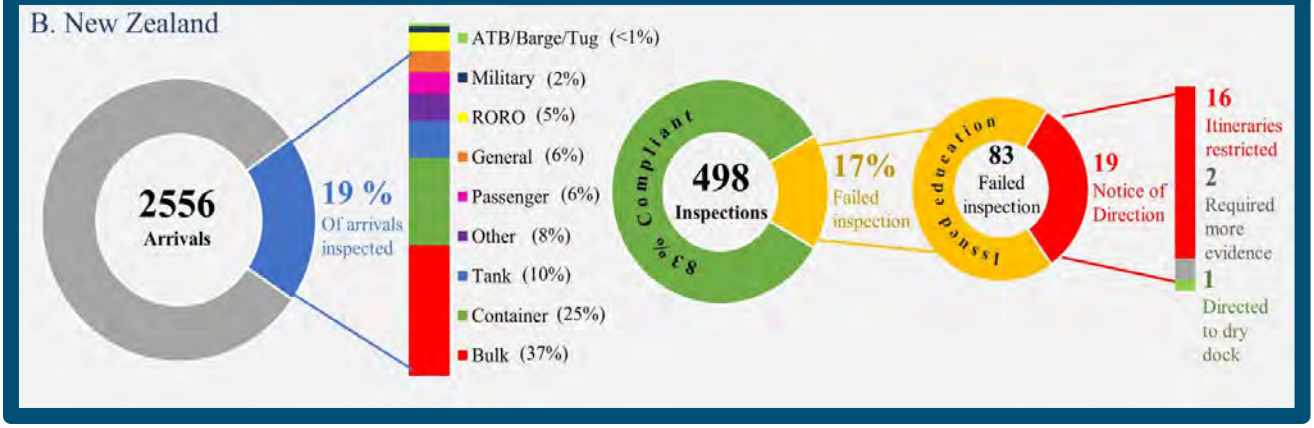
create a barrier and leads to travelers simply going elsewhere. Free cleaning stations do help reduce the spread of invasive species [60], but this requires other funding to build and maintain the stations. Staff members and volunteers can also provide an external incentive, either by simply providing reminders to use materials or by teaching travelers how to correctly perform the action [51], [62]. In one study, for example, researchers compared prevention behaviors at two lakes: one with stewards posted at boat launches and one with no stewards [63]. A year later, visitors at the lake with stewards were more likely to report cleaning their boats. As our interviews with invasive species specialists highlighted, though, many locations do not have the luxury of volunteers or extra staff hours for this kind of purpose.

Several studies in our review highlighted the importance of pairing infrastructure and regulations with outreach.

Multiple interviewees brought up New Zealand's biosecurity practices as a good example of a prevention program, one that combines infrastructure with external incentives. The New Zealand model was implemented in 2018 after several years of outreach and includes pre-arrival information about prevention steps that boaters must take as well as inspections upon arrival. Most inspections are free, but in some cases where the inspection reveals concerns (hull fouling, pest infestation, etc.), the boat owner is responsible for the added cost to address the issue [64]. This model reduces opportunity barriers by providing inspections at multiple arrival locations; at the same time, the combination of mandatory measures, free inspections, and fines for lack of compliance provides a strong incentive for travelers to follow the requirements. These strict measures have had an impact on traveler behavior, with more travelers meeting the requirements each year [65]. Several other studies in our review also highlighted the importance of pairing infrastructure and regulations with outreach [62], such as the quasi-experiment that found the combination of infrastructure and messaging was more effective than either approach alone [66].

New Zealand Biosecurity Enforcement and Outcomes, 2018-2019 [65]

(All high-risk and long-stay [including recreational] and randomly selected low-risk vessels were inspected.)



The New Zealand model also provides an example of another opportunity factor: message timing or matching the most relevant information to travelers' time and place. As discussed in section 2.1, this includes tailoring messages to the stage of travel, such as targeting travelers on their way to a destination rather than upon arrival [67] or providing reminders just before or after travelers engage in a specific activity [44], [52]. While section 2.1 discussed message timing in relation to self-efficacy messages and highly engaged audiences, this opportunity barrier applies to all audiences and is important to consider regardless of the message frame chosen. At the same time, timing can be used to our advantage, as in campaigns such as Don't Pack a Pest. This campaign targets travelers at several stages of travel by using advertisements on travel websites and TV stations to reach travelers before they leave along with signs and videos in airports and on airplanes to provide information once travelers are en route [68]. Similarly, the New Zealand model provides information to boaters in advance, including requiring travelers to provide documentation before they even arrive in a New Zealand port [64].

Messages should be tailored to travelers' time and place.

The final opportunity factor we identified in our review is social norms. Norms fall under the social aspect of opportunity because they involve the impact that others' behavior and others' expectations of us has on our behavior. Social norms appeals often include two types of norms: those that describe typical behaviors (descriptive norms) and those that describe desired behaviors or behaviors that important others think you should do (injunctive norms) [69]. Below is an example of descriptive and injunctive norms in the context of invasive species prevention, as seen in the Texas boater study we discussed in section 2.1 [45]. Meta-analyses show that injunctive norms appeals have a stronger impact on behavior than descriptive norms [53], [69] and that this is true even when focusing specifically on environmental research [53], suggesting these may be the most useful to prioritize if space is limited.

Descriptive (left) and Injunctive (right) Norm Messages [45]



Social norms were discussed in many of the invasive species studies we reviewed [39], [45], [70], [71], and while most of these did not experimentally test social norms as a messaging strategy, two did. Both are studies we previously reviewed in section 2.1, the Western States boater study [39] and the Texas boater study [45], and both focus on aquatic invasive species prevention among recreational boaters. In both studies, when the authors conducted an analysis of their full sample, they found that there was no difference in participants' willingness to take prevention steps when they saw any of the social norms conditions (Texas boater study: descriptive or injunctive [Figure 6]; Western States boater study: descriptive, injunctive, or both) than when they saw the typical "Clean, Drain, Dry" message. These are only two studies, though, so it is helpful to turn to a meta-analysis for a more holistic picture. In the Nisa meta-analysis, social comparison was one of the five categories of interventions the authors compared [30]. Their results showed that social norms interventions had a consistent effect on behavior change. While this effect was small, it was larger than the effect for information-only interventions. Since social norms interventions may require just an additional line or two of text, that small benefit is relatively impressive.



Social norms appeals do work, then, so why did both the Western States boater study [39] and the Texas boater study [45] find that they didn't? Likely because social norms appeals work better for some audiences than for others, as discussed in section 2.1. For example, a 2020 meta-analysis of 110 empirical studies of social norms appeals found that norms worked better for younger audiences

than older audiences and for participants in Asia than participants in other regions [53]. Remember also that the Texas boater study found that norms appeals were effective for less engaged participants but not for participants who were already highly motivated to take prevention steps [45]. This may help explain the results of the two invasive species studies evaluating social norms, since the participants of the Western States boater study were older and were avid recreationists who engaged in many prevention behaviors already [39]. That makes sense when we remember that injunctive norms (what important others expect you to do) are best for environmental messages [53]; an injunctive norms message might tell a traveler that fellow travelers want them to clean their boat, but if this person is already doing so, the normative message is unlikely to change their behavior.

When a social norm is enforced not only through public support but through laws and through consequences for breaking those laws, the message it sends to travelers is much stronger.

At the same time, these results speak to the interplay between public support, social norms, and regulations [51]. When a social norm is enforced not only through public support ("Texans expect…") but through laws and through consequences for breaking those laws, the message it sends to travelers is much stronger. This may explain why, in the Texas boater study [45], the regulation message ("It's the law") did perform better than the control message even in the full analysis; the regulation message itself conveys an injunctive norm (the existence and communication of the law suggests that this is what others think I should do) along with consequences for defying that norm. Similarly, in the New Zealand model that our interviewees frequently mentioned as an exemplar, the mandatory nature of biosecurity practices helps establish the norm and that norm is then reinforced through inspections, fines, and mitigation measures [64].

One caution with social norms messaging: it is important to pay attention to actual norms and behavior and then tailor the messaging as needed. Social norms messaging can backfire if there is an obvious discrepancy between the norms message and reality or if the messaging indicates that people are, in fact, not engaging in the behavior. For example, if signs try to motivate behavior change by saying that 90% of people don't surrender their fruit at the airport, travelers are likely to feel perfectly comfortable being part of that 90% [72]. Similarly, if a message notes that 99% of visitors clean up their trash but the picnic area is covered in litter, such messaging won't be persuasive. Injunctive norms appeals and appeals that highlight trends or the possibility of social change can be effective strategies to avoid this [73]. Several of the studies we reviewed in the invasive species context also suggested targeting a variety of audiences for social norms messaging to build and strengthen such norms [47], [74]. For example, one study of lake visitors recommended targeting less traditional audiences (including those with less motivation or those who pose a lower risk, such as swimmers or cabin owners) along with more traditional audiences (boaters, anglers,

etc.) [74]. The authors suggested this would build community norms more broadly, pressuring other lake users to take prevention steps and raising overall support for invasive species management.

So, what does all this tell us about barriers and benefits related to invasive species prevention behavior? Opportunity matters, but it can be hard to address. This is largely because opportunity factors seldom work alone and can seldom be fixed with a single, simple change; instead, addressing opportunity factors often requires coordination across entities [75]. In our interviews, invasive species specialists frequently brought up both the difficulty of coordinating with other stakeholders and the benefits of doing so. They gave examples of working with everyone from government agencies to conservation groups to travel companies such as airlines or hotels. While many of the campaigns we reviewed involved these types of fruitful partnerships [68], our interviews also highlighted the time, effort, and resources necessary for this coordination to occur. Despite these challenges, our review demonstrates the importance of system-level coordination in creating widespread change.



OPPORTUNITY FACTORS MATTER BUT CAN BE HARD TO ADDRESS…THEY SELDOM CAN BE FIXED WITH A SINGLE, SIMPLE CHANGE. INSTEAD, ADDRESSING OPPORTUNITY FACTORS OFTEN REQUIRES COORDINATION ACROSS ENTITIES.

SECTION 2.2.3: MOTIVATION

The last broad theme related to barriers and benefits is motivation, which includes both cognitive and emotional factors that influence a traveler's willingness to perform a behavior [2]. This includes analytical decision-making as well as motivation based on emotion, habit, or other triggers. We found three primary themes related to motivation: perception of invasive species, individual values, and the personal relevance of the issue.

Not all invasive species are seen as problematic in the eyes of travelers. When a species is seen as less problematic or even common to a particular location, it can be more difficult to motivate behavior change [76]. Some invasive species are seen as beautiful or attractive, perhaps even one of the reasons that travelers choose to visit a particular location. For example, researchers in New Zealand conducted a survey about perceptions of native and nonnative plants [27]. They found that the attractive Russell lupins were highly rated, and support for management or eradication plans targeting this species was low. On the opposite end, there are also cases where travelers view

particular invasive species as harmful but still do not take action, such as boaters who report awareness of the impacts of aquatic invasive species but still do not engage in prevention behaviors [51].

In one experiment, researchers sought to explore whether message frames targeting perceptions of invasive species could change people's intention to perform prevention behaviors [49]. Participants were randomly assigned to see a message that either portrayed an invasive plant as a driver of ecological change or a "passenger" that is simply responding to other environmental changes. The driver condition was more effective than the passenger condition, with participants more likely to report that they were willing to take action when they saw the driver message. This was particularly true when the message also mentioned that the invasive plant was initially introduced through human actions. This experiment tells us that it may be possible to change perceptions of invasive species, including those seen as tourist attractions, if we discuss the impact the invasive species have on the ecosystem as well as the role that humans played in introducing them initially.



Along with perceptions of invasive species, a second motivation we encountered in our review was values, particularly those related to the environment. It seems reasonable that environmental protection values and a love of nature would be related to greater invasive species prevention behaviors, but experimental research is mixed. In one field experiment, researchers reported no difference in behavior when participants saw a sign meant to induce awe and stewardship ("Let's

protect Mt. Fuji") than when they saw a sign with a behavioral goal ("Don't bring non-native plants") [28]. Interestingly, participants were less likely to clean their shoes when they reported a higher sense of awe toward Mt. Fuji. This may point to flaws in the study design, however, as the researchers didn't include manipulation checks. Another experiment showed that messages relating to environmental harm are effective regardless of people's environmental values, which may suggest that environmental values are less important than we would expect.



Non-experimental research, in contrast, is more likely to show an association between environmental values and prevention behavior. For example, interviews with water recreationists found that their sense of environmental responsibility was a motivating factor for engaging in prevention behaviors [77]. Another study used surveys to show that anglers who reported stronger values related to nature preservation were also more likely to believe that invasive species had an impact on their life [33]. This greater sense of personal relevance, in turn, was related to a greater likelihood of performing prevention behaviors.

This brings us to the final motivational factors we identified in our review of barriers and benefits: personal relevance and personal susceptibility. The angler survey mentioned above highlighted the importance of travelers believing that invasive species affect them personally [33]. In that study, the researchers found that participants with stronger nature preservation values were more likely to believe that invasive species were both a risk to them personally and a risk to the others (including

the environment and economy of the area). However, only personal risk was associated with a greater willingness to engage in prevention behaviors or to advocate for policies related to invasive species management. Other studies have used interviews [78], surveys [79], and survey-experiments [80] to similarly show that travelers are most likely to be concerned about invasive species when the impacts personally affect them.

Closely tied to personal relevance is the sense of personal responsibility. Travelers may believe that the impact of invasive species affects them personally but think that their specific behavior isn't making a difference [81] or that everyone else is the problem. In one study, for example, researchers visited marinas to interview boaters as well as to take samples from the hulls of their boats. They found invasive species or potentially invasive species on 80% of the boats, and yet numerous boaters reported that they believed their boats were clean [82]. Showing travelers evidence that they are indeed transporting invasive species, whether on the hull of a boat or in a suitcase or on the sole of a shoe [34], could help increase their sense of personal responsibility. Campaigns such as Don't Pack a Pest draw on this idea in a more cost-effective way by using images to show that many invasive species are too small to be easily identified with the naked eye. We did not find any experiments testing an intervention related to personal responsibility, although the driver/passenger experiment discussed above demonstrates the potential of broadly highlighting the role of human action in spreading invasive species [49].

