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Investigating the Management of Visitor Experiences in Recreational Boating

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INVESTIGATING THE MANAGEMENT OF VISITOR EXPERIENCES IN RECREATIONAL BOATING

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by
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ABSTRACT

Recreational boating is a popular activity on public waterways. Boaters enjoy a multitude of natural lakes and rivers, but these waterways are a limited natural resource. In some cases, crowding caused by high rates of boating participation has strained the capacity of this natural resource base, generating conflict between participants and environmental impacts. Therefore, waterway managers may develop regulations for the number or types of boats allowed at one time. This is often referred to as visitor capacity.

With many waterways in the U.S. located in protected areas (PAs), their management are guided by legal regulations or statutory frameworks such as the Wilderness Act (1964) and the Wild and Scenic Rivers Act (1968). Therefore, waterway managers need to develop and implement comprehensive visitor use strategies that cover various visitor types and address a wide range of possible impacts on resources and visitor experiences.

In defining the quality of boating experiences, consideration is given to the safety and enjoyment of boaters. To better understand acceptable boating conditions, waterway managers need to investigate 1) the maximum amounts and types of boating use that an area can accommodate while achieving and maintaining the desired conditions and experiences (i.e., boating thresholds), and 2) how boaters respond to various weather and climatic conditions.

This dissertation represents a substantial contribution to the outdoor recreation field because past studies about the on-site experiences of recreational boaters in public waterways are often dated or underexplored. Specifically, the influence of weather on

recreation-particularly water-based recreation-is often assumed rather than demonstrated. Boaters are often exposed to the elements of weather with minimal protection, therefore it is important to understand how weather influences boating use levels. Additionally, weather and climate research has mainly focused on tourism while paying little attention to recreation. With regards to boating thresholds, they are in some cases from sources that may be out of date, with some being more than 20 years old. These thresholds are still being used by agencies to manage boating. Also, by simulating current and projected recreational boat use levels, waterways managers may begin to better understand boaters' patterns of use and how they intersect with empirically-based thresholds for boating.

In the dissertation two distinct sites (i.e., reservoirs from a hydro-power project, and a wild and scenic river system) were selected. A quantitative approach was applied in this study. Surveys, field cameras and Global Positioning System devices were used to collect data. The study findings update and provide context-specific standards for boating density based on boaters' perceptions. Additionally, the findings can help waterway agencies better manage short-term boater demand because of changes in weather, and adapt to long-term climate changes in visitor use patterns. The findings may also help managing agencies identify areas that experiential capacities are being exceeded, and the points in time when these violations take place. Therefore, these findings may inform the development of visitor use management plans.

DEDICATION

This dissertation is dedicated to my big sister Tabitha Makena Riungu who passed away before its completion. She helped me learn to appreciate the simple things in life and to power through challenges. These life lessons have kept me going.

Tabby, we did it!

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CHAPTER ONE

INTRODUCTION

In defining the quality of the recreational boating (RB) experiences, consideration is given to the safety and comfort of boaters. The ability of recreation managers to respond to on-site environmental and social conditions can shape visitors' experiences. Environmental conditions such as weather and climate are often assumed to influence the level of satisfaction and participation in outdoor recreation activities. However, this has not been empirically demonstrated (Machete, Lopes, Gómez-Martín & Fraga, 2014). Additionally, studies have largely examined the influence of weather and climate on tourism with limited studies focused on recreation (Verbos, Altschuler, & Brownlee, 2017). Consequently, recreation managers have often overlooked the influence of weather and climate on visitor experiences.

The rational for overlooking weather and climate in recreation management is that it cannot be controlled or manipulated by management action. However, it is still an important consideration because recreational boaters are exposed to the elements of weather (e.g., air temperature, relative humidity, wind speed, precipitation and cloud cover) with minimal protection. Additionally, prevalent weather conditions directly influence the water temperature and wave height (Zhang & Wang, 2013). These variables are extremely important for the safety and comfort of boaters. Therefore, a better understanding of visitors' responses to various weather and climatic conditions can help recreation managers better manage short-term visitor demand and adapt to long-term climate changes in visitor use patterns (Perkins & Debbage, 2016).

Adverse social conditions resulting from increased boating levels diminish boaters' experiences, raise safety issues, and can strain infrastructure and facilities such as boat ramps and parking areas (Itami, Gimblett & Poe, 2017, Sunger, Teske, Nappier & Haas, 2012). Therefore, waterway managers may develop regulations for the number or types of boats allowed at one time. This is often referred to as visitor capacity. Agencies managing waterways may be mandated to address resource and experiential impacts associated with visitation, specifically including setting capacities. For example, the Federal Energy Regulatory Commission (FERC) is an independent federal agency with a mission to regulate and oversee energy industries. FERC licenses and relicenses hydroelectric projects and compels licensees to compile a report of the use and development of recreational facilities, the use capacity for each type of recreation facility, and the annual costs to develop, operate, and maintain the public recreation facilities.

