Education and Outreach

Human dimensions of aquatic invasive species transport at Lake Mead National Recreation Area

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Abstract

Since the January 2007 discovery of quagga mussels (*Dreissena rostriformis bugensis*) at Lake Mead National Recreation Area, the National Park Service has worked with numerous agencies and partners to prevent further spread of invasive species through inspection and decontamination of recreational vessels and boater education programs. We applied geographic and demographic analysis techniques to data collected at inspection and decontamination stations within the park and data from inspection stations across the western United States to better understand the visitor boating population. Using ArcGIS ESRI Tapestry software and the home zip codes of recreational boaters whose vessels were inspected within the park, we classified local and non-local boaters into demographic groups with the goal of developing more targeted educational programs. Demographic results indicate distinctive trends within the boating population including: higher median incomes, high levels of education, and boat owner median ages in the mid-30s. Economic and behavioral patterns of Lake Mead boater demographics combined with a synthesis of available research on behavior change in environmental campaign design demonstrate the need for targeted outreach to increase the effectiveness of aquatic invasive species (AIS) programs and further reduce AIS transmission risk.

Key words: quagga mussels, Lake Mead, demographic analysis, outreach, education

Introduction

Mitigating the impacts of non-native species costs an estimated 120 billion dollars annually in the United States alone (Pimentel et al. 2005). The rapid invasion and establishment of quagga mussels (*Dreissena rostriformis bugensis* [Andrusov, 1987]) west of the 100th meridian (Figure 1) necessitated widespread efforts to mitigate deleterious consequences to ecological and economic systems (Wong and Gerstenberger 2011). Water control structures such as dams are exceptionally vulnerable to quagga mussel fouling, which is concerning given the growing reliance on small reservoirs for municipal water management to support human population growth (Turner et al. 2011). High fecundity and the ability to thrive in a wide range of environments,

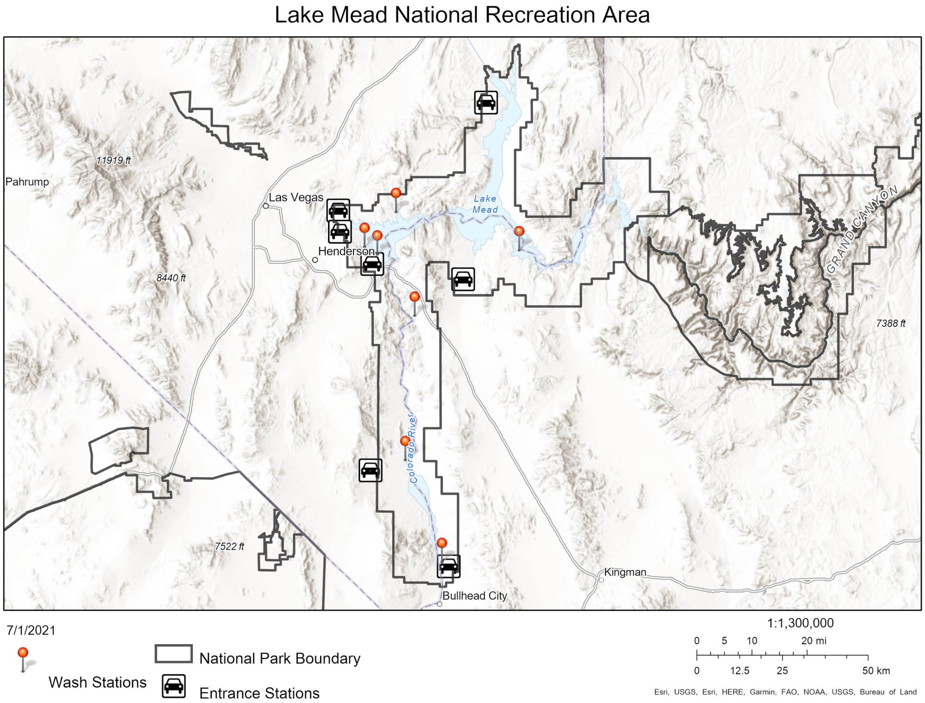

Figure 1. Lake Mead National Recreation Area (LAKE) is located on the border of Nevada and Arizona. It became the first body of water west of the 100th meridian to detect quagga mussels in 2007. To prevent the spread of quagga mussels to other bodies of water, LAKE installed seven inspection and decontamination wash stations—three in Arizona and four in Nevada—as indicated by the orange pins. This study analyzed data collected at the four AIS inspection stations located on the Nevada side of LAKE.

including broad temperature ranges and low interspecific competition, allow quagga mussel invasions to occur quickly (Mills et al. 1996). Mussels can be found at depths of up to 130 m (USGS 2019) and are able to settle on almost any surface or substrate (Rosen et al. 2012). Established populations filter large volumes of phytoplankton, and in many cases deplete food resources for native species, disrupting food web dynamics (Sousa et al. 2014). The primary transmission vector is widely thought to be overland transport of recreational boats and equipment contaminated with planktonic larval veligers or live adult mussels (Dalton and Cottrell 2013). Eradication in natural, open systems is currently not possible (Mueting and Gerstenberger 2011). As a result, management efforts rely heavily on outreach, education, and containment at infested water bodies (Hickey 2010).