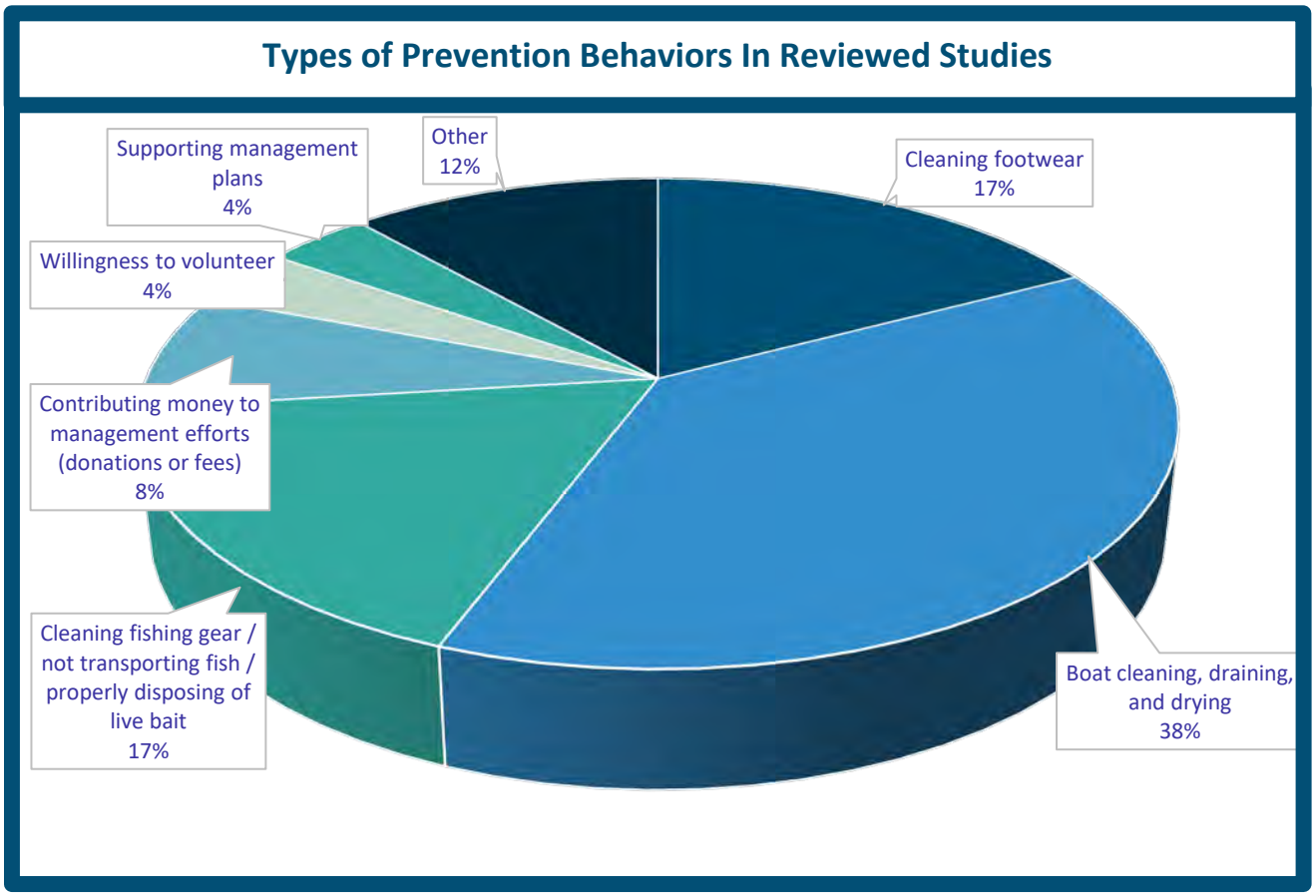
Showing travelers evidence that they are indeed transporting invasive species could help increase their sense of personal responsibility.



SECTION 2.3: DESIRED BEHAVIORS

The final “it depends” factor we identified in our review is the desired behavior. What prevention steps would we like travelers to take?

In the studies we reviewed, researchers looked at a variety of behaviors (see below), ranging from cleaning shoes or donating money for management efforts to pressure washing boats or volunteering for invasive species clean-up days. We’ll note briefly that the vast majority of studies measured self-report behaviors in a survey or interview or measured behavioral intentions rather than actual behavior. Only a handful of studies included observation of participants’ behavior [29], [50], [70].



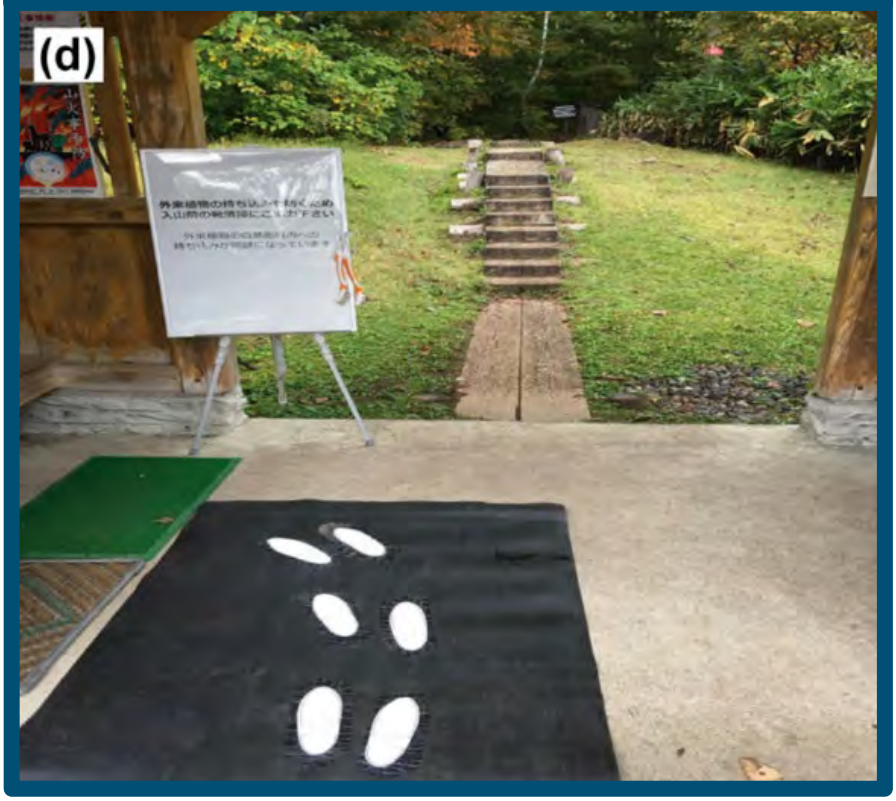
SECTION 2.3.1: BEHAVIORAL COMPLEXITY

One aspect of desired behavior that affects the choice of intervention is the complexity of the behavior we’re asking travelers to do. As the chart above shows, we saw quite a lot of variety in this aspect across the studies we reviewed as well as in our interviews with invasive species specialists. This variety demonstrates the necessity of considering behavior complexity; it’s a much bigger ask to

request that boaters pressure wash their boat after every trip than to request that visitors to throw away an apple upon arriving at an island (and yet our interviewees noted that even the latter can be difficult to encourage). Which campaigns or interventions work, then, and which behaviors do they work for?

Let's start by returning to the Mt. Myoko study [29], in which the researchers placed signs at the entrance to a hiking trail and then observed whether participants used the boot brush station to clean their shoes. We previously reviewed three of the four conditions in this study: factual knowledge, procedural knowledge, and the blank sign acting as the control condition. However, in this study, the researchers also explored a type of behavior-change intervention known as choice architecture or "nudges." Nudges focus on changing the environment in which people make a choice in order to make it easier for them to engage in the desired behavior without removing their choices [83]. For example, cafeterias can place healthy foods at eye level and chocolates in locations that are more difficult to access. In the Mt. Myoko study, the fourth condition included the factual knowledge message ("Please clean your footwear to prevent introduction of invasive plant seeds. Seeds introduction into natural areas causes problems") along with a visual nudge, a mat laid on the trail with footprints pointing toward the boot brush station.

The "Nudge" Condition in the Mt. Myoko Study [29]



Their results were interesting. The researchers found that the "nudge" condition was by far the most effective, with 42.7% of participants in this condition cleaning their shoes compared to 3.4% in the

control condition. The procedural knowledge condition was also effective but much less so than the nudge condition. As we reviewed above, the authors also later asked participants if they noticed the boot brush station. Recall that noticing the cleaning station was not related to using the station in the factual knowledge, procedural knowledge, or control conditions. The opposite was true for the nudge condition; hikers who noticed the boot brush station in the nudge condition actually were more likely to clean their shoes.

Again, we prefer to not make recommendations based on the results of a single study, so we turn back to the Nisa meta-analysis discussed previously [30]. This was the meta-analysis of 83 field experiments, all randomized controlled trials. Knowledge/education interventions were one of the categories the authors identified, and choice architecture[2]/nudges were another. Their results provide strong support for the Mt. Myoko study; of the five types of interventions in the Nisa meta-analysis, nudges had the strongest effect. The authors translated the statistical results this way: participants exposed to a nudge or choice architecture condition increased the probability of engaging in climate change mitigation behaviors by a quarter. You'll remember that the probability of behavior change for knowledge/education interventions was only 3.4%; a 25% change is very significant in comparison.



[2] Choice architecture refers to how choices are presented to people and how the design of these presentations can influence decision-making. It's about organizing the context in which people make decisions in ways that make certain choices easier or even automatic (such as with automatic opt in), more appealing, or more obvious than others.

These results suggest that nudge interventions hold promise for invasive species prevention, but as other researchers have pointed out, there are considerable differences in the effectiveness of nudges across contexts, [84], [85], [86], [87]. Nudges are a relatively new intervention, and we don't yet know precisely when they are likely to work and when they aren't. However, given the results of studies like the Mt. Myoko study [29], it seems that nudges might be a viable intervention for behaviors that are high in importance but low in complexity. The Mt. Myoko study, for example, focused on cleaning shoes at a boot brush station – a behavior that several other studies also explored [26], [50], [70]. Shoe cleaning is a relatively simple behavior, applicable to a wide audience (anyone who arrives at the trailhead) and with barriers that can be overcome (e.g., ensuring that the boot brush station is well-stocked and accessible). Other behaviors, such as cleaning boats or surrendering non-native fruits at a port of entry, similarly are fairly simple and achievable if travelers are motivated to use them. Might these interventions be more effective if travelers were nudged toward them, such as placing boot brush stations in a more visible place or using a mat with footprints to point to them? Likely yes, especially since visibility was a barrier we discussed in section 2.2. Similarly, nudges might be a useful option for the repeat messaging or stage-of-travel messaging that several studies and interviewees mentioned are needed [44], [49], [67], [88].

However, this isn't a perfect solution. As we've highlighted throughout this review, prevention systems must operate in tandem. A nudge that persuades travelers to engage in a behavior can be negated by other factors; if the stations are too crowded, if the lines are too long, if necessary supplies are missing–there are many reasons that nudges might not be enough. When such issues are addressed, nudge interventions appear to be a viable tool for encouraging travelers to take action with a low-complexity behavior.

Nudge interventions appear to be a viable tool for encouraging travelers to take action with a low-complexity behavior.

More complex behaviors are a different story. High-commitment behaviors, the kind that even highly engaged audiences are unwilling to do [39], are unlikely to be affected by nudges alone. Even so, these interventions could be useful in tandem with other suggestions. For example, several of the invasive species specialists we interviewed mentioned the idea of an app to reach travelers before they travel; travelers could sign up to receive push notifications on a certain day reminding them to remove plant materials from their bags or to check their boat hull before they leave port. Some existing campaigns are notable for employing this approach. The Travel Pono effort in Hawai‘i uses a multi-pronged approach that includes pre-trip emails and an informational video on the plane to inform visitors about culture and conservation (although with minimal emphasis on invasive species specifically).

SECTION 2.3.2: BEHAVIOR FREQUENCY

A second factor that can affect the choice of intervention is the frequency of the desired behavior. When the desired behavior requires repetition, repeated messaging can again be helpful. Along with several studies noting the relative ineffectiveness of one-time messaging [49], [80], other research demonstrates that repeated messaging can help attract attention and improve information retention. For example, one study showed a public service announcement about aquatic invasive species prevention during the pre-movie advertisements at a cinema and then interviewed movie-goers as they left the theater [88]. Their final sample was small, as only 15 out of 135 participants identified as boaters (the target audience) and also remembered seeing the invasive species ad. Interestingly, though, 100% of those who remembered seeing the ad also reported seeing or hearing information about aquatic invasive species from other sources within the past year. For frequent or repeated behaviors, then, frequent or repeated exposure to messaging can increase information recall, which can help ensure that travelers remember the needed information when it comes time to engage in the prevention behavior.



Repeated messaging is particularly effective when the message is simple, consistent, and ideally focused on self-efficacy or procedural knowledge [62]. Campaigns such as Clean, Drain, Dry have adopted this approach by using the same simple slogan across many types of outreach: signage at marinas and docks, cleaning kits and stations, billboards, live outreach events, and more. Survey research demonstrates that this approach has been effective in reaching large numbers of water recreationists [43]; the campaign is now widely recognized, and many boaters report taking at least some of the recommended prevention steps [31].

Repeated messaging is particularly effective when the message is simple, consistent, and ideally focused on self-efficacy or procedural knowledge.