With many waterways located in protected areas, their management is guided by legal regulations or statutory frameworks like the Wilderness Act (1964), Land and Water Conservation Fund Act (1964), Wild and Scenic Rivers Act (1968), National Trail System Act (1968), and the National Parks and Recreation Act (1978). Additionally, enabling legislation such as the Organic Act of 1916 indicate that the National Park Service (NPS) must provide for public opportunities to enjoy a park unit's natural and cultural resources. This has spurred a need to consider the visitor experience, its management, and the related issue of visitor capacity as a core elements of any park's efforts.

Waterway managers need to develop and implement comprehensive visitor use strategies that cover various visitor types and address a wide range of possible impacts on resources and visitor experiences. To guide this process a number of frameworks have been developed. For example, the Visitor Use Management (VUM) framework employs a management-by-objectives approach to identify and develop indicators and thresholds of quality experiences. It also tracks the effects of management practices or actions (Interagency Visitor Use Management Council [IVUMC], 2016).

Outdoor recreation management frameworks are based on identification of objectives for the appropriate desired conditions of resource and the visitor experience. Management objectives reflecting these desired conditions are expressed in the form of indicators and thresholds. For water-based recreation, potential indicators may include: the number of Boats At One Time (BAOT) at specific sites, number of boats encountered per day, litter, and noise levels (Manning, 2011). The minimum acceptable condition of identified indicator variables are then determined. These are referred to as thresholds. The indicator variables are then monitored to make sure that the thresholds are maintained. If the thresholds are violated, then management actions should be taken to bring the indicators into compliance with the thresholds (Manning, 2011; National Park Service, 1997).

Density-related thresholds for boating maybe the most challenging but fundamental component of visitor capacity in waterways. Boating thresholds vary depending on users’ preferences, which may be site-specific. However, these thresholds are in some cases from sources that may be more than 20 years old (e.g., Bureau of

Outdoor Recreation [BOR], 1977; Warren & Rea 1989). Further, some thresholds appear to lack empirical evidence that demonstrate well-established practices in the determination of visitor capacity (Manning, 2011). Specifically, they do not incorporate users' attitudes and opinions in the use limits set to manage the experience of recreational boaters.

Normative theory has been widely used to develop thresholds and evaluate resource, social, and/or managerial conditions at protected areas. Normative theory suggests that visitors have shared norms that can be used to formulate thresholds of quality for different park conditions and experiences (Alazaizeh, Hallo, Backman, Norman, & Vogel, 2016: Kuentzel & Heberlein, 2003; Manning, 2011). Thresholds allow managers to be proactive and establish priorities for management actions (Vaske, Whittaker, Shelby & Manfredo, 2002). By determining the ideal boating conditions, it is possible for waterway managers to observe when resource or social impacts are approaching or exceeding the defined levels, rather than reacting to the problems after they occur.

Waterway managers may also use the defined boating thresholds to compare against projected future changes in use levels. Computer simulation modelling allows for different management scenarios to be tested in a comprehensive, low-cost way, and managers can see what effects their various alternatives would have in a variety of future use conditions (Lawson, Manning, Valliere, & Wang, 2003). For example, boating thresholds for a particular waterway can be evaluated against anticipated changes in boating use levels to estimate the temporal and spatial points that the minimum acceptable conditions may be violated. Simulation models use the static information that is collected through traditional techniques such as visitor surveys and GPS-based tracking methods in a more predictive way (Skov-Petersen & Gimblett, 2008). Simulation models can be complex, but are often the only method of understanding systems with many interacting components (Itami et al., 2017). Therefore, extending the application of simulation models to waterway management provides managers with a practical tool to implement outdoor recreation management frameworks.

Statement of the problem

This dissertation is intended to begin to address the lack of empirical studies regarding the management of boaters' experiences in public waterways. Specifically, this study extends the application of boaters' perceptions about crowding and safety. The perception of crowding among visitors has seldom been used to determine boating thresholds (Diedrich Huguet & Subirana, 2011). This is despite the fact that overcrowding of recreational boats, and perceived crowding, can affect the well-being and safety of boaters (Tseng et al., 2009).