Lake Mead National Recreation Area (LAKE) was established October 8, 1964 as the National Park Service's first national recreation area and is situated along the state line between Nevada and Arizona (National Park Service 2016a, b). LAKE encompasses nearly 1.5 million acres including 225,000 acres of water and is the largest designated recreation area in the United States hosting nearly eight million visitors each year (National Park Service PS 2016b). LAKE includes two large reservoirs: Lake Mead and Lake Mohave. Lake Mead was formed by the construction of the Hoover Dam in 1935 (National Park Service 2016c), and Lake Mohave was formed by the construction of Davis Dam in 1951 (Figure 1). Lake Mead has four marinas: Lake Mead Marina, Las Vegas Boat Harbor, Callville Bay, and Temple Bar. Lake Mohave has three marinas: Willow Beach, Cottonwood Cove, and Katherine Landing. All marinas are open to both day use boaters and long-term boat docking and each presents potential for aquatic invasive species (AIS) spread upon exiting park boundaries. In partnership with state agencies and park concessioners, free hot water decontaminations are available prior to leaving LAKE and are required for long-term boats (vessels that have been slipped or moored for five days or more).

A three-tiered approach to AIS mitigation is employed at LAKE, through partnership with the Nevada Department of Wildlife (NDOW), and throughout much of the western U.S., including prevention, containment, and enforcement. Prevention efforts are aimed at protecting water bodies where AIS do not have a verifiable presence. Containment activities focus on preventing the spread of AIS from infected waterbodies. Enforcement further prevents AIS spread through a variety of federal and state programs that include inspection stations, decontamination mandates, and a series of fees and penalties for negligent AIS transport. A network of AIS inspection and decontamination stations at both containment and prevention stage water bodies minimizes AIS spread, with emphasis on quagga mussels. The network includes federal and state-run intervention programs with coverage across major highway transport routes to inspect vessels traveling from one waterbody to a subsequent destination.

Boaters visiting LAKE are educated about proper boat cleaning procedures through signs, online resources, and interactions with park staff in order to eliminate potential spread of live adult mussels or veligers. The widely accepted procedure for day use boaters (those who launch and retrieve their boats in the same day) is to "Clean, Drain, Dry" their vessel, which includes cleaning off any dirt, mud, or visible plants attached to the boat; draining all compartments which may hold water such as live wells, hulls, bait storage, or coolers that may have come in contact with lake water; and drying any visible or remaining water from the boat surface or compartments (Nevada Department of Wildlife 2017). However, Cimino and Strecker (2018) found that only 25–32% of boaters saw signage regarding AIS when arriving at Tenmile Lake, Oregon, and even fewer (5–6%) saw signage regarding AIS when leaving the lake. This suggests that in order to initiate repetitive behavior changes within the boating population, more targeted educational techniques are needed (McKenzie-Mohr 2000).

State and Federal privacy laws impose limitations on data collection and analytical methods which largely inhibit the use of standard social science methods used to investigate human dimensions of ecological interaction. Human dimensions is an all-encompassing term covering anthropogenic influences, behaviors or action having a subsequent impact on ecological health. However, the use of data collected at inspection stations does not infringe upon privacy regulations and may provide insight on how AIS education and outreach could be refined to generate a more positive impact on target audiences. Demographic analysis is a technique used to develop an understanding of the composition of a population based on factors such as age, income, or education, and is often employed as part of market research strategies by private sector entities. To our knowledge it has yet to be applied to a boating population from an AIS program perspective. Thus, the goal of this study is to understand the geographic context of AIS spread in the Western U.S., and classify and compare LAKE boaters by major demographic groups to make recommendations for AIS boater outreach and education programs at LAKE and other Western states.

Materials and methods

Geographic analysis of recreational boater destinations

We used state inspection station data to investigate potential geographic gaps in the Western AIS inspection station network along major interstate and highway routes. Vessel data records (n = 2,280) from 2016 to 2018 were obtained from AIS inspection stations in eleven states (California, Nevada, Arizona, New Mexico, Colorado, Utah, Wyoming, Idaho, Oregon, Montana, and Washington). Data (origin, destination city, destination state, destination longitude, destination latitude, and number of vessels) were extracted from inspection reports and filtered to include only vessels with a reported origin of Lake Mead or Lake Mohave and a reported identifiable destination point (known city, state, or an official waterbody name). Reports were then combined to generate a regional dataset consisting of 1,636 total vessel records. An approximate latitude and longitude for each destination was assigned to each record and plotted within a geographic information system. These destinations were then compared to an inspection station database created by the Pacific States Marine Fisheries Commission (PSMFC). This database provides locations of inspection stations in the Western U.S., while also providing information such as station hours and number of active days. Any stations that were missing from the database and currently in operation as of 2018 were added manually and plotted in ArcGIS using addresses, geographic coordinates, or approximate locations. Major travel routes from LAKE to reported destinations were compared using National Highway Network data to determine the prevalence of geographic gaps in the Western AIS inspection network.