What about when the behavior need only be done once? Efficacy messages are again effective [48], as are messages using fear appeals or loss frames along with efficacy information. Fear appeals are messages that highlight the threat of invasive species, often also including information to show that the message recipient is susceptible to this threat [89]. We identified only one study evaluating fear appeals in the context of invasive species (Figure 9), but it did indeed find that greater fear or sense of threat severity predicted greater willingness to engage in prevention steps [80]. This finding is supported by a 2015 meta-analysis, which reviewed 248 experiments to test the effect of fear appeals on attitudes, behavior, or intentions [90]. The studies included in this meta-analysis came from a variety of domains, but as with other review studies, the results are still useful for our purposes. The authors found that fear appeals were effective, with an average effect size of .29. In addition, and relevant to our question about behavioral frequency, they found that fear appeals were more effective for one-time behaviors than for repeated behaviors.



Loss frames, particularly in the context of invasive species, are relatively similar to fear appeals [91]. These messages highlight the potential losses that will occur if the recommend action is not taken, such as the loss of native habitats or native species as a result of invasive species introduction. We identified two experiments testing the use of loss frames with invasive species prevention. One loss/gain study asked participants about their support for an invasive species management plan after showing one of five messages: ecological loss frame (e.g., highlighting species destruction or loss of native habitats if the plan was not implemented), ecological gain frame (e.g., benefits to native species if the plan was implemented), economic gain frame (e.g., increases in production and tax revenue if the plan was implemented), economic loss frame (e.g., continued production and tax revenue losses if the plan was not implemented), and a control message (information about the plan) [92].

The results of the loss/gain study showed that both loss and gain frames were effective compared to the control condition, but loss frames were more effective [92]. This was only true in the ecological loss condition; highlighting the economic consequences of invasive species was not effective.

Interestingly, the authors found that the ecological messages were effective both for participants who identified as environmentalists and participants who did not. Ecological loss messages, then, appear to be a cost-effective option, as they resonate well across groups.

Fear appeals or loss frames are an effective message strategy for one-time behaviors.

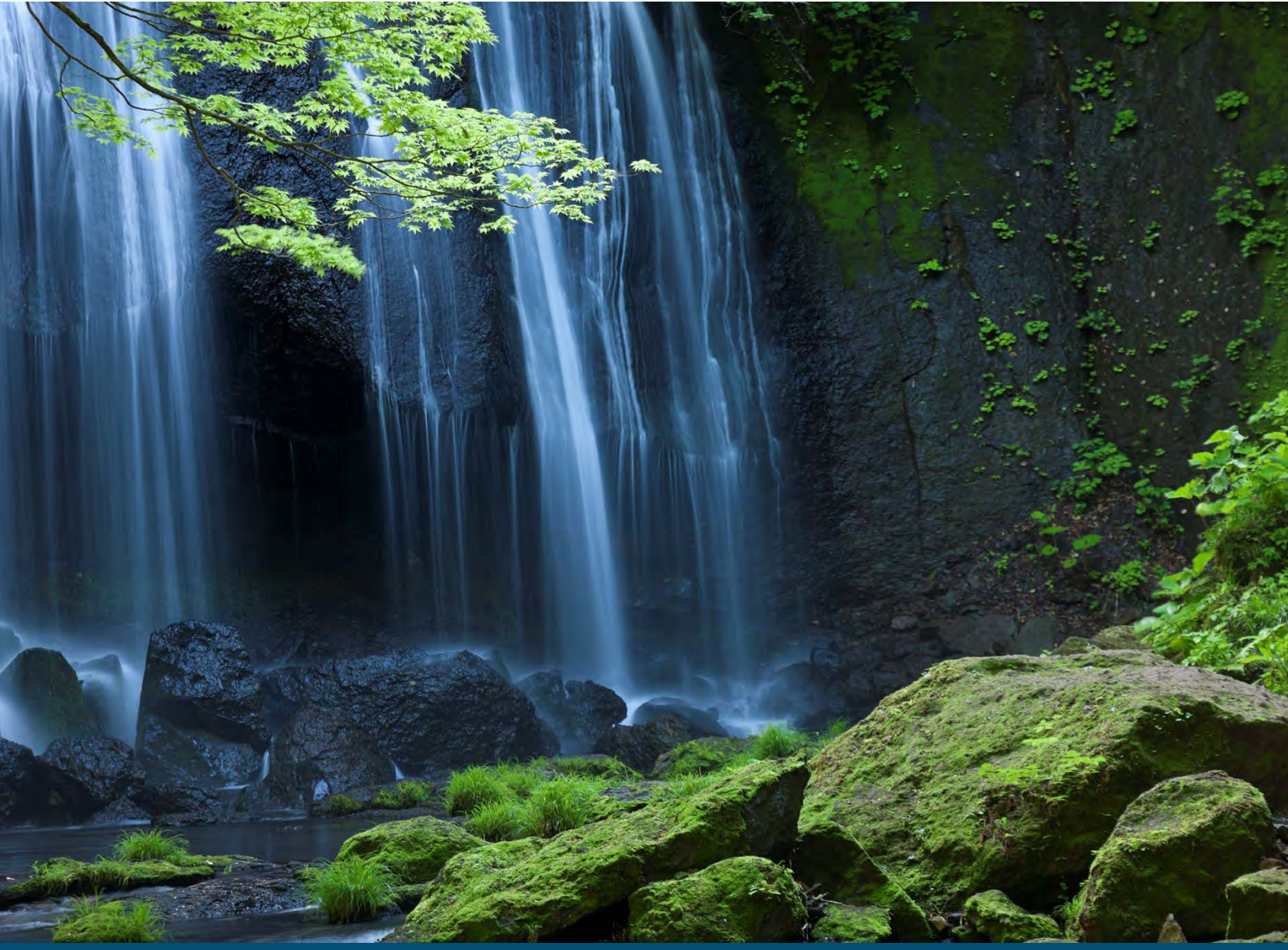
Both this study [92] and the fear appeals meta-analysis [90] provide support for the idea that fear appeals or loss frames are an effective message strategy for one-time behaviors. This idea is also supported by the second invasive species study we found, the Western states boater study discussed previously [39]. While that study tested loss and gain frames but found no difference between either message and the control condition [39], it seems likely that their results again related to their sample. The Western States boater study focused on avid recreationists who go boating regularly and therefore are being asked to engage in invasive species prevention behaviors regularly. If the same loss frame were used for a one-time behavior, the results likely would have been different.

Fear appeals are more effective when they also include efficacy information.

This brings us to one final but important point regarding fear appeals and loss frames: efficacy. We've mentioned efficacy several times in this review, and the fear appeals meta-analysis explored it as well [90]. They found that fear appeals were more effective when they also included efficacy information, again demonstrating the importance of efficacy [48].

What might this look like in the context of invasive species prevention, then? In our interviews, invasive species specialists on both smaller and larger islands discussed the difficulty of persuading travelers to pack appropriately for travel to the island. In some cases, this included tourists packing items for vacations, but it also included researchers or contractors or campers being asked to follow specific rules about how to pack. As many island travelers are one-time visitors, a message that utilizes a fear appeal or loss frame along with efficacy information is likely to work well. Such a message might emphasize the harm that invasive species do to the island ecosystem that the individual is traveling so far to visit, as well as include specific steps the traveler can take to prevent that outcome.

As this example shows, many of the message design features we've discussed work best in tandem with other features as well as with support from the public and the regulatory structure more broadly. For example, in our interviews with invasive species specialists, several interviewees mentioned the possibility that island residents might spread invasive plant or pest species when carrying gifts of flowers or plants to their loved ones on other islands or on the mainland. A campaign might begin by using loss frames and appealing to residents' desire to protect their home. Providing this message along with efficacy information might encourage the behavior initially, with later messages invoking injunctive norms to emphasize the increasing prevalence of other types of gifts.



Section 3: Recommendations

In our review, we sought to answer the question: what does existing research tell us about audiences and communication campaigns or interventions to motivate invasive species prevention behavior change? Two broad recommendations emerged.

First, every site will be different. The social marketing framework can help you understand your specific audience; their current behaviors, perceived benefits, and perceived barriers; and the particular behavior you would like to change. Then, use the COM-B model to decide where to intervene [2]. The studies we reviewed provide interventions or messaging ideas that work well in different contexts, summarized in Table 2, but behavior change campaigns are most effective when they pair messaging with engineering and enforcement approaches as well [22].



Second, evaluation is key. Evaluating outreach campaigns can help you determine what works for your site and what doesn't. Experimental manipulation of various interventions provides you with knowledge about which approach, or combination of approaches, works best for your specific site. This knowledge will also help inform others; our review demonstrates a relative lack of evaluated interventions or campaigns related to invasive species, especially in comparison to the many approaches currently being used across the U.S. Careful evaluation of interventions would benefit each specific site as well as the field generally.

Every site will be different.

It is important to evaluate outreach campaigns.

The table below and section 3.1 offer additional recommendations focused on specific communication approaches and on the island traveler context.

Intervention	Context	Example	COM-B Elements
Self-efficacy or procedural knowledge messages	Good for highly motivated travelers. Most effective when focusing on the most important behaviors rather than trying to promote all prevention steps	"Please remove soil from your footwear sole using the mat/brush" [29].	Capability: Psychological
Stage-of-Travel/Repetition Messaging	Necessary for behaviors that must be repeated. Good for encouraging highly motivated travelers to do all steps. Best if messages can be tailored to a particular stage of travel (packing, pre-boarding, arrival, etc.) and timed appropriately.	"Clean, drain, and dry your boat, trailer, and gear every time" [39], [42], [45].	Capability: Psychological Motivation: Reflective
Nudges or choice architecture	Show promise as a biosecurity intervention. Likely best for behaviors with low complexity but high importance.	Mat with footprints guiding hikers toward a boot brush station [29]	Motivation: Automatic
Social norms messaging (especially injunctive norms)	Good for travelers with low motivation to take prevention steps or high perceived barriers. Good for one-time or repeated messaging. Best when norms are supported by regulation or public opinion. Should be used carefully to avoid incentivizing the wrong behavior.	"Texans expect you to clean, drain, & dry" [45].	Opportunity: Social
Fear appeals or loss messaging	Most effective when combined with efficacy information. Good for one-time behaviors or initial information. Loss messages work well regardless of environmental values. May pair well with messages highlighting personal susceptibility.	"The Department has identified major ecological losses if the program is not implemented: continued decline in population numbers of important native and endangered California species…[and] destruction of iconic habitat" [92].	Motivation: Automatic
Messages emphasizing invasive species as drivers of ecological change	More effective than framing invasive species as the result of other environmental changes. Likely best in combination with other messages/campaigns. Strengthen by including human cause of species introduction.	"Due to the characteristics of tamarisk that allow it to spread along rivers in the American southwest and displace other species, many ecologists consider this plant to be a primary cause or "*driver*" of changes in these ecosystems" [49]. [People introduced this species.]	Motivation: Reflective

Intervention	Context	Example	COM-B Elements
Knowledge/awareness messages	Important but seldom sufficient for behavior change. Should be combined with other interventions for best results.	"Please clean your footwear to prevent introduction of invasive plant seeds. Seeds introduction into natural areas can cause problems" [29].	Capability: Psychological Motivation: Reflective
Attention-catching messages	Important but seldom sufficient for behavior change. Should be combined with other interventions for best results.	Messages with graphic design elements [50] or comics [55]	Capability: Psychological

SECTION 3.1: BRINGING IT ALL TOGETHER: SOCIAL MARKETING FRAMEWORK FOR ISLAND TRAVELER INVASIVE SPECIES PREVENTION

Along with the broad recommendations above, we bring together findings from our literature review and interviews under the social marketing framework.

While interview findings should be considered valuable contextual insights rather than empirical evidence, they provide essential real-world perspectives on island-specific challenges that complement and enhance the peer-reviewed literature.

1. Behavior Selection

Theoretical and Conceptual Factors to Consider

- The literature emphasizes identifying discrete, specific behaviors that directly impact desired outcomes.
- According to the COM-B model, behaviors should be analyzed for capability, opportunity, and motivation factors.
- Behavior complexity and frequency significantly impact intervention selection (see Section 2.3).

Types of Behaviors

- Low complexity behaviors (boot cleaning, surrendering food) respond well to nudge interventions (Mt. Myoko study [29]).
- High complexity behaviors (pressure washing boats) require more intensive interventions.

- Repeat behaviors need consistent messaging (Clean, Drain, Dry) and infrastructure support.

Interview Insights on Critical Behaviors (Appendix D, section 1-2)

- High-impact traveler actions include: failure to clean personal gear, venturing off designated trails, transporting potentially contaminated items, improper ballast water management
- Behaviors with change potential: gear cleaning protocols, trail adherence, pre-arrival preparation, inspection of personal items



2. Audience Characterization

Evidence-Based Segmentation Approaches

- Knowledge levels vary significantly but knowledge alone doesn't change behavior.
- Highly engaged recreationists (already aware of invasive species) respond differently than casual visitors.
- Frequent travelers vs. one-time visitors require different messaging strategies.

Audience Response Patterns

- Less engaged travelers respond well to social norms messaging (Texas boater study [45]).
- Highly engaged travelers respond better to self-efficacy and procedural knowledge focused on specific steps.
- Audiences with strong environmental values may be more responsive (but still need action guidance).