Crowding-related thresholds for boating can be modeled to determine where and when these thresholds may be violated. Agent based models may also be used to determine the project the effect of increased boating use levels on existing thresholds. Such models may help waterway managers maintain recreation impacts at acceptable levels.

The study also examines visitor responses to changes in weather conditions to RB use levels. Changes in weather can lead to increased or decreased short-term demand for outdoor recreation activities. However, research has largely focused on tourism, and often relied on aggregated secondary meteorological data and high-level visitation data (Verbos et al., 2017). A closer look at how weather influences daily participation in a particular activity (e.g., boating) at a site level may provide more practical planning information than a broad overview of the effect of weather on park-wide visitation. Therefore, this study assesses real-time, weather-related changes in RB use levels at selected sites.

Three overarching goals guide this research:

1. To apply normative approaches to review boating thresholds.
2. To apply agent-based modelling to determine RB capacity.
3. To investigate the relationship between weather conditions and RB use levels.

Research sites

Two distinct sites were selected for this study: 1) reservoirs formed by constructing dams across a flowing river, and 2) a river formed through a natural process. These sites are subject to varying legislation and are managed by different agencies.

Site 1: Priest Rapids Hydroelectric Project— PRHP consists of the Wanapum and Priest Rapids (PR) Reservoirs, which are located on the Mid-Columbia River in Central Washington. Grant County Public Utility District owns and operates the PRHP, but is subject to regulation by the Federal Energy Regulatory Commission (FERC). FERC is the agency tasked with the licensing, regulating, and oversight of non-federal hydropower dams, including the reservoirs associated with them. FERC requires operators holding hydropower licenses (i.e., a licensee) to provide recreation amenities at their project, such as boat launches. The primary statuary framework used by FERC is the Federal Power Act, as amended.

Site 2: Delaware Water Gap National Recreation Area—DEWA is managed by the U.S. National Park Service (NPS) and has 40 miles of the Middle Delaware Scenic and Recreational River included in the national wild and scenic river system. These designations indicate that recreation opportunities must be provided for the public whilst protecting the park's natural and cultural resources.

At both sites, boaters' perceptions about safe and enjoyable experiences were investigated. Specifically, the study examined both the boaters' experienced and acceptable boat launch wait times, and perceived and expected crowding in the study area.

Structure of the Document

The remainder of this dissertation is comprised of four chapters. Each chapter (except for Chapter 5) follows an article-style format and includes an introduction, literature review, description of the methods and analysis, results, limitations and a discussion.

The first article (i.e., Chapter 2) aims to update and provide context-specific thresholds for boating density at Site 1's reservoirs based on boaters' perceptions and normative methods. The article addresses the following research questions.

1. What are the boaters' perceptions about crowding at PRHP?
2. What are the boaters' thresholds for crowding at PRHP?

The second article (i.e., Chapter 3) describes the outcome of applying simulation modelling to the determination of visitor capacities on the Middle Delaware Scenic and Recreational River within DEWA. The article addresses the following research questions.

1. What are the indicators and thresholds for quality experiences for RB in DEWA?
2. How do current perceived and observed RB use levels compare to the determined thresholds?
3. Where and at what point would crowding-related thresholds for RB be violated?
4. Are there differences in the model outcomes for perceived crowding thresholds for boating applied on uneven viewsheds?

The third article (i.e., Chapter 4) examines the influence of daily weather conditions on RB use levels at DEWA. The article tested the following research hypotheses:

1. There is a significant relationship between hourly weather conditions and real-time boat arrivals.
2. Boat arrivals are a better measure of the influence of hourly weather conditions on boating levels compared to boat departures.

Chapter 5 is a summary of the major findings from these three studies. This chapter expands the discussion on the dissertation's implications on the theory and management of RB experiences.

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CHAPTER TWO

Water-based recreation management: A normative approach to reviewing boating thresholds

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Abstract

Recreational boating is one of the major water-based recreation activities in the US, but the public waterways where these activities occur are a limited natural resource. Man-made reservoirs have increased opportunities for flatwater-boating, but even these areas are at times quite crowded. To ensure that both resource and experiential capacities are not exceeded, density-related thresholds for boating, measured in surface acres of water per watercraft, need to be determined. Despite these density-related thresholds being enforced in some locations, agencies managing waterways often apply these thresholds that are not site-specific, evidence-based, and fail to solicit input from the public. Therefore, thresholds for boating capacity vary widely. To improve this situation, this article applied normative approaches to estimate utilization of boating amenities and update boating thresholds at two reservoirs in Washington State. Social norms have been widely applied in park and outdoor recreation management, hence are likely to enhance the consistency, objectivity and accuracy of boating capacity estimation and utilization. The study found visitor's perceived level of crowding was a significant predictor to their perceptions of safety and security at both reservoirs. Therefore, there is a safety-related need for waterway managers to determine and implement crowding-based boating thresholds derived from visitor perceptions.