Demographic analysis of recreational boater populations

Demographic analysis was conducted using vessel registration zip codes and associated census demographics. Vessel information was obtained from 2,031 inspections conducted at four NDOW inspection stations within LAKE between 2016 and 2018. Zip codes representing the home origin of each vessel were compiled. Vessel registration zip code was used as a proxy for vessel owner home zip code, assuming this is the zip code where the vessel owners resides. Records with invalid, international, or duplicate zip codes were removed, resulting in 1,636 records and 671 zip codes in the data set. All demographic analysis was conducted using 2018 ESRI Tapestry Segmentation (ESRI 2018). ESRI Tapestry is a geodemographic segmentation system which combines traditional heuristic cluster analysis with data mining techniques. Tapestry is a market-based analytical data processing system, providing demographic data from across U.S. neighborhoods and socioeconomic segments. Tapestry provides information on behavioral and economic patterns associated with neighborhood demographic profiles.

Tapestry categorizes individuals into 14 Life Modes and 67 Segmentations based on U.S. Census reported attributes including: household characteristics (e.g. family size), living situation (e.g. rent or own), and personal attributes (e.g. age, gender, etc.) (ESRI 2020). Life Modes are summary groups depicting various lifestyles, whereas Segmentations are neighborhood classifications based both on demographics and socioeconomic characteristics (ESRI 2020). All Segmentations fit into one of the larger Life Modes. Data output for the Tapestry analysis includes an index to compare the Tapestry Segment of the selected zip code to the overall demographics of the United States as well as median income, home value and median age of each of the analyzed population of interest. Tapestry Life Mode and Segmentation categorization nomenclature is programmed into the analysis software and not assigned or created by the authors.

Tapestry limits the input data set to 500 unique values. To comply with these limits, zip codes with two or more reported vessels (n = 271) were chosen to represent the demographic boater profile. Tapestry Segmentation analysis was run to determine the top three Tapestry Life Modes representing the boating population contacted at inspection stations within LAKE. To ensure that Tapestry did not overrepresent zip codes with less than two boats or underrepresent zip codes with five or more boats, a sensitivity analysis was conducted using individual zip codes and the Tapestry ZIP [code] Lookup tool. This provides the top three tapestry segments along with the percentage of the population represented by each zip code. The total number of inspected or decontaminated boats from each zip code was multiplied by the percentage of each of the top three life segments (segment percentage) resulting in an approximated number of boaters represented by that particular segment (boats × segment percentage = approximate representation). Totals for each zip code were then compared against the total number of boaters to generate a percentage of the total boater population for each segment. Segment percentages were then totaled according to Life Modes to generate a percentage of the total boater population for each Life Mode (Supplementary material Table S2). Sensitivity analyses were also conducted to ensure certain boating populations and inspection techniques were not inaccurately over- or under-represented within the larger dataset by removing local boaters from Nevada and Arizona.

Most vessel inspections and decontaminations conducted at NDOW stations within LAKE are voluntary and initiated by day-use or short-term use boaters (four days or less) before leaving the park. Conversely, LAKE requires decontamination of vessels that have been slipped and moored for five days or more. In our data set there were 838 decontaminated vessels with 100% compliance of NDOW AIS protocols as reported records are only available for compliant vessels. Inspections that take place outside of the LAKE are considered mandatory – if a vessel comes upon an inspection station during operating hours, they are required to stop. These stations are state-run and target boaters traveling on federal and state highways. To compare demographics between boaters undergoing inspections within the park and inspections outside of the park, Tapestry Segmentation analysis was performed using home zip codes from four states inspection stations outside of LAKE (Idaho, Oregon, Utah, and Montana). Of the eleven states that contributed data only these four routinely collect and require information on boater's home zip code. These boaters listed their last known water body as Lake Mead or Lake Mohave and were stopped for an inspection by another state wildlife agency in one of four states. Only entries with a unique, complete, and accurate zip code were entered in Tapestry (n = 481).

Results

Demographic analysis of recreational boater populations

The top three Tapestry Life Modes for boats inspected outside of LAKE (n = 481) include Life Mode 8 (13.59%), Life Mode 4 (13.17%), and Life Mode 7 (12.54%) (Figure S3). These segments are characterized by a median home value of $287,138, a median household income of $62,567 and a median age of 36.4 with 65% of the selected population completing at least some college education (Figure S3). Similarities among these Life Modes include above average income, professional level jobs, high reliance on technology, and college level education (Figure 2). The top three Tapestry Life Modes for boats inspected within LAKE (n = 271) include Life Mode 7 (18.66%), Life Mode 1 (18.12%), and Life Mode 4 (10.94%) (Figure S2). These Life Modes are characterized by a median home value of $364,351, median household income of $69,920, and a median age of 35.9 with 64% of the selected population completing at least some college education (Figure S2). Similarities among these Life Modes include above average incomes, professional jobs, high reliance on technology, and college level education. Results of the manually calculated Tapestry analysis returned the same top Tapestry Life Modes of Life Modes 7 (25.87%), 1 (16.24%), and 4 (14.22%) (Table S2). General characteristics of each Life Mode can be found in Table S1.