Interview Insights on Audience Segments

- High-risk traveler segments: one-time tourists, inter-island travelers, research personnel, contractors, cruise passengers
- Demographics include broad range with age-related differences in compliance
- Activity-based segments: ATV users, divers and snorkelers, backpackers, water users vs. land-based recreators
- Travel patterns: organized tour groups (more accessible for education) vs. independent travelers (harder to reach)

3. Behavioral Barrier and Benefit Analysis

General Behavioral Benefits

- Protection of recreational opportunities (fishing, hiking) from degradation
- Personal protection of valued destinations (Section 2.2 on personal relevance)
- Social approval and norm-following satisfaction (if normative appeals and approaches are used)
- Alignment with environmental values and identity
- Avoiding potential guilt or responsibility for ecological damage
- Protection of natural areas for future generations

Capability Barriers

- Knowledge gaps about invasive species threats and prevention steps
- Lack of procedural knowledge (e.g., how to clean equipment properly)
- Self-efficacy concerns (perceived ability to take prevention steps)
- Messaging failing to catch and hold travelers' attention

Opportunity Barriers

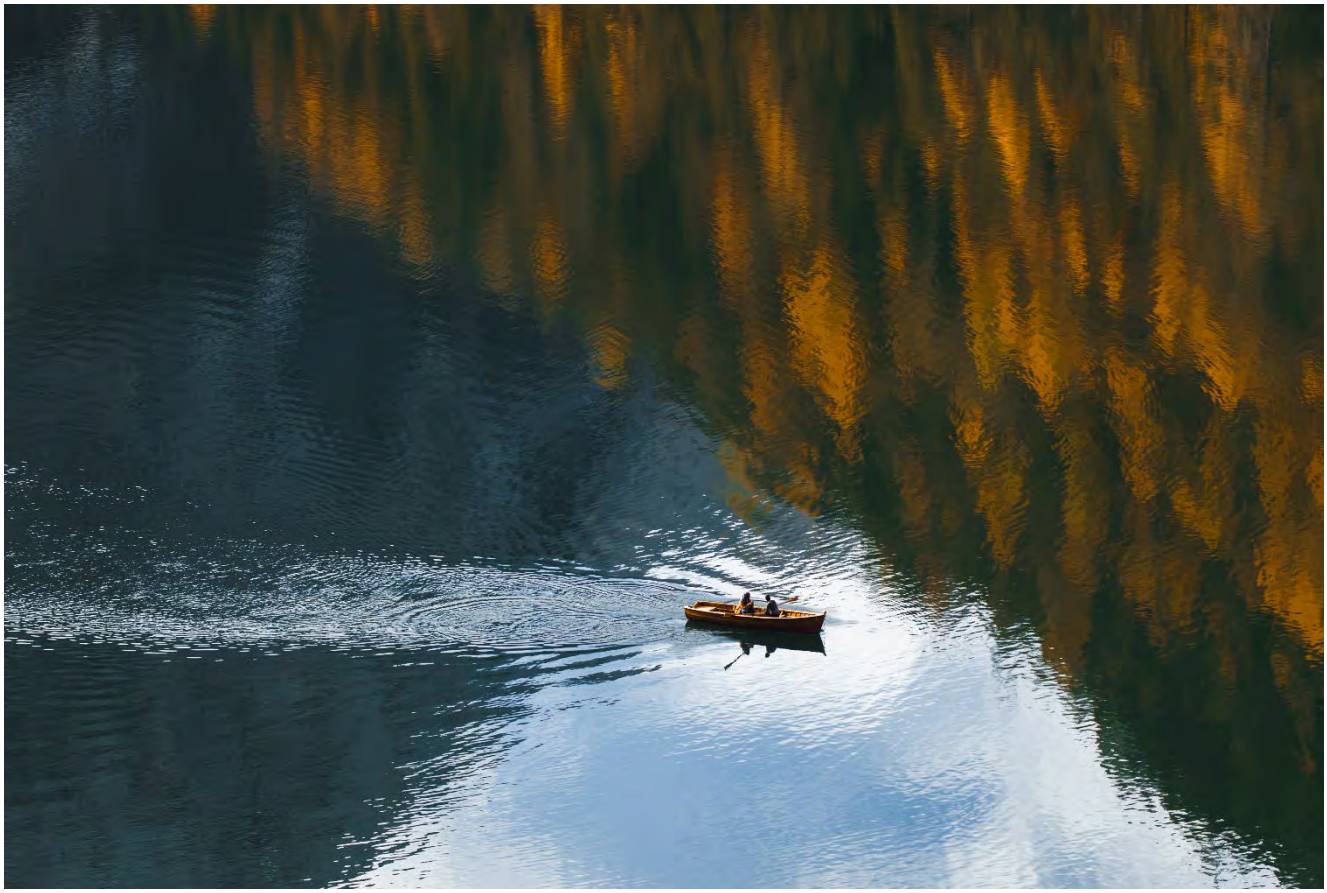
- Infrastructure limitations (cleaning stations, supplies)
- Timing challenges (need for both arrival and departure protocols)
- Environmental factors that make compliance difficult
- Behaviors not seen as normative (e.g., nobody else pressure washes their boats)

Motivation Barriers

- Perceptions of invasive species (some viewed positively by travelers)
- Lack of personal relevance or susceptibility
- Environmental values not always translating to behavior

Interview Insights on Barriers

- Limited awareness of invasive species impacts
- Time constraints for proper gear inspection and cleaning
- Resource limitations (availability of cleaning stations, materials like isopropyl alcohol)
- Existing educational material quality issues (length, engagement level, frequency of reminders)



4. Strategy Development

Message Design Approaches (see also Table 2)

- Self-efficacy or procedural knowledge messages: Effective for motivated travelers (and for all travelers)
- Stage-of-travel/repetition messaging: Important for repeated behaviors
- Nudges or choice architecture: Best for low-complexity, high-importance behaviors
- Social norms messaging: Effective for less-engaged travelers
- Fear appeals or loss messaging: Effective for one-time behaviors when combined with efficacy information
- Messaging framing invasive species as drivers of ecological change: best in combination with other message designs.

Key Principles from Research

- Knowledge/awareness alone is insufficient to change behavior
- Attention-catching messages must be paired with action guidance
- Messages should be tailored to specific travel stages
- Repeated exposure is more effective than one-time messaging

Applying COM-B in Communication

- Capability: Provide procedural knowledge and self-efficacy messages; use creative approaches and visible materials to catch attention
- Opportunity: Address infrastructure needs and message timing, social norms (particularly injunctive norms, what others expect of an audience's behavior)
- Motivation: Use loss frames and personal relevance (strengthen by referring to invasive species as *drivers* of ecological change and the role people play), nudges, and stage-of-travel messaging

Interview Insights on Implementation

- Perceived effective campaign elements: visual communication, action-oriented messaging, clear procedural guidance
- Development of location-specific digital tools (suggested app for pre-trip planning)
- Enhanced coordination between islands sharing common threats
- Potential partnerships: transportation providers, tour operators, conservation organizations, research institutions
- Implementation challenges: variability in island needs, resource limitations, reaching independent travelers

5. Evaluation: Measuring Success

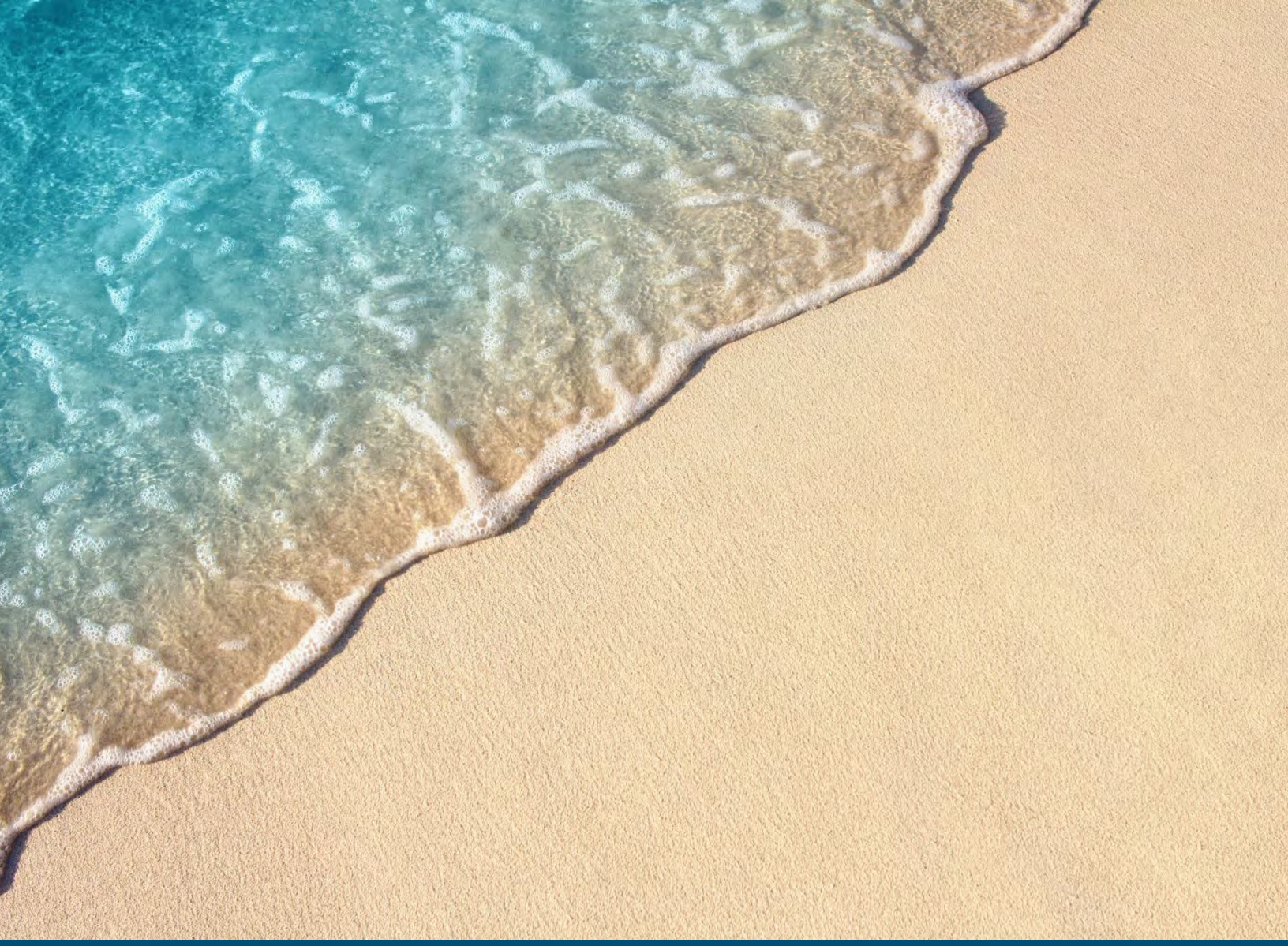
Recommendations from Literature

- Behavior change (not just awareness of invasive species or awareness of campaign) should be the primary outcome measure
- Experimental designs provide strongest evidence for intervention effectiveness
- Lake Rototoa case study (see section 5 below) shows process of analysis, intervention design, and evaluation

Interview Insights on Evaluation

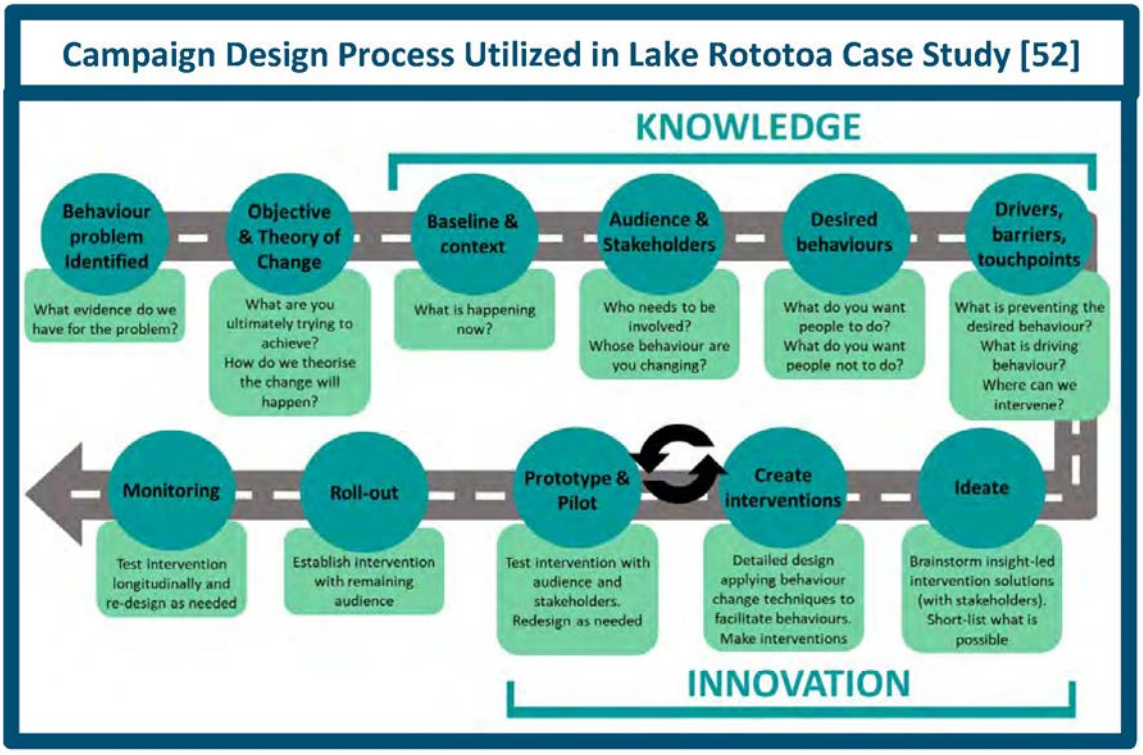
- Need for improved evaluation mechanisms for existing programs





Section 4: Case Study

We conclude this review by discussing an invasive species prevention campaign [52] that provides an example of applying the information discussed throughout this report. This campaign was conducted at two lakes in New Zealand, including Lake Rototoa, where the team began by analyzing the location and gathering information. They identified invasive species threats at each location; surveyed visitors to understand the audience, current behaviors, and benefits/barriers (step 2-3 in section 3.1); and identified the desired prevention behaviors they wanted to target at each location (step 1 in section 3.1).