Key words: Recreational boating, social norms, thresholds, carrying capacity, reservoir, FERC

Water is an important component of the outdoor recreation experience in both water-based (i.e., dependent) activities (e.g., fishing and boating) and water-enhanced activities (e.g., hiking and photography). One major water-based activities is recreational boating. Recreational boating involves the use of watercraft that are operated out on the water for recreation, not for commercial purposes. The United States Coast Guard (USCG, 2012, p.9) identifies recreational boats to include: "outboard, inboard and stern-drive power boats, jet boats, pontoon boats, houseboats, rowboats, canoes, kayaks, personal watercraft (e.g., jet skis), inflatable boats, kiteboards, sailboards, stand-up paddleboards and various types of sail boats." The classification also includes rented boats, with the exception of captained charter or party boats, ferries, cruise ships or toy boats. Activities that include recreational fishing while boating are also considered recreational boating.

Participation in recreational boating in the U.S. steadily increased during the 1960's to the early 1990's, but has since started to level off (Mahoney & Stynes, 1995; USCG, 2014). Participation in recreational boating is steady and substantial, with 36% of U.S. households participating in it annually (National Marine Manufacturers Association [NMMA], 2017a). In 2016, the total recreational marine expenditures (i.e., boats, engines, accessories and related costs) in the U.S. totaled $36 billion (NMMA, 2017b).

Recreational boaters enjoy a multitude of public natural lakes and rivers for boating, but these waterways are a limited natural resource. In some cases crowding caused by high rates of boating participation has strained the capacity of this natural resource base, generating conflict between participants and environmental impacts (Hammitt, Cole, & Monz, 2015; Manning, 2011; Pigram, 2007). The overcrowding of lakes and rivers also threatens public health and detracts from one's recreational experience (Kusler, 1972; Sunger, Teske, Nappier & Haas, 2012). In these situations displacement may occur with some boaters moving to other lakes that have previously been for fishing only and not multiple use recreation (Gyllenskog, 1996; Kuentzel & Heberlein, 2003; Tseng et al., 2009). The building of dams and their associated reservoirs have increased opportunities for flat-water motorized and non-motorized boating, but even these areas at times remain quite crowded.

Organizations and stakeholders that govern lakes, rivers and reservoirs often develop regulations for the number or types of boats allowed at one time. This is often referred to as visitor capacity. This concept has also generated a lot of interest among lake property owners who try to protect their “riparian rights” (Warbach, 1994). The underlying concept of capacity originated in wildlife and range management where it refers to the number of animals that can be maintained in a given habitat (Wagar, 1964). The concept has been extended to management of parks and protected areas, like public waterbodies, with focus placed on the impacts that recreational use can have on natural resources (Hammitt, Cole, & Monz, 2015; Leung & Marion, 2000) as well as on visitors’ experience (Manning, 2011). Visitor capacity is described as “the maximum amounts and types of visitor use that an area can accommodate while achieving and maintaining the desired resource conditions and visitor experiences that are consistent with the purposes for which the area was established” (Interagency Visitor Use Management Council, 2016, p.9).

Density-related thresholds for boating, measured in surface acres of water per watercraft, may be the most challenging but fundamental component of visitor capacity because thresholds may vary depending on users’ preferences, activity type, or other considerations, all which may be site-specific. Additionally, some density-related thresholds are aggregated to apply to an entire waterbody, while others specify a density for each type of watercraft. Therefore, thresholds for boating capacity vary widely, from 1 to over 3,000 surface acres of water allowed per boat (Aukerman, Haas & Associates, 2011; ERM, Inc., 2004; Haas, Aukerman, Lovejoy & Welch, 2004; Kusler 1972; Radomski & Schultz, 2005; Wagner, 1991; Warren & Rea, 1989).

Studies to help formulate thresholds in outdoor recreation management have typically applied normative theory and methods (Manning, 2007; Vaske & Whitaker, 2004). Norms are described as generally accepted understandings that govern individuals' behavior in society (Ellickson, 2001). They can also be described as thresholds that individuals and groups use for evaluating ecological and social conditions (Shelby & Vaske, 1991). These social norms have been applied in parks and outdoor recreation management to determine acceptable levels of use and establish thresholds (Manning, 2007; Vaske & Whitaker, 2004). However, boaters' crowding-related social norms have seldom been used to determine recreational boating thresholds (Tseng et al., 2009, Manning, Valliere & Hallo, 2010). This is despite the fact that overcrowding of recreational boats can affect the well-being and safety of visitors, and crowding and safety are strongly connected to people's perceptions (Tseng et al., 2009).