Figure 2. Educational outreach signs posted at boating launch sites on the Nevada side of LAKE and on launch ramps at Glen Canyon National Recreation Area (GLCA). LAKE and GLCA coordinated with state agencies to ensure signs at both lakes were uniform and delivered the same easy to understand message. This signage is an example of direct communication to the public and is constructed so the information is accessible to all demographic groups boating at LAKE. The infographic provides a clear objective, followed by stepwise actions and accompanying imagery. The sign also includes a QR code and web address for more technologically savvy demographic groups to gain further information via their smartphones.

Many local boaters (residents of Clark County, Nevada, or Mohave County, Arizona) frequently recreate on Lakes Mead and Mohave. Since local boaters may only use their vessels at LAKE, and thus are less likely to spread AIS they may inaccurately influence demographic groupings. To ensure that the demographic analysis was not being overly influenced by the local population, Tapestry Segmentation was run on a subset of zip codes by eliminating any zip code in Clark County, Nevada, or Mohave County, Arizona which both border LAKE. The remaining zip codes (n = 214) were analyzed with the elimination of four zip codes not matching the tapestry database (n = 210). The top three Tapestry Life Modes for boats inspected within LAKE but excluding those from local zip codes include Life Modes 1 (21.46%), 7 (16.78%), and 2 (11.06%). These Life Modes are characterized by a higher median home value of $405,064, a higher median household income of $75,744, and a lower median age of 35.4 with 66% of the selected population completing at least some college education. These

Table 1. To understand possible gaps in the AIS inspection station program, it is important to analyze travel routes of visitors leaving LAKE. This table identifies some of the most popular destinations of boaters leaving LAKE, the quickest route to that destination (based on Google Maps directions), and how many AIS inspection stations are located on said route. See Supplementary material Table S3 for full table.

Destination	Travel Route *	Number of Inspection Stations Outside of LAKE
Los Angeles, CA	Interstate 15 South to CA Highway 210 West	2
San Diego, CA	Interstate 15 South to Interstate 215 South back to Interstate 15 South	2
Salt Lake City, UT	Interstate 15 North	1
Boise, ID	Highway 93 North to NV 318 North back to Highway 93 North and Interstate 84 West	4
Seattle, WA	Highway 93 North to Interstate 84 West to Interstate 90 West	7
San Francisco, CA	Interstate 15 South to CA Highway 58 West to Interstate 5 North to Interstate 580 West	3

* Most efficient travel route according to Google Maps connecting the Lake Mead National Recreation Area Visitor Center to the destination.

two groups (local and non-local boaters) were analyzed separately using Tapestry, but produced similar enough demographic results that they were left together as one larger dataset to more accurately reflect boater usage at LAKE. The manually calculated segments accounted for the number of boaters with the same zip code and more accurately represented zip codes with higher numbers of boaters (Table S2). Additionally, we compared data collected from inspections of day-use vessels and inspections of slipped and moored (5+ days in water) vessels to ensure there no significant bias of results due to differences in data collection methods. No significant differences in distributions were found.

Geographic analysis of recreational boater destinations

We found no physical geographic gaps in AIS inspection station coverage along interstate highways, U.S. routes, or state highways within western states, or along major travel routes connecting LAKE with popular destinations within western states (Table 1). Commonly used travel routes from LAKE include Interstate 15 North to Salt Lake City, UT, and Interstate 15 South to southern CA. All vessels traveling via these routes would have had to pass through at least one state inspection station outside of LAKE and most would have had to pass through two state inspection stations if not traveling to a state bordering Nevada (Table 1). See Table S3 for a more detailed description of travel routes and specific AIS inspections stations on route. Eighty-three vessels that did not travel to the destination provided to inspection station workers were identified. These vessels include those traveling to Colorado, Montana, New Mexico, Arizona, Utah, California, Idaho, Washington, Oregon and Wyoming. An example of this mismatch is a boater listing Lake Mead, NV as their point of origin and San Diego, CA as their destination, but records showing a vessel inspection in Wyoming after departure from Lake Mead. It is possible this boater traveled a route outside of the most logical recorded routes or had an impromptu change of plans. It could also represent inaccurate reporting from a boater either by accident or with the intention to avoid additional decontamination efforts. Records like this one represent a small sample of unresolved challenges of data sharing and accuracy within an interconnected state and federal enforcement system. See Figure S1 for a comparison of destination locations for both inspected at Lake Mead and those intercepted at stations throughout the Western U.S.

Discussion

The introduction of invasive mussels into western water bodies has led to great concern regarding the potential spread to the Pacific Northwest, with many states in the Columbia River Basin already implementing early detection monitoring programs (Wells et al. 2011). Managing vectors, namely overland transport of recreational boats, is widely recognized as the most effective means of combating the spread of quagga mussels and other aquatic invasive species (Cimino and Strecker 2018; Rothlisberger et al. 2010). However, it requires public awareness of proper boat cleaning procedures and the institution of mandatory boater checkpoints, as participation in voluntary cleaning programs is often low (Cimino and Strecker 2018). For example, Rothlisberger et al. (2010) found that in the Great Lakes Region only one-third of the boating community performed visual inspections, hand removal of invasive macrophytes, and high-pressure washing of small-bodied organisms. Further, investigators found that boaters are less likely to participate in high-pressure washing than they are to conduct visual inspections and hand removal techniques (Connelly et al. 2016; Seekamp et al. 2016).