The initial analysis in this case study [52] revealed that swimming was the most popular activity at both lakes, for example, but this activity is unlikely to spread invasive species. At one lake, the second most common activity was kayaking, and so the team aimed to persuade kayakers at this location to check for and remove pests before entering the water and again when they went home. Overall awareness of invasive species was low, and only a quarter of visitors already performed the desired behaviors.

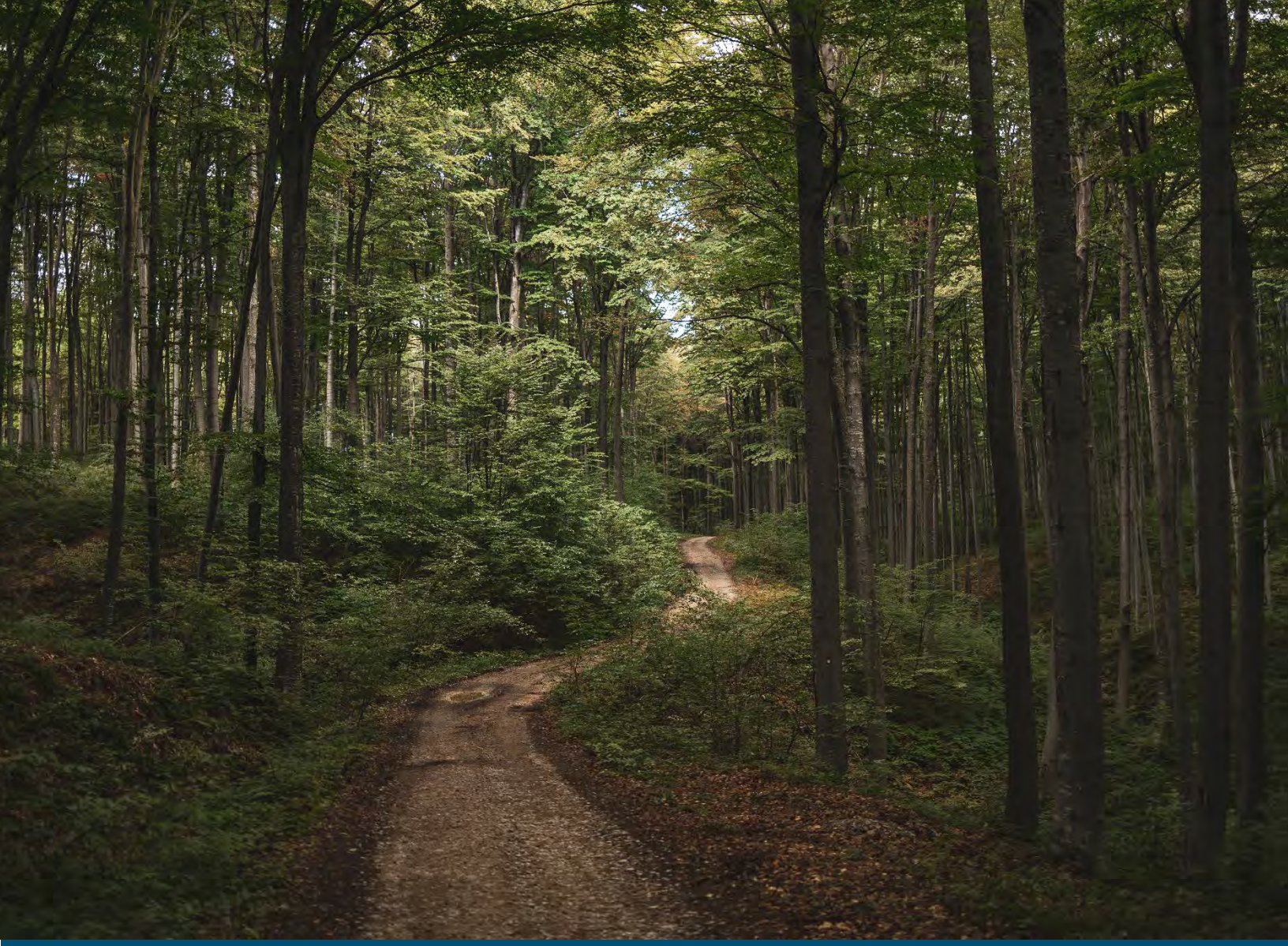
With this information, the team moved into designing and evaluating their strategy (steps 4 and 5 in section 3.1). They added a kayak cleaning station (opportunity: infrastructure), signs with information about how to check and clean a kayak (capability: procedural knowledge) placed them where visitors had to walk past them (capability: attention), added directional signs pointing visitors toward the cleaning station (motivation: nudges), and included messages emphasizing the harm that invasive species cause to the lake (motivation: loss messaging; capability: factual knowledge) as well as a board where kayakers could sign their name (motivation: commitment). Their signs also included

interactive elements (capability: attention), which other invasive species studies have also explored [54].

Kayak Cleaning Station and Directional Signs in Lake Rototoa Case Study [52]



While this case study included evaluation of the interventions, the evaluation was limited by the small number of kayakers who visited the lake during that period and the team concluded that further investigation was needed. The minimal evaluation meant that we were unable to include this case study in our list of evaluated campaigns or experiments (Appendix A), and it's difficult to draw clear conclusions about the effectiveness of the interventions at Lake Rototoa. Even so, this case study provides an example of using social marketing and the COM-B model to evaluate a site, determine and apply interventions that match the site's needs, and follow up with evaluation and further changes as needed.



Section 5: Appendices

APPENDIX A: RESEARCH EVALUATING CAMPAIGNS OR INTERVENTIONS

DeGolia et al., 2019 [92]

DeGolia and colleagues (2019) conducted a survey experiment with 1,077 California residents in which they tested five messages about a fictional plan to deal with invasive wild hogs. The messages emphasized ecological gains (benefits to native species), ecological losses (loss of native habitat, etc.), economic gains (increase in economic production and tax revenue), economic losses (decrease in economic production and tax revenue), or a control condition. The authors found participants were significantly more likely to support the invasive species plan when they saw the ecological messages than when they saw the economic messages or the control message, with loss messages more effective than gain messages. Overall, ecological messages were more effective than economic messages for participants who identified as liberals or environmentalists, while both ecological messages and economic messages were equally effective for participants who identified as conservative or non-environmentalists. **These results suggest that loss frames and ecological messages are likely to be the most effective for promoting invasive species prevention across political ideologies.**

Hands et al., 2018 [55]

A survey-experiment was conducted with 181 residents in the City of Knox in Australia. Surveys were randomly selected to either include or not include a comic about invasive plants in gardens and their impact on the environment. The researchers found that the group who received the comic reported a significantly higher willingness to choose native plants for their gardens in the future compared to those who did not receive the comic. **While this study does not focus on traveler behaviors, it provides experimental evidence that creative interventions such as comics can help catch attention and affect behavioral intentions.**

Hart & Larson, 2014 [49]

Hart and Larson (2014) conducted a survey experiment examining whether invasive species is more effective in promoting support for prevention actions when the messaging focuses on invasive species as drivers of ecological change (driver model) or as the product of other environmental changes (passenger model). 436 U.S. undergraduate students participated in an experiment where they saw one of four messages: driver model with a mention that the invasive plant (garlic mustard or tamarisk) was initially introduced through human actions; driver model with no mention of human action; passenger model with human action; and passenger model with no mention of human action. Participants who saw the driver model were significantly more willing to take action to reduce invasive species, compared to those who saw the passenger model. This was particularly true when the message emphasized human action. **These results suggest that it is better to 1) talk about invasive species' impacts on ecosystems than to portray invasive species as the result of other ecological changes and 2) highlight the role of humans in spreading invasive species.** The authors found that

several pathways helped explain these findings, including participants' perception of the risk invasive species pose to humans and to the environment as well as their perception of individuals' responsibility in both spreading invasive species and in addressing them.

Hutchins et al., 2023 [80]

This online survey experiment examined the role of threat and efficacy message frames in promoting behaviors to reduce the spread of aquatic invasive species among wading anglers in the Great Lakes region. The authors tested three messages, each of which included both text and accompanying images: threat-focused ("Invasive species can harm fishing"), efficacy-focused ("YOU can stop the spread of invasive species"), and combined threat/efficacy ("Invasive species can harm fishing, but YOU can take action.") The authors also measured several other factors, including participants' perceptions of the threat of invasive species, their sense of efficacy in addressing the threat, and their reactance or perception that the message was manipulative or overstated. The results showed no differences among the three messages in participants' willingness to take prevention steps. Additional analysis showed that a strong sense of self-efficacy (the perception that the participant is able to take prevention steps) was related to greater behavioral intentions and lower reactance. The authors also found that participants' attitudes toward aquatic invasive species before viewing the message was among the best predictors of their behavioral intentions. Since the sample participants tended to be frequent and experienced fishermen, **this may suggest that for regular travelers, the contents of a single message are less important than repeated, frequent reminders about self-efficacy and simple steps to take.**

Kyle et al., 2022 [39]

In this report for the Western Regional Panel on Aquatic Nuisance Species, the researchers conducted a survey-experiment to evaluate aquatic invasive species (AIS) messaging strategies. 3,880 boaters from around the Western U.S. participated. The experiment included the control message with typical wording from the Clean, Drain, Dry campaign as well as nineteen messages with Clean, Drain, Dry wording along with: 1) "Stop Aquatic Hitchhikers"; 2) "It's the law"; 3-6) messages highlighting their identity as a boater, hunter, paddler, or angler; 7-10) economic/ecological gain/loss messages from DeGolia et al. (2019); 11-13) descriptive norms, injunctive norms, or both; 14-17) metaphor messages from Shaw et al. (2014); 18) informing boaters that the lake has aquatic AIS; and 19) the need to clean, drain, and dry every time. After viewing the message, participants were asked to rate the severity of aquatic invasive species and their willingness to take steps to prevent AIS. The authors found no statistically significant differences across conditions. However, they noted that the sample consisted of experienced and regular boaters who generally reported a high willingness to engage in prevention steps. The authors also noted that the boaters were typically more willing to engage in some prevention steps (cleaning, draining, and drying their boats) than others (washing their boats with hot water or a pressure cleaner). **These results suggest that many messaging frames have little effect when targeting individuals who are already aware of the threat of invasive species and who already take steps to prevent their spread.**

Mitsui et al., 2024 [70]

Using a field experiment on a Mt. Fuji hiking trail, the authors examined the role of two messaging frames (awe/natural beauty and rationality/logic) in encouraging hikers to use a boot brush station at the trailhead. The authors developed two signs that were posted next to the cleaning station on alternating days in 2021 (10/9 days respectively over the period of July-September). The first message featured existing signage on Mt. Fuji trails, which emphasized the mountain's natural beauty ("Let's protect Mt. Fuji.") The second sign used a rational frame and emphasized the specific goal of the behavior ("Don't bring non-native plants.") Both signs included the same image of a stick figure wiping their shoes and the additional sentence "Please use this mat to remove mud and invasive plant seeds from your shoes." Researchers observed whether visitors utilized the boot brush stations (337 visitors) and later approached them with a questionnaire to measure additional factors such as prior knowledge of invasive species and their sense of efficacy in using boot brush stations. In comparing the two messages, the authors found that visitors who viewed the logic message were more likely to wipe their shoes than those who viewed the natural beauty message. However, when the authors conducted an additional analysis incorporating the measures from the questionnaire, it did not matter which sign was displayed. Instead, perceived behavioral control (participants' sense that they are able to clean their shoes), prior knowledge, and invasive species knowledge gained from viewing the signs were related to a higher likelihood of cleaning shoes. Participants were less likely to clean their shoes when they didn't believe boot brush stations were important or effective. Interestingly, participants were also less likely to perform the behavior when their sense of awe for Mt. Fuji was higher. Finally, the authors also found that participants with stronger norms regarding invasive species prevention were more likely to clean their shoes when they saw the logic message, while those with lower norms were more likely to do so when they saw the natural beauty message. **These results demonstrate the importance of considering audience factors such as norms, efficacy, knowledge, and attitudes toward invasive species and using different messages to target various audience groups.**

Nishizawa et al., 2023 [29]

In this field experiment, the authors wanted to know which type of message would best encourage hikers to utilize the available boot brush station at the trailhead. They posted a sign before the station on a hiking trail in Japan, with the sign rotated every 1.5 hours over the course of eleven days in August-September 2018. Their four signs included a factual knowledge message ("Please clean your footwear to prevent introduction of invasive plant seeds. Seeds introduction into natural areas causes problems"), a message with the same factual knowledge plus procedural knowledge ("Please remove soil from your footwear sole using the mat/brush"), and a message with the same factual knowledge along with a visual nudge (a mat laid on the trail with footprints pointing toward the boot brush station). The control condition included a blank poster. The researchers used video footage to observe which hikers utilized the boot brush station. Then, researchers met hikers further down the trail to ask them some additional questions. 296 participants completed the experiment. The authors found that participants in the nudge condition were significantly more likely to wipe their shoes (42.7%) than those in the control condition (3.4%). The procedural knowledge condition was also effective but much less so than the nudge condition. Participants with greater knowledge of the

threat of invasive species were more likely to clean their shoes in the nudge and procedural conditions, while participants who reported noticing the cleaning tools and who recognized that they might be transporting invasive species were also more likely to clean their shoes in the nudge condition. **These results suggest that visual cues or nudges (such as painted footprints leading to a boot brush station) are particularly effective in promoting behaviors to prevent invasive species. Providing basic knowledge does not change travelers' behavior.**

Rice et al., 2023 [50]

Using a field experiment, the authors explored the degree to which graphic design elements on signage can capture visitors' attention and improve invasive species prevention behaviors. They developed six messages, including four with various graphic design features and two with words only. All signs included a header ("Wipe your shoes") followed by a subheading (either "Support native plants along community trails" or "I know the impact of invasive species firsthand") and additional supportive text (a stewardship and social norms message directly addressing the audience or included in a quote from a volunteer). The signs were posted with a boot brush station at the exit of a conservation lands trail in Montana in order to encourage hikers to clean their shoes as they left. The six signs and a control condition (no sign) were posted during alternating times between April and June of 2022. Researchers observed 809 visitors, measuring their attention (ignoring, glancing at, or stopping to read the sign) and behavior (cleaning shoes or not). The results showed that participants who viewed any of the signs were more likely to clean their shoes than those in the control condition who saw no sign. Visitors who stopped and read the sign were 405x more likely to clean their shoes than those who ignored the sign, as were those who glanced at it (85x). Among the six signs, the most effective at capturing attention and promoting behavior was a sign that included "typology as image" (images of invasive plants twining around the letters), contrasting colors, and the second set of messages listed above. **These results suggest that simply capturing attention is key. Graphic design features are worth considering along with message content, and that "typology as image" and contrasting colors may be effective graphic design choices.** However, it is worth noting that 1) this study simultaneously tested messages about keeping dogs on leashes, which may have reduced visitors' focus on the invasive species prevention message, and 2) the study did not systematically isolate elements of the design, making it difficult to know which message feature led to the results.