A norm-based approach is needed to update boating capacity thresholds, make them more specific, provide a mechanism to take into account the context of a boating site, and to provide a defensible basis for boating carrying capacity decisions. The primary objective of this paper is to update and provide context-specific thresholds for boating density at two reservoirs based on boaters' perceptions and normative methods. An additional objective is to understand the perceptions of crowding and how they relate to the safety of water-dependent activities at both reservoirs.

Literature review

Recreational boating can be classified into motorized and non-motorized, with the latter being the earlier form of boating that primarily relied on wind power and/or human-powered propulsion. Canoes and sailboats are probably the oldest form of recreational boating. As a recreational activity, sailing primarily has its origins in the 1800s (Cox, 2000). Canoeing for recreation likely started centuries before this. Motor boating was a product of the nineteenth century, resulting from the development of motors (Jennings, 2007). Between the late 20th and early 21st centuries, popularity in motorized recreational boating increased due to the production of faster and more agile machines like speedboats and jet skis (Schemel, 2001).

In the U.S. the regulation of recreational boating encompasses several agencies. These include the U.S. Fish & Wildlife Service, the U.S. Army Corps of Engineers, the National Park Service, the Bureau of Land Management, the U.S. Forest Service, the

Bureau of Reclamation, the National Oceanic and Atmospheric Administration, and the USCG. Furthermore, all states require motorized recreational boats to be registered, and several also extend this to non-motorized boats as well (USCG, 2011 & 2012). Therefore multi-agency efforts are essential for promoting and managing recreational boating, including its safety.

The Federal Energy Regulatory Commission (FERC) is the agency tasked with the licensing, regulating, and oversight of non-federal hydropower dams, including the reservoirs associated with them (where recreational boating often occurs). The entire area licensed by FERC at a specific site is termed a *project*. FERC requires many operators holding hydropower licenses (i.e., a licensee) to provide recreation amenities at their project, such as boat launches and facilities. Licensees are required to periodically – every 6 years – report the number and type of recreation amenities, capacity utilization of each amenity, and recreational use levels at the project (Hallo et al., 2016). However, the FERC Form 80 that this information is reported on does not describe how an amenity's capacity is, or should be, determined. It is largely left open to a licensees' interpretation, which may result in inconsistent, subjective, or inaccurate estimates of an amenity's capacity utilization (Whittaker, Shelby & Gangemi, 2005). Normative thresholds may be applied to help overcome these issues with determining and reporting capacity utilization to FERC, minimizing the negative impacts of boating.

Impacts of Recreational Boating

Accidents and fatalities. The high recreational boating participation rate in the U.S. has been associated with substantial accidents and fatalities (USCG, 2012). This makes boating safety a perennial concern for both boaters and agencies that manage boating. However, laws and regulations regarding boating (e.g., the Federal Boating Act of 1958 and the Federal Boat Safety Act of 1971) have contributed to a significant reduction in the number of recreational boating accidents (USCG, 2011). Since the late 1990s the decline in boating casualties appears to have leveled off, remaining relatively constant at about 700 deaths per year. However, this rate is still higher than those reported for general aviation, rail and bus transportation (United States Department of Transportation [USDOT], 2014). The number of boating accidents recorded is still relatively high, with over 4,000 reported, and many more accidents go unreported (USCG, 2014).

Previous studies have demonstrated that perceptions of boating safety have been significantly correlated with crowding among recreational boaters, with more boats perceived to be less safe (Titre, Gilbert, Cherokee CRC & Jones, 2010; Tseng et al., 2009). Further, Marshburn (2014) determined that a direct relationship exists between boat density and boating accidents. This means that higher boat densities increase the probability of accident risk. Therefore, examining boaters' thresholds for crowding may be an important measure for providing safe boating conditions.

Diminished recreational experience. Due to the limited boating opportunities for Americans residing away from the coast, water bodies such as rivers, lakes, reservoirs and inland bays are experiencing growth in use (Sidman & Fik, 2005). Additionally, diminishing space due to increased siltation (i.e., sedimentation) of water bodies has magnified the problem (Lee, Hosking, & Du Preez, 2014). With the building of dams, opportunities for water-based recreation have partially increased, but so has use of these areas.

Overcrowding of water bodies not only threatens public health but detracts from one's recreational experience (