This study represents just one aspect of the complex challenge of understanding AIS compliance and education at LAKE and is not without application limitations due to variation in data collection, data sharing, and analytics. The available data were compiled from eleven different states, many with individual data collection and reporting procedures, which made it difficult to accurately merge datasets and interpret results. Vessel records from four states had incomplete boater zip code data and several LAKE boater data fields were missing or inaccurate. Further, the use of zip code data has inherent limitations and biases that we were unable to correct for. Dataset filtering to include only vessels with identifiable destination points also resulted in the exclusion of large numbers of vessel records which could impact the results of the demographic analysis. The use of data from compliant vessel owners inherently biases the demographics of the dataset; however, data from vessels that were not inspected was not available for inclusion. Thus, our analysis focused exclusively on the AIS inspection and outreach program at LAKE and cannot be used to draw broad conclusions about the implementation of educational programs or inspections stations outside of LAKE during 2016–2018.

Geographic analysis of recreational boater destinations

The current AIS containment network covers large land expanses, multiple watersheds, and thousands of miles of major travel routes. While our analysis did not reveal any physical gaps in station location coverage along major highways and transit routes, several notable pseudo-geographic gaps were identified which may influence AIS transmission risk. Most inspection stations are only operational during daylight hours. Boaters traveling at night or early morning are therefore unlikely to encounter an open station and may not see posted AIS signage unless lighting is installed. Maintaining adequate staffing levels, particularly at remote stations, can be challenging and in some cases has led to reduced hours of operation. Inspection and interception data from between 2016–2018 showed a total of 126 boats departing from LAKE (7.7%) were traveling along a route away from or not on route to their reported final destination. We identified several possible reasons for this: 1) Vessel owners may have traveled to their destination without receiving an additional inspection (e.g. state entrance inspection), 2) Vessel owners visited another body of water prior to reaching their final destination and did not report the last water body visited as Lake Mead or Mohave, 3) Vessel owners changed their plans or destinations along their route, 4) The vessel was not intercepted while passing through a border or inspection station due to a station closure or a failure on the part of the boat owner to exit the highway and undergo inspection.

Increasing adoption of universal data collection systems among agencies, such as the Watercraft Inspection and Decontamination Web (WID) developed by the State of Colorado (https://watercraftinspection.org) could reduce or eliminate vessel-tracking gaps, allowing state and federal agencies to more easily share information and generate a precise transit history for individual vessels, further reducing the risk of AIS transmission. Increasing the specificity of inspection questions by requesting intermediate and final destination locations (e.g. name of city, or water body), home or boat registration zip codes, and ensuring clarity of destination location (home vs. next stop) would greatly improve the effectiveness of the AIS network. Asking boaters to list all launch locations within the last thirty days would help to eliminate any accidental transport of AIS and provide a more accurate manifest of the interconnectedness of western U.S. water bodies. Measures will need to be developed to ensure accuracy of reported locations, particularly in cases where generalized or incomplete information is often provided. For example, boaters reporting they launched at Lake Mead when in fact they launched in the Colorado River below Lake Mohave or on Lake Havasu.

Demographic analysis of recreational boater populations

Demographic analysis shows the boater population at LAKE to be similar in age, income level, and degree of reported environmental concern.

Similarities among the top demographic groups representing LAKE boaters include average income, levels of education, technology usage, as well as family dynamics and spending (Table S1; Figures S2, S3). The average LAKE boater identified by this study is in his or her mid-thirties and is accustomed to utilizing a wide variety of technological means to access information on boating and the natural environment. Meaningful incentives for behavior change among LAKE boaters likely include low cost, convenience, and technological capabilities (ESRI 2018). While there are slight differences among Tapestry Life Modes identified and between stratified analytical groups (e.g. inspections at LAKE and outside of LAKE), the cumulative demographic composition of visiting boaters supports the use of a cohesive AIS communication and education campaign.

Currently, most LAKE AIS education and outreach is conducted through park signage, social media, interpretive programming, and the distribution of information pamphlets (Figure 2). Through a formal partnership with NDOW, state inspection workers provide outreach at paved boat ramps year-round. While LAKE utilizes a variety of communication mediums, using demographic research to refine which mediums best reach boaters at LAKE and in the Western U.S. could increase effectiveness of park and program outreach. Demographics are known to directly influence communication medium preference and have an impact on communication effectiveness (Park and Avery 2016). Of the demographic variables investigated, Park and Avery found that only age had a significant impact on effectiveness. Participants aged 35+ tended to use television to get their information, and media type influenced their intent to follow instructions. Magazine readers scored the lowest for willingness to follow instructions while those who used social media and friends/family for information scored the highest. LAKE has primarily focused on social media as the media-related educational tool, however this may suggest that LAKE utilize more traditional forms of media including television, radio, and newspapers to communicate AIS information. Diversifying communication mediums to include more traditional forms of media may help target demographics of boaters that have been previously missed—increasing both the reach and effectiveness of the message.