Schwartz et al., 2018 [66]

Researchers used a quasi-experimental field study to examine the effectiveness of messaging, infrastructure, and a combination of both approaches on trail use. The study included four conditions: one of two informational messages (e.g., "To protect OSMP lands, please stay on designated trails. This is not a designated trail."), a physical barrier (fence placed across the trail), a message and a barrier, and a control condition with no sign or barrier. These conditions were randomly placed on alternating days/times to 20 trail junctions in large parks in Boulder, Colorado. Researchers then observed 101 hikers on the trails to see whether they used the undesignated trail or stayed on the designated trail. Further up the trail, participants were approached and asked to take a survey about their trail behaviors, preferences, norms, knowledge of the Leave No Trace outreach program, and

behavioral intentions. The experimental results showed that the combination condition was the most effective at mitigating off-trail use. Additional analysis of the survey variables showed that participants who had favorable attitudes toward Leave No Trace, thought the behaviors were easy to do and effective, and reported norms supporting on-trail use were more willing to use designated trails in the future. However, only self-efficacy predicted actual behavior. **These results suggest that a combination of messaging and physical cues is effective at changing actual behavior. Self-efficacy is the best predictor of both behavior and behavioral intentions.** While this study does not focus on invasive species, we include it here because off-trail use is related to invasive species spread and came up in our interviews.

Shannon et al., 2020 [56]

In this quasi-experiment, researchers assessed the effectiveness of an e-learning intervention to improve attitudes and behavior related to invasive species. They developed a 1-2 hour online course and distributed it to 32 undergraduate students and 46 professionals, targeting those who conduct fieldwork or whose work brings them in contact with invasive species. Participants complete pre- and post-surveys about their awareness and perceptions of invasive species, their self-reported biosecurity behaviors (e.g., cleaning equipment, transport, and clothing), and whether they consciously utilized biosecurity practices in the field. The post-test was conducted six months after the training. Results showed that awareness of invasive species and conscious utilization of biosecurity practices increased after viewing the training. Interestingly, the training had no impact on cleaning behavior or the perception that the individual's behaviors could contribute to the spread of invasive species. **These results suggest that e-learning is a viable tool for spreading awareness and increasing conscious attention to one's own biosecurity practices but may not always change behavior**.

Sharp et al., 2017 [63]

A quasi-experiment was used to examine the impact of active lakeside outreach on boaters' and anglers' attitudes toward invasive species and their prevention behaviors. In the summer of 2012, active outreach was conducted at Canandaigua Lake in New York, including volunteers who inspected boats and taught boaters how to engage in prevention steps. The following summer, the authors conducted a survey at Canandaigua Lake as well as at another, comparable lake where no outreach had been conducted. They collected 400 surveys in total. They found that, surprisingly, participants at the lake with no previous outreach were significantly more likely to take prevention steps and to report a higher sense of urgency about invasive species management. The authors noted that participants at the second lake were more likely to be anglers rather than recreational boaters, which is associated with improved biosecurity practices and concern about the impacts of invasive species on fishing. The authors also noted that recreators often travel between lakes, and so there is no guarantee that survey participants in summer 2013 interacted with the outreach program in summer 2012. **While the tested intervention (a volunteer steward program) did not have the expected impact in this study, the results demonstrate the problems with a one-size-fits-all approach and the need to consider tailored outreach.**

Shaw et al., 2014 [88]

In this experiment, the authors wanted to know which message frames were the most engaging as well as the most cost-effective for sharing invasive species prevention information via social media. The advertisements appeared on Facebook ten times (for four days at a time, Thursday through Sunday) during the summer of 2018. Each advertisement showed unique users an image: science ("Zebra mussels impact fisheries and recreation"), protective/nurturing ("You can help protect our lakes"), hitchhiker ("Stop zebra mussels from hitching a ride"), nativist ("Zebra mussels: not native, not welcome"), and militaristic ("Stop the zebra mussel invasion"). Each advertisement also included accompanying text to provide additional information. The authors found that cost-per-click was higher for the hitchhiker and protective messages than for the science message, indicating that they were more expensive and less effective. The hitchhiker message had more shares than the science frame; there were no other differences in the number of shares or the number of comments. However, the authors also reviewed the content of the comments and noted some ethical concerns about the nativist message. They also looked at differences by gender and found that women had a higher cost-per-click and fewer comments than men did. **These results suggest that a basic science message may be the best choice, as it performed nearly as well as any other message but was cheaper and engaged both men and women.** The authors noted that the hitchhiker frame was slightly more effective than the science frame but was more expensive; using a more recognizable logo (e.g., the official Stop Aquatic Hitchhikers logo) might have affected those results. Finally, **it is also worth noting that this experiment did not measure behavior or behavioral intentions, so it is unclear whether any of the tested messages would lead to behavioral changes.**

Wallen & Kyle, 2018 [45]

In this survey experiment, 1,338 Texas boaters were presented with one of four messages about aquatic invasive species prevention. The control message utilized standard language from the Clean, Drain, Dry campaign ("Don't be a carrier for aquatic invasives") while the three experimental conditions added a message about regulation ("It's the law"), descriptive norms ("Most Texans clean, drain, and dry"), or injunctive norms ("Texans expect you to clean, drain, and dry"). The authors predicted that participants who viewed the three experimental conditions would report higher intentions to engage in prevention behavior than those who viewed the control condition. They found that the regulation condition performed better than the control, but contrary to their expectations, neither of the social norms conditions did. They also explored whether these results changed when considering participants' past behavior and perceived barriers. The regulation and injunctive norms conditions were most effective among participants who previously engaged in less prevention behavior and who perceived more barriers. **This suggests that messages highlighting laws and the expectations of others might be particularly effective when targeting populations who currently engage in few prevention behaviors.** However, this study took place in Texas, where laws and fines regarding aquatic invasive species prevention exist. Regulation-frame messaging would be more difficult to implement in locations that lack relevant regulations.

APPENDIX B: SURVEY AND INTERVIEW AUDIENCE RESEARCH

Study	Study details
Bouchard et al., 2015 [93] COM-B: • Capability	Table Mountain National Park, Western Cape province, South Africa Method: Interviewed 68 hikers, dogwalkers, and cyclists about their activities in the park and their recent outdoor activities. Also collected soil samples from shoes, bikes, and dogs' paws as well as along the trail. Findings: • 26% of visitors were carrying seeds. • Dog walkers were more likely to be carrying seeds than other types of visitors, and more invasive species were found in the soil along the dog path than the other routes. Key takeaway: While this study does not focus on a particular prevention behavior, it does suggest that it is important to consider local travelers as well as those who have traveled farther.
Chivers et al., 2017 [60] COM-B: • Capability • Opportunity	Ontario, Canada Method: Surveyed 580 recreational boaters about their boating habits and how their habits might change if a boat washing station was provided for free versus for $16; modeled the spread of aquatic invasive species based on these responses. Findings: • More invasions would be mitigated if boat washing stations were free. (But this benefit went down when more hypothetical lakes had mandatory washing stations.) • With a $16 fee, boat traffic redistributed to other nearby lakes, leading to minimal impact on invasive species control. • Implementing many washing stations over a 10-year period (16-32 stations, depending on the invasive species) brought the number of invasions to 0. Key takeaway: Cleaning stations seem to help, especially when they are free.

Cole et al., 2016 [31] COM-B: • Capability • Opportunity	Illinois, USA Method: Surveyed 515 recreational boaters about their knowledge of IS and adoption of 4 prevention methods (cleaning 1) boat exterior, 2) interior, 3) fishing tackle, 4) not intentionally transporting and releasing organisms. Also interviewed 14 managers at aquatic invasive species outreach organizations about their use of public outreach/education programs related to invasive species. Findings: • IS knowledge and prevention behavior were similar across regions regardless of how much the region spent on outreach, suggesting that prevention behavior does not solely depend on knowledge or awareness. • Almost all boaters avoid intentional transport and release by cleaning interior (68%, exterior (63%), or fishing tackle (47%). • Travelers are more likely to take all 4 steps than non-travelers. Limitations: • Used a convenience sample, so respondents may be more motivated than the average boater. Key takeaway: Prevention behavior does not solely depend on knowledge or awareness. Even so, many boaters are trying to take steps.
Cole et al., 2019 [40] COM-B: • Capability	Illinois, USA Method: Surveyed 295 recreational boaters about the last five locations where they launched their boat and the frequency of their aquatic invasive species prevention behavior. Conducted network analysis. Findings: • Network analysis showed strong connections between waterbodies, suggesting that boaters are traveling from one location to another. • 28% of participants reported not 'Always' cleaning the boat exterior, 22% not cleaning interior, 45% not cleaning fishing gear. 4% reported intentionally transporting organisms. • After removing survey participants who reported 'Always' taking prevention steps, the network connections change very little – suggesting that spread is driven by boaters who don't always take actions. • There were significant correlations between the number of visits from 'Not always' boaters and the number of invasive species in a lake.

	Key takeaway: Many boaters engage in some prevention steps, but invasive species spread is driven by those who don't 'Always' do so.
Cimino & Strecker, 2018 [51] COM-B: • Capability • Opportunity	Tenmile Lake, Oregon, USA Education program: Referred to Clean, Drain, Dry Method: Surveyed 199 recreational boaters before the installation of a boat cleaning station; surveyed 200 boaters after installation. Observed boaters prevention behaviors and use of cleaning station. Asked about boating habits, awareness of regulations and cleaning procedures, knowledge of invasive species, and observations of outreach materials at the cleaning station. Findings: • Many boaters recognize the importance of addressing invasive species and value the protection of ecosystems. • Less than half engaged in preventative actions. • Barriers included dissatisfaction with the cleaning station, inconvenience, lack of perceived necessity (e.g., infrequent boaters). • Limited laws and enforcement of laws, as well as inconsistent regulations across states, reduce compliance. • Boaters suggested improvements such as better equipment, reduced waiting times, increased visibility of AIS signage, and volunteer assistance at cleaning stations. Key takeaway: There is a gap between knowledge and action. It is important to address barriers such as equipment or sense of personal responsibility.
Davidson et al., 2010 [41] COM-B: • Capability	San Francisco, CA, USA Method: Surveyed 212 recreational boaters about their boat (type of boat, use of antifouling paint, manual hull cleaning) and their travel plans (home marina, voyage information). Also used an underwater camera and specimen collection to identify invasive species on the hull. Findings: • Several invasive species were identified on boat hulls. • Low risk boaters: lots of travel around waterbodies but very clean hull; all trips within the same waterbody, regardless of hull fouling; heavy fouling but no travel • Higher risk of primary introduction: travel from more distant waterbodies, especially after long port stays (mitigated by good maintenance habits) • Higher risk of secondary spread: regular travel to nearby waterbodies (mitigated by good maintenance habits)

	Key takeaway: The risk of invasive species spread by boaters varies, but boaters can reduce their risk by using good maintenance practices regardless of how often they travel.
De Ventura et al., 2017 [46] COM-B: • Opportunity • Motivation	Switzerland Education program: Referenced Clean, Drain, Dry Method: Mail-in survey of 3,561 boat owners across Switzerland about their awareness and perceptions of invasive species, barriers and benefits, perceived costs, and prevention behaviors. Key findings: • Reported cleaning rates are high, but cleaning methods are ineffective. • Those who perceived high costs (as perceived difficulty, time expenditure, estimated monetary costs and strenuousness of cleaning) cleaned their boat significantly less often. • Awareness, knowledge of boaters' role in spreading invasive species, and monetary cleaning costs did not impact behavior. • If perceived severity of AIS ecological impact was high, the were more likely to do a high-pressure (i.e., effective) clean of their boat. Key takeaway: Many boaters take prevention steps but are less likely to do the more arduous (but more effective) behaviors.
Dehez, 2023 [94] COM-B: • Capability • Motivation	Lac d'Aureilhan, France Method: Surveyed 295 recreational lake users, both locals and tourists, about their knowledge and perceptions of invasive species, attitudes on species management, perceived benefits or damages from invasive species, and willingness to engage in prevention steps (volunteering to clean up invasive plants, sharing information, giving money, changing how they use the lake.) Findings: • Participants were more willing to change how they use the lake or inform others about invasive plants than volunteer or donate. • They were generally more willing to act when they thought damage from invasive species was higher or benefits were lower, but it depended on the action. Key takeaway: Requests for the public to take action need to think about how big the ask is.