Applying demographic analysis to AIS education

Environmental communication research shows that increased knowledge of an environmental issue does not necessarily lead to a change in behavior (McKenzie-Mohr 2000). Kollmuss and Agyeman (2002) sought to explain the gap between environmental knowledge and environmental action by identifying common behavioral barriers such as demographic factors, external factors (institutional, economic, social and cultural), and internal factors (motivation, environmental knowledge, values, attitudes, locus of control, etc.). No single model can fully explain the barriers that prevent people from taking environmental action. However, establishing a successful campaign that identifies and works to eliminate barriers is more likely to achieve sustainable pro-environmental behavior from its constituents (Kollmuss and Agyeman 2002). Multiple studies of AIS programs demonstrate that awareness and knowledge alone do not equate into action (Cimino and Strecker 2018; Seekamp et al. 2016; McKenzie-Mohr 2000), indicating that barriers are likely related to motivation, sense of responsibility, locus of control, or social normative behavior. AIS education programs focusing primarily on information dissemination via signs, hand-outs, and social media could increase their impact and reach by coupling demographic analysis with behavioral barrier identification in the design and implementation of educational strategies and materials. Nanayakkara et al. (2018) emphasizes the importance of providing AIS information that is jargon-free, easy to understand, and concise. Too much information may overwhelm visitors, while short, jargon-filled material may leave visitors confused and unable or unwilling to follow instructions. Incorporating interactive technology, social media, and easily accessible AIS information through platforms such as mobile websites, Google Maps and downloadable smartphone apps, with uniform information tailored to each entity, could encourage great interest in boater responsibilities and encourage compliance with state AIS laws (Davis et al. 2018).

Community-based social marketing utilizes a combination of information, psychology, and social marketing applied within community systems to enact behavior change (McKenzie-Mohr 2000). van Riper et al. (2019) suggests that land managers should design AIS outreach campaigns to encourage social normative behavior. This may help drive the idea that taking steps to prevent the spread of AIS is a routine behavior that others in the boating/fishing/recreationist community take part in. Wakefield et al. (2006) found that people who had friendly, helpful neighbors and communities were more likely to engage in pro-environmental behaviors, as well as people who belonged to an environmental group, and attended school board and city council meetings. Eiswerth et al. (2011) emphasizes the importance of community groups and their influence on individuals' pro-environmental behavior. Fishing and boating groups, lake owner associations, recreational clubs, etc. are all influencers in creating social normative behaviors related to AIS management. These groups often consist of friends and family groups, which may enable peer pressure to be a contributor to positive action and help solidify the idea that taking steps to prevent the spread of AIS is a social norm. It may be beneficial for LAKE to employ outreach strategies involving direct engagement with local community groups to develop personal relationships with visitors, gauge their knowledge and attitudes towards AIS management, and encourage accountability within groups. Past research on these group values are helpful in making broad assumptions about boaters, however as many researchers have emphasized, encouraging sustainable pro-environmental behavior is a complex issue that must be conducted according to specific site and demographic factors.

Improving information flow by targeting specific demographic groups increases the likelihood that people will engage in pro-environmental behavior. Applying market research principles to environmental campaigns has proven successful, such as the 2011 "Don't Buy this Jacket" social media campaign by the outdoor supplier Patagonia and the 1986 "Don't Mess with Texas" anti-littering campaign. Patagonia's campaign was designed to make their consumers aware of the environmental impacts of their purchases, shock the consumer, and encourage eco-friendly consumerism targeted specifically for the outdoor enthusiast purchasing Patagonia clothing (Patagonia 2011). Patagonia has since seen continual company growth by resonating directly with the objectives and ideals of their target audience. Similarly, the "Don't Mess with Texas" campaign started as an advertising pitch adopted by the Texas Department of Transportation to reduce highway litter (Smithsonian 2017). Using demographic market research, they discovered that males between the ages of 16 and 24 were most likely to produce highway litter (Smithsonian 2017) and focused their campaign on appeals to state pride. The slogan reduced highway litter by 70% in its first 4 years and the state continues to see a declining litter rate (Smithsonian 2017). The success and wide reach of these and similar campaigns highlights the need to shift from information-only communication to communication that targets key demographics with specific behavior change goals in mind.

Conclusions

This study represents an initial step in the complex process of untangling how compliance, inspection, and education function in tandem to prevent AIS transport out of Lake Mead. Results will help LAKE and other entities to better understand the characteristics and habits of those visiting LAKE and travelling to other bodies of water, and how the AIS decontamination and inspection station system is utilized by boaters. Additionally, this information can be used to better target user groups with AIS messaging, thus increasing the efficacy of the LAKE AIS outreach campaigns. The establishment of a large audience and furthering outreach efforts through a structured plan is the most effective way to convey a scientific message (Davis et al. 2018). Additional visiting boater survey work could help managers build a targeted outreach campaign to reach identified needs at multiple levels. The novel use of market-based analytics as a tool for understanding visiting boater populations presented here could be applied on a larger scale to park visitors. Subsequent research should seek to further refine the application of demographic analysis to broader populations and explore visiting boater patterns throughout the western U.S. This would allow for data-driven collaboration on AIS messaging and education among states, parks, and other entities that rely on successful development and implementation of educational and outreach programs to accomplish land management and conservation goals.

Understanding the social and psychological behaviors that contribute to pro-environmental behavior, specifically the transport of AIS, is the key to developing effective environmental management strategies (van Riper et al. 2019). The human connection with nature is a vital component of instilling values of environmental stewardship (Dunlap et al. 2000). Developing a human-nature connection where one does not already exist and shaping social behavior around AIS could be a critical step in invasive species management (van Riper et al. 2019). Results from this study are expected to assist in the development and implementation of new targeted education and outreach efforts, which are another major component of reducing potential invasive species spread (Lauber et al. 2014). The implementation of a unified data network with effective database management in conjunction with tailored outreach strategies will increase compliance with AIS procedures and develop an interconnected western network to address the concerns of potential AIS spread. Mueting and Gerstenberger (2011) conclude that mandatory inspection stations are still the most effective tool in preventing the spread of AIS. However, funding, staffing, and enforcement remain challenges that managers and policymakers must seek to address to realize the protective benefits of mandatory inspections combined with adequate resources.

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References

Cimino SA, Strecker AL (2018) Boater knowledge and behavior regarding aquatic invasive species at a boast wash station. *Northwest Science* 92: 224–233, https://doi.org/10.3955/046.092.0308

Connelly NA, Lauber TB, Stedman RC, Knuth BA (2016) The role of anglers in preventing the spread of aquatic invasive species in the Great Lakes region. *Journal of Great Lakes Research* 42: 703–707, https://doi.org/10.1016/j.jglr.2016.03.016

Dalton LB, Cottrell S (2013) Quagga and zebra mussel risk via veliger transfer by overland hauled boats. *Management of Biological Invasions* 4: 129–133, https://doi.org/10.3391/mbi.2013.4.2.05

Davis E, Caffrey JM, Coughlan NE, Dick JTA, Lucy FE (2018) Communications, outreach and citizen science: spreading the word about invasive alien species. *Management of Biological Invasions* 9: 515–525, https://doi.org/10.3391/mbi.2018.9.4.14

Dunlap RE, Van Liere KD, Mertig AG, Jones RE (2000) New trends in measuring environmental attitudes: measuring endoresement of the new ecological paradigm: a revised NEP scale. *Journal of Social Issues* 56: 425–442, https://doi.org/10.1111/0022-4537.00176
Eiswerth ME, Yen, ST, van Kooten GC (2011) Factors determining awareness and knowledge of aquatic invasive species. *Ecological Economics* 70: 1672–1679, https://doi.org/10.1016/j.ecolecon.2011.04.012
ESRI (2018) Tapestry Segmentation: Methodology. ESRI White Paper. https://downloads.esri.com/esri_content_doc/dbl/us/J9941_Tapestry_Segmentation_Methodology_2018.pdf (accessed 7 August 2019)
ESRI (2020) Tapestry Segmentation. https://www.esri.com/en-us/arcgis/products/data/data-portfolio/tapestry-segmentation (accessed 28 February 2020)
Hickey V (2010) The quagga mussel crisis at Lake Mead National Recreation Area, Nevada (U.S.A). *Conservation Biology* 24: 931–937, https://doi.org/10.1111/j.1523-1739.2010.01490.x
Kollmuss A, and Agyeman J (2002) Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research* 8: 239–260, https://doi.org/10.1080/13504620220145401
Lauber TB, Connelly NA, Stedman RC (2014) Aquatic invasive species outreach to boaters and anglers in the Lake Ontario basin. HDRU Publ. No. 14-5. Dept. of. Nat. Resour., Coll. Agric. and Life Sci., Cornell Univ., Ithaca, N.Y., 59 pp, https://core.ac.uk/download/pdf/79045245.pdf
McKenzie-Mohr D (2000) Promoting Sustainable Behavior: An Introduction to Community-Based Social Marketing. *Journal of Social Issues* 56: 543–554, https://doi.org/10.1111/0022-4537.00183
Mills EL, Rosenberg G, Spidle A, Ludyanskiy P, Pligin M, May B (1996) A review of the biology and ecology of the quagga mussel (*Dreissena bugensis*), a second species of freshwater Dreissenid introduced to North America. *American Zoologist* 36: 271–286, https://doi.org/10.1093/icb/36.3.271
Mueting SA, Gerstenberger SL (2011) The 100th Meridian Initiative at the Lake Mead National Recreation Area, NV, USA: Differences between boater behaviors before and after a quagga mussel, *Driessena rostiformis bugesis*, invasion. *Aquatic Invasions* 2: 223–229, https://doi.org/10.3391/ai.2011.6.2.11
Nanayakkara L, Jurdi-Hage R, Leavitt PR (2018) In lakes but not in minds: stakeholder knowledge of invasive species in prairie lakes. *Biological Invasions* 20: 633–652, https://doi.org/10.1007/s10530-017-1564-4
National Park Service (2016a) Management - Lake Mead National Recreation Area (U.S. National Park Service). http://www.nps.gov/lake/learn/management/index.htm (accessed 4 November 2020)
National Park Service (2016b) Foundation Document Overview: Lake Mead National Recreation Area. Arizona and Nevada: U.S. Department of the Interior, 15 pp
National Park Service (2016c) History & Culture - Lake Mead National Recreation Area (U.S. National Park Service). http://www.nps.gov/lake/learn/historyculture/index.htm (accessed 4 November 2020)
Nevada Department of Wildlife (2017) Nevada Aquatic Invasive Species Management Plan. Reno, Nevada, USA, 106 pp
Park S, Avery EJ (2016) Effects of Media Channel, Crisis Type and Demographics on Audience Intent to Follow Instructing Information During Crisis. *Journal of Contingencies and Crisis Management* 26: 69–78, https://doi.org/10.1111/1468-5973.12137
Patagonia (2011) Don't Buy This Jacket, Black Friday and the New York Times. https://www.patagonia.com/blog/2011/11/dont-buy-this-jacket-black-friday-and-the-new-york-times/ (accessed 22 July 2019)
Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52: 273–288, https://doi.org/10.1016/j.ecolecon.2004.10.002
Rothlisberger JD, Chadderton WL, McNulty J, Lodge DM (2010) Aquatic invasive species transport via trailered boats: what is being moved, who is moving it, and what can be done. *Fisheries* 35: 121–132, https://doi.org/10.1577/1548-8446-35.3.121
Rosen MR, Turner K, Goodbred SL, Miller JM (2012) A synthesis of aquatic science for management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 pp, https://doi.org/10.3133/cir1381
Seekamp EA, McCreary A, Mayer J, Zack S, Charlebois P, Pasternak L (2016) Exploring the efficacy of an aquatic invasive species prevention campaign among water recreationists. *Biological Invasions* 18: 1745–1758, https://doi.org/10.1007/s10530-016-1117-2
Smithsonian (2017) The Trashy Beginnings of "Don't Mess with Texas". https://www.smithsonianmag.com/history/trashy-beginnings-dont-mess-texas-180962490/ (accessed 22 July 2019)
Sousa R, Novais A, Costa R, Strayer DL (2014) Invasive bivalves in fresh waters: Impacts from individuals to ecosystems and possible control strategies. *Hydrobiologia* 735: 233–251, https://doi.org/10.1007/s10750-012-1409-1
Turner K, Wong WH, Gerstenberger S, Miller JM (2011) Interagency monitoring action plan (I-MAP) for quagga mussels in Lake Mead, Nevada-Arizona, USA. *Aquatic Invasions* 6: 195–204, https://doi.org/10.3391/ai.2011.6.2.08