Dolman & Marion, 2022 [26] COM-B: • Capability • Opportunity	Appalachian Trail, Virginia, USA Theory: Theory of Planned Behavior Education program: Leave No Trace Method: Surveyed thru-hikers about their knowledge of invasive species' impacts and the role of boot brush stations, their use of boot brush stations, and whether they'd noticed a station along the trail. Findings: • Hikers generally had limited awareness of the impacts of invasive species on trails. • When they were informed about the risks, most hikers reported a willingness to take prevention steps. • Self-reported footwear cleaning behavior was associated with knowledge that brushes remove invasive species, age, education level, and the presence of a boot brush station. Key takeaway: Hikers are generally willing to clean their footwear when equipment is available and visible, and when they are advised to do so.
Eiswerth et al., 2011 [38] COM-B: • Capability	Bayfield County, Wisconsin, USA Method: Surveyed 666 lake district property owners by mail. Asked about their lake use, boat ownership, membership in a lake association, and knowledge of invasive species. Findings: • Highly-engaged recreators (frequent visits to other lakes, membership in an association) are likely to have higher awareness, understand the impacts more, and understand how invasive species spread between lakes. Key takeaway: Highly-engaged travelers may already have greater knowledge and awareness.
Fera et al., 2015 [62] COM-B: • Capability • Opportunity • Motivation	Ontario, Canada and worldwide Method: Interviewed 23 regional, national, and international outreach specialists about their programs, operations, and funding. Findings: • Outreach often uses traditional approaches (signs, brochures, etc.) but programs increasingly also use targeted messaging and other new techniques.

	• The simplest approaches were often the most successful, especially when messaging was consistent. • A combination of communication, direct/indirect approaches, legislation, and infrastructure was most conducive to change. Key takeaway: Use simple, consistent messaging backed up with legislation and solid infrastructure.
Floerl et al., 2016 [95] COM-B: • Capability • Motivation	New Zealand marinas Method: Surveyed boaters (domestic and international) about their hull-cleaning practices. Used a susceptible-infected-resistant model to simulate risk level and response. Findings: • Convincing boaters to renew their hull coating can be an effective way to avoid secondary spread. • Targeting only the 'worst offenders' (>720 days since last hull coating) only worked if compliance was very high; better to target medium offenders (>360 days; 77% of population) . Key takeaway: modest behavior change in a large percentage of the population is more likely to reduce invasive species spread more than aiming for significant behavior change in a small percentage.
Garcia-Llorente et al., 2011 [67] COM-B: • Capability • Motivation	Doñana Natural Protected Area, Andalucia, Spain Method: On-site surveys of 421 residents and visitors to the park, along with electronic surveys of 51 invasive species experts. Survey questions asked about invasive species knowledge, motivations to support invasive species management, and willingness to pay for management. Findings: • Factors such as interest in nature, sense of place, and knowledge of invasive species made participants more willing to pay. Key takeaway: This study focused on financial support for management actions (prevention or eradication) rather than traveler behavior, but still highlights motivations for support such as love of nature.

Gill et al., 2020 [32] COM-B: • Capability • Opportunity • Motivation	Kosciuszko National Park, New South Wales, Australia Theory: Theory of Planned Behavior Method: Surveyed 116 hikers at the park about their invasive species knowledge, prevention behaviors (footwear cleaning) and barriers. Findings: • Most hikers don't clean their shoes before or after a walk, but would be willing to do so if advised. • Knowledge was not related to cleaning behavior. • The largest perceived barrier was lack of equipment. • If a cleaning station was provided, half of participants said there were no other barriers; the other half noted wait times, equipment condition, cleaning station access/visibility, and knowledge of what to do. • Perceived benefits included biosecurity and cleanliness of own car or house. Key takeaway: Most hikers, regardless of knowledge, don't clean their footwear but would be willing to do so. It helps if stations are available, accessible/visible, maintained, and include procedural knowledge.
Golebie et al., 2021 [33] COM-B: • Motivation	Counties adjacent to the Great Lakes, USA Theory: "knowledge-action gap" Method: Surveyed 788 licensed recreational anglers about their prevention behavior, values, and risk perceptions. Findings: • Participants who cared more for nature were more likely to report that invasive species were a threat to them personally and to the broader area (economically and ecologically). • Participants with higher values related to self-interest were more likely to view invasive species as a personal threat. • Personal risk was associated with prevention behavior & public behavior (e.g., advocating for policies); social risk was not. • General altruism was not related to risk perceptions. Key takeaway: Emphasize the impact of invasive species on travelers themselves rather than just the broader ecological threat in order to speak to a broader audience.

Golebie et al., 2023 [96] COM-B: • Motivation	Illinois, USA Theory: Health Belief Model Education program: Referred to Clean, Drain, Dry Method: Surveyed 507 recreational water users about their perceptions of invasive species, prevention behavioral intentions and self-efficacy of behaviors, perceived benefits and barriers, and response efficacy (whether prevention behaviors actually reduce the risk). Findings: • Higher self and response efficacy increased the likelihood of engaging in prevention steps: cleaning equipment, disposing of live bait in the trash. A higher sense of threat from invasive species was related to more prevention behavior for boaters. • The factors that predicted behavioral intentions depended on perceived barriers. When barriers were low, seeing more benefits helped. When barriers were moderate to very high, recreators who had reported higher self-efficacy, response efficacy, and/or perceived risk were more willing to take prevention steps. Key takeaway: Emphasizing self-efficacy, response efficacy, and the risk of invasive species are effective at motivating behavior, especially in groups who report higher barriers.
Gozlan et al., 2013 [97] COM-B: • Capability • Opportunity • Motivation	Bournemouth, Cardiff, and London; UK Education program: Referred to Clean, Drain, Dry Methods: Surveyed 132 conservation professionals (electronic), 103 anglers (electronic), and 187 members of the public (street survey) about invasive species knowledge, risk perceptions. Reviewed media reports, scientific research, and actual risk scores for five species (harlequin ladybird, signal crayfish, Japanese knotwood, topmouth gudgeon, and gray squirrel). Findings: • Conservation managers saw the risk as higher than the public did, and also saw humans as a greater threat. • Public awareness was higher for terrestrial species than aquatic; anglers saw some aquatic species as high risk but not all. • Participants' perception of risk from the five species was similar to the risk reported by the media but not the actual risk or the amount of scientific research on that topic.

	Key takeaway: Perceptions of invasive species risk are more likely to be based on media reports than scientific research.
Harvey et al., 2016 [98] COM-B: • Motivation	Florida, USA Education program: Python Challenge Methods: Survey of 660 Floridians about their perceptions of pythons, including participants in the Python Challenge and non-participants. Findings: • Non-participants were more concerned about invasive pythons than participants, but overall concern was high. Limitation: non-participants were recruited at a Python Challenge Awareness Event and may not represent the public. Key takeaway: Outreach events can be helpful in raising awareness.
Joubert et al., 2022 [76] COM-B: • Capability	South Africa Method: Online survey of 100 registered anglers, asking about their knowledge of aquatic invasive species and regulations. Findings: • Anglers were largely aware of some regulations (fishing license, equipment limitations, some size limits). • Knowledge of specific regulations by location was low. • Many anglers couldn't identify specific species or define invasive/alien species. Key takeaway: It can be difficult to keep track of complex regulatory structures, even for motivated audiences. Common species may not be viewed as invasive.
Kemp et al., 2017 [77] COM-B: • Capability • Motivation	Illinois, USA Theory: "Knowledge-action gap" Method: Interviewed 10 recreational water users and 9 organism-in-trade hobbyists about their knowledge of invasive species, prevention behavior, relationship with nature, and perceptions of outreach campaigns (Be a Hero Transport Zero, Be a Hero Release Zero, Stop Aquatic Hitchhikers, Habitattitude) Findings: • Both groups had some awareness, but species varied.

	• Most engage in some prevention actions, and structural factors / regulations affected their actions. • More familiar with SAH and Habitattitude campaigns/logos. • They found some of the campaign imagery confusing or not applicable. Key takeaway: Campaign materials must make sense to the audience.
Levers & Pradhanga, 2021 [99] COM-B: • Capability • Motivation	Four lakes in Minnesota, USA Method: In-person surveys of 704 lake visitors, asking about their visit motivations and lake uses, perceptions of invasive species, and the fee amount they would be willing to pay to aid management efforts. Findings: • Visitors were willing to pay an average fee of $9.97. • Locals and those who came to the lake to be alone would pay less; higher perceived risk, higher awareness, and being female were associated with a willingness to pay a higher fee. • The amount visitors would be willing to pay didn't differ across lakes, even though the lakes had different invasion levels. Key takeaway: Visitors are willing to pay a fee to aid management efforts, regardless of the impact of invasive species at that location.
Lovelock et al., 2022 [19] COM-B: • Capability • Motivation	Queenstown and Arrowtown, New Zealand Theory: "Knowledge-attitude behavior connection" Method: On-site survey of 238 tourists, both domestic and international. Asked about awareness of the impacts of invasive species, perceptions of specific plants, and behavioral intentions. Findings: • Most tourists had low awareness of the risk, especially international tourists. • Some plants were more accepted than others, especially plants that are tourist attractions due to their aesthetic appeal. Key takeaway: It's important to not treat tourists as a single group but instead to consider factors such as tourism expectations and cultural backgrounds.

Lovelock et al., 2023 [27] COM-B: • Capability • Motivation	South Island, New Zealand Method: On-site survey of 231 domestic and international tourists, asking knowledge of and views on invasive species. Findings: • International visitors have less knowledge and greater acceptance of invasive plant species than domestic visitors. • China and other Asian tourists showed higher acceptance and tolerance of introduced species and less support for eradication. Differences exist, but Asian tourists' attitudes are not strongly positive toward invasive species or strongly negative toward managing invasives. Key takeaway: The study was more about implications for management than specific tourist behaviors but highlights audience differences.
Martínez-Laiz et al., 2019 [82] COM-B: • Capability	Marinas along the Mediterranean Sea (Greece, France, Italy, Turkey) Method: Interviewed 247 recreational boaters about their boat maintenance habits, travel patterns, and awareness of invasive species generally and on their boat specifically. Also took biological samples from boat hulls. Findings: • Many boats carried invasive species (56%) or potentially invasive species (79%). • Boaters were unaware of the risk. • Many believed their boats were clean despite biofouling. • Boaters were likely to clean their boats in the water because it's cheaper. Key takeaway: Travelers may not see themselves as a vector for invasive species spread even when they are.
Mejía & Brandt, 2017 [100] COM-B: • Capability • Opportunity	Galapagos Islands, Ecuador Method: On-site survey-experiment of 252 visitors (study 1) and 297 visitors (study 2). The experiment manipulated the price of a trip and the amount of information provided about invasive species to see if this would affect the probability of a tourist choosing a short or long trip. Findings:

Melly & Hanrahan, 2020 [57] COM-B: • Capability	Tourist attractions across Ireland Education program: referenced Clean, Drain, Dry Method: On-site survey of 475 outdoor recreational tourists asking about their awareness of biosecurity measures and communication to tourists about these measures along with prevention behaviors. Findings: • Most tourists engaged in some outdoor recreation but the vast majority (93%) reported not taking any biosecurity measures. • Most (70%) were unaware of biosecurity measures, and many didn't know what biosecurity meant (60%). Awareness was higher among those who had visited countries with strong biosecurity outreach (e.g., UK, New Zealand, Australia). • Most saw no biosecurity outreach during their trip. • Only 20% of those who saw biosecurity messaging acted on it. Key takeaway: Awareness and prevention behavior among tourists is still low; even when outreach is provided, many tourists don't act on it.
Mineur et al., 2008 [79] COM-B: • Capability	Marinas in France and Spain Method: On-site survey 149 small yacht owners, asking about their journey, boat maintenance behaviors (dry docking, use of antifouling paints), and awareness of aquatic invasive species. Findings: • Yacht owners are aware of invasive seaweed and take prevention steps (dry dock and apply a coating annually) because they believe its presence would make their vessel less responsive. Key takeaway: Connecting invasive species prevention actions on sailing yachts to vessel performance may be an effective approach even if the risk is low.
Moore et al., 2024 [47] COM-B: • Capability • Motivation	Illinois, USA Method: Online survey of 507 recreational boaters across the state, asking about perceived risk of invasive species, self-efficacy, and behavioral intentions. Findings: • Self-efficacy was the strongest predictor of behavioral intent. As such, discrete actions

	• Those that live further from invasions are less knowledgeable and have lower perceived risk. • Risk severity (more than susceptibility) predicted behavioral intent. Key takeaway: Highlight discrete actions rather than the importance or consequences of performing those behaviors. Emphasizing risk severity and targeting audiences that live further from invaded waters are also recommended.
Muehlenbein et al., 2021 [101] COM-B: • Capability • Motivation	Saint Kitts, UK Method: On-site survey of 1097 tourists about their environmental attitudes, concerns, and interactions with monkeys. Findings: • Most tourists were aware that humans and monkeys can transmit diseases to each other but many still had contact with monkeys during their trip. Key takeaways: Knowledge alone does not prevent risky actions.
Mueting & Gerstenberger, 2011 [35] COM-B: • Capability	Lake Mead National Recreation Area, Nevada, USA Education campaign: 100th Meridian Initiative Method: Interviewed 242 boaters in 2002-2003 and 236 boaters in 2007-2008. Asked about their boating habits, prevention behaviors, and awareness of invasive species. Findings: • Awareness increased a great deal, but behavior did not change. • Authors suggested this could be due to differeing definitions of cleaning among boaters. Key takeaway: Cleaning needs to be clearly and simply defined and promoted.
Nanayakkara et al., 2018 [74] COM-B: • Capability	Lakes in Saskatchewan, Canada Method: On-site survey of 440 lake visitors, asking about their lake use and their knowledge of invasive species and prevention behaviors. Findings: • Fishing was an important positive predictor of AIS knowledge, likely due to exposure to outreach campaigns and developed sense of personal responsibility; non-fishing recreation was associated with less knowledge about invasive fish presence.