USGS (2019) United States Geological Survey. *Dreissena rostriformis bugensis* Factsheet. https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=95

van Riper CJ, Browning MHEM, Becker D, Stewart W, Suski CD, Browning L, Golebie E (2019) Human-nature relationships and normative beliefs influence behaviors that reduce the spread of aquatic invasive species. *Environmental Management* 63: 69–79, https://doi.org/10.1007/s00267-018-1111-9

Wakefield SEL, Elliott SJ, Eyles JD, Cole DC (2006) Taking Environmental Action: The Role of Local Composition, Context, and Collective. *Environmental Management* 37: 40–53, https://doi.org/10.1007/s00267-004-0323-3

Wells SW, Counihan TD, Puls A, Sytsma M, Adair B (2011) Prioritizing zebra and quagga mussel monitoring in the Columbia River basin. Center for Lakes and Reservoirs Publications and Presentations. Technical Report No 10, http://archives.pdx.edu/ds/psu/7123

Wong WH, Gerstenberger SL (2011) Quagga mussels in the western United States: Monitoring and Management. *Aquatic Invasions* 6: 125–129, https://doi.org/10.3391/ai.2011.6.2.01

Supplementary material

The following supplementary material is available for this article:

Figure S1. Final destinations of vessels leaving LAKE and if they were inspected by NDOW (blue) or another state inspection station (red). The size of the bubbles is directly proportional to the number of vessels with the same destination location.
Figure S2. Tapestry analysis infographic output for boats inspected at LAKE. The infographic shows the age distribution, household incomes, and key demographics of all 271 unique zip codes and the tapestry life modes in order of prevalence percentage for the population.
Figure S3. Tapestry analysis infographic output for boats inspected outside of LAKE. The infographic shows the age distribution, household incomes, and key demographics of all 481 unique zip codes and the tapestry life modes in order of prevalence percentage for the population.
Table S1. General Characteristic of ESRI Tapestry Life Mode Categorization. This table is also available on the ESRI Tapestry Website (https://doc.arcgis.com/en/esri-demographics/data/tapestry-segmentation.htm).
Table S2. Results of manually calculated tapestry segments for vessels inspected at LAKE. This includes 920 boaters representing 271 unique zip codes.
Table S3. Popular destinations, likely travel routes, and route specific AIS inspection stations for vessels leaving LAKE.

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