	• Those who used all three lake regions or used a lake for work showed higher invasive species knowledge than the rest. • Recreational swimming was negatively associated with knowledge of fish presence and impacts of plants and mussels. • Cabin ownership was negatively related to awareness of quagga mussels, possibly due to seasonal usage patterns. Key takeaways: Target a broad array of recreationists, even those who are not key vectors (e.g. bird watchers, swimmers, cabin owners), and draw connections between recreationists desired lake-related activity and the impact of AIS. The authors believed this would pressure boat-owning or fishing neighbors to be more attentive to AIS transmission and create more supportive communities for AIS management.
Nishizawa et al., 2021 [34] COM-B: • Capability	Chubusangaku National Park, Japan Method: Surveyed 344 park visitors about their knowledge of invasive species and human-mediated seed introduction, information sources, and self-reported behavior. Also sampled the soil on visitors' shoes. Findings: • 7.8% of tourists had seeds on their boots that germinated into non-native plant species. • The number of seedlings was significantly lower in samples from participants who cleaned their footwear before their visit compared to those from participants who did not. • No association of knowledge and attitudes with ACTUAL behavior. Key takeaway: Cleaning footwear is helpful; knowledge and attitudes are not correlated with footwear cleaning behavior.
Nolan et al., 2019 [81] COM-B: • Capability • Opportunity • Motivation	River Severn catchment, UK Method: Semi-structured interviews with 12 anglers, asking about their values, motivations, fishing preferences, and views on conservation. Findings: • Values: Strong conservation ethic, even while practicing catch-and-release of invasive species; balance between supporting pikeperch fishing opportunities and concern for native species • Primary Motivations: Catch-related factors (size, challenge, anticipation); experience of catching wild fish in natural settings • Social Influences: Peer pressure and community norms strongly shaped behavior; angler-led initiatives often drove management practices at local level.

	• Knowledge Factors: Skepticism toward culling as effective management; belief that catch-and-release of invasive species causes minimal ecological harm. Key takeaway: Effective communication should leverage existing conservation values while addressing misconceptions, work through established angling community channels, and recognize the complex motivations that drive angler behavior. Appeals to existing conservation values could be more persuasive than confrontational tactics
Ovenden & Studholme, 2021 [52] COM-B: • Capability • Opportunity • Motivation	Lake Tomorātā and Lake Rototoa, New Zealand Education program: Clean, Drain, Dry Method: Social marketing campaign targeting lake visitors. Initial survey of 314 visitors asked about their use of the lake, prevention behaviors, and awareness of invasive species. Several interventions were developed and implemented (see section 5.) Findings: • About half of visitors were aware of invasive species. • Only a quarter 'Always' take prevention steps. Key takeaway: Awareness and behavior are not always related; audience analysis can help determine the needs for that site.
Pavlovski et al., 2019 [78] COM-B: • Capability • Motivation	Eastern peninsula of Upper Michigan, USA Method: interviews with 80 aquatic-based recreators about their knowledge, awareness, and risk perceptions regarding viral hemorrhagic septicemia (a viral disease that affects fish). Findings: • Most had never heard of VHS or knew little about it. • Highest concerns were the risk to the environment, fishing, and their own health; previous awareness of VHS was associated with concern about the disease affecting fishing. Key takeaways: Awareness for some species or diseases is lower than for others.

Seekamp et al., 2016 [102] COM-B: • Capability	Illinois and Indiana, USA Education program: Stop Aquatic Hitchhikers Method: On-site survey of 618 aquatic recreationists along with focus groups. Asked about their knowledge of invasive species and sense of personal responsibility, prevention behavior, and awareness of campaign Findings: • Familiarity with the campaign was associated with higher knowledge, personal responsibility, and self-reported behavior. • Recreators are more likely to do easier prevention steps than steps that require more effort or resources. • They are more likely to take prevention steps if they know there are aquatic invasive species in the waterbody they visited. Key takeaway: Exposure to educational campaigns seem to help, particularly with less arduous behaviors.
Shannon et al., 2020 [103] COM-B: • Capability • Motivation	England and Wales Theory: Theory of Planned Behavior Method: Interviewed 14 individuals from the recreational boating sector or the shellfish industry about their marine activities, knowledge and attitudes toward invasive species and related policies, and motivations. Findings: • Biosecurity practices are part of the regulatory practices for the shellfish industry, and there are financial and legal incentives. • Boaters are much less regulated, and compliance relies on voluntary behavior. • Lack of infrastructure and enforcement played a role. Key takeaway: Infrastructure, regulation, and social norms might help.
Shaw et al., 2014 [88] COM-B: • Capability	Rothschild, Wisconsin, USA Method: On-site intercept interviews of 52 boaters who were at the movies and were exposed to an ad about invasive species prevention. Asked about seeing the ad, recalling its message, and usual prevention behaviors. Findings: • 29% recalled seeing the ad; those who remembered it were able to list at least one prevention step.

	• All respondents who recalled the ad had previously encountered aquatic invasive species-related information elsewhere. Key takeaway: Repeated messaging helps increase awareness and could encourage individuals to think more deeply about the issue.
Smith et al., 2020 [43] COM-B: • Capability	UK Education program: Clean, Drain, Dry Method: Online survey of 640 British anglers about their fishing patterns, prevention behaviors, and awareness of invasive species. Findings: • Approximately 40% of anglers use their equipment to fish in other countries. • Prevention behaviors have improved since the CDD campaign was launched, but many anglers still don't complete all the steps every time. Key takeaway: Anglers represent an important vector for invasive species spread within and between countries. Campaigns like Clean, Drain, Dry seem to help, but not all anglers engage in prevention.
Smith et al., 2023 [42] COM-B: • Capability	UK Education program: Clean, Drain, Dry Method: Online/self-administered survey of 680 freshwater anglers about their awareness of biosecurity measures and prevention behavior since the campaign was launched. Findings: • Approximately half of regular anglers clean and dry their equipment after every trip. • Those who were aware of CDD were more likely to engage in prevention behaviors; since the launch of the campaign, biosecurity compliance has increased. • Barriers included lack of accessible cleaning stations, the perceived visual cleanliness of equipment, and reliance on inadequate cleaning methods like cold water. Key takeaway: Exposure to educational campaigns seems to help, but it's important to emphasize how to do the behavior correctly and to consider infrastructure and availability of supplies.

Timar & Phaneuf, 2009 [61] COM-B: • Opportunity	Wisconsin, USA Methods: Used econometric with existing survey data on recreational boaters' prevention behaviors. Findings: • Free inspections were more effective at reducing predicted spread than inspections with fees or site closures. • Higher fees or site closures incentivize visiting other lakes, which increases the risk of spread. Key takeaway: Free inspections work; boaters are sensitive to costs.
van Riper et al., 2019 [71] COM-B: • Motivation	Chain O'Lakes State Park and North Point Marina, Illinois, USA Method: On-site surveys of 104 recreational boaters and anglers about their normative beliefs, relationships with nature, and self-reported pro-environmental behaviors. Findings: • Social norms influence prevention behavior. • Recommendations: o Design AIS management programs that focus on building social normative beliefs. o Establish norms around desirable activities to encourage and sustain AIS reduction strategies. o Pair existing routine behaviors (like trash removal) with desired behaviors (like boat washing). o Leverage existing negative attitudes toward certain invasive species (like Asian carp) to promote harvesting. o Use normative appeals in signage (thumbs up, smiley faces) to activate social pressure. o Depict people displaying positive attitudes while engaging in desired behaviors to suggest prevalence. Key takeaway: Social norms are helpful in promoting prevention behavior, and there are multiple ways to leverage them.

APPENDIX C: EXISTING INVASIVE SPECIES CAMPAIGNS

Inspiration for a more unified approach/campaign may be inspired by several of the existing campaigns we were alerted to from our interviews, a study by [39], and the literature review. We provide a list and links (when available) for consult. If evaluation information about the campaign was mentioned, it's included.

Island Travelers (broad, not always specific to invasive species)

- Pono Pledge **(Hawai'i Island, Hawai'i)** - Focuses on Environmental Threats and Protected Species. Creates awareness about island environments, particularly focused on Maui and how visitors can care for the islands
- Malama Maui Pledge **(Maui, Hawai'i)** – "asks visitors to acknowledge, protect, respect, and learn about the islands' culture, natural resources, and community during (their) stay."
- Kuleana Campaign **(Hawai'i Tourism Authority)** - Provides informational videos shown to arriving airline passengers (cruise ship participation unclear). Conservation videos include mention of invasive species, but not sole focus.
- Travel Pono **(Hawaiian Airlines)** – Effort centralized on an informational video played on all Hawaiian airline's transpacific flights containing messages about culture, conservation, and safety. The effort also includes pre-trip emails, a trip-planning website, blog, and social media posts. This is very well done and executed, but does not focus on invasive species as much as it could; it's not mentioned in the in-flight video, and there is only one blog post.
- **Silent Invasion** (**CGAPS)** – Focuses on invasive species in Hawai'i
- New Zealand Biosecurity – A centralized effort with a handful of specific campaigns or focus areas. Correlational study suggested that "Targeted messages to different stakeholder groups were crucial components of a successful outreach campaign. Ship owners, operations departments, vessel crews, trade associations, ports, and other regulatory agencies all require slightly different messaging targeted at their direct roles in achieving compliance and risk reduction." [65]

Aquatic Invasive Species

- **Protect the Lakes You Love (Texas)** - Rated highly for both familiarity and effectiveness*
- **Clean Boats, Clean Waters (Wisconsin)** - Rated highly for familiarity*
- **Clean In Clean Out (Minnesota)** - Rated highly for familiarity*
- **Clean, Drain, Dry (National)** - Rated highly for both familiarity and effectiveness* [42] [43]
- **STD of the Sea (Utah)** - Rated highly for effectiveness*
- **Stop Aquatic Hitchhikers (National)** - Rated highly for effectiveness*

Agricultural and Terrestrial Pests/Invasive Species

- **PlayCleanGo® (National)** - Rated highly for effectiveness* [59]
- **Don't Pack a Pest (National)** – "educate(s) travelers about the risks associated with carrying certain types of food, plants, or other agricultural items in passenger baggage and encouraging travelers to declare agricultural items and Don't Pack a Pest." Besides reach metrics, no evaluation data seems to be available.
    - Ad Campaigns
        - General video
        - Guam - customs
            - little fire ants
            - rhino beetle
            - Brown tree snake
                - 10-min documentary on brown tree snakes
- **Don't Let It Loose (National)** – aimed at convincing pet owners to not release pets into the wild.
- **Stay Wild (Isle Royale National Park)**
- **Weed Whackers (Alaska)** – K-6 educational materials regarding invasive species

*[39]

APPENDIX D: KEY TAKEAWAYS FROM 14 INTERVIEWS

1. Species & Impact Analysis

Primary Invasive Threats

- Terrestrial mammals emerge as significant threats across multiple island ecosystems
- Plant species represent a substantial but often under-discussed threat vector
- Aquatic invasive species are mentioned less frequently than terrestrial threats

Introduction & Spread Patterns

- Multiple transportation vectors identified including:
    - Personal gear (boots, clothing, backpacks)
    - Gift items (particularly floral gifts)
    - Food products (especially fruits)
    - Vehicle-related vectors (ballast water, cruise ships, boats, contractor equipment)
- Spread patterns vary significantly by traveler type and destination

Primary Spread Vectors by Audience Segment

- Tourists: Personal gear, staying off designated trails, food items
- Inter-island residents: Personal items, gifts, food transport
- Researchers/Staff: Scientific equipment, field gear
- Contractors/Workers: Heavy equipment, vehicles, construction materials

2. Critical Behaviors

High-Impact Traveler Actions

- Failure to clean personal gear (particularly boot treads, backpacks, clothing)
- Venturing off designated trails and protected areas
- Transportation of potentially contaminated items between islands
- Improper management of ballast water (specific to watercraft)

Behaviors with Change Potential

- Gear cleaning protocols (particularly when supported by available facilities)
- Adherence to designated pathways and trails
- Pre-arrival preparation and awareness
- Inspection of personal items before inter-island transport

Barriers to Behavior Change

- Limited awareness of invasive species impacts
- Time constraints for proper gear inspection and cleaning
- Procedural knowledge gaps (how to properly clean/inspect)
- Resource limitations (availability of cleaning stations, materials like isopropyl alcohol)
- Timing challenges (need for both arrival and departure protocols)
- Educational material quality issues (length, engagement level, frequency of reminders)

3. Target Audience Definition

High-Risk Traveler Segments

- One-time tourists/visitors
- Regular inter-island travelers
- Research personnel
- Contractors and construction workers
- Cruise ship passengers and crew

Segment Characteristics

- Demographics: Broad demographic range with some age-related differences in compliance
- Geographic Origin: Mix of domestic (US) and international travelers with varying awareness levels
- Travel Patterns:
    - Organized tour groups (more accessible for education)
    - Independent travelers (harder to reach with messaging)
    - Private boat operators (minimal oversight opportunities)

- Activity-Based Segments:
    - ATV/off-road vehicle users
    - Divers and snorkelers
    - Backpackers and campers
    - Recreational water users vs. land-based recreators

4. Campaign Analysis

Perceived (Anecdotal) Effective Campaign Elements

- Visual communication approaches that create memorable impressions
- Action-oriented messaging that connects behaviors to outcomes
- Clear procedural guidance (specific steps for compliance)
- In-person intervention and educational opportunities

Identified Gaps and Opportunities

- Limited utilization of social media channels
- Insufficient pre-arrival engagement and education
- Inadequate on-site staffing for enforcement and education
- Need for more consistent monitoring and spot-checking

Potential Partnership Models

- Transportation providers (ports, airlines, airports)
- Tour operators and concessionaires
- Conservation organizations and special interest groups (birding, etc.)
- Research institutions and government agencies
- Local community engagement initiatives

5. Additional Observations

Implementation Challenges

- Significant variability in island needs and contexts requires customized approaches

- Resource limitations for consistent staffing and monitoring
- Reaching independent travelers who bypass official entry points

Future Directions

- Development of location-specific digital tools (suggested app for pre-trip planning)
- Enhanced coordination between islands sharing common threats
- Improved evaluation mechanisms for existing programs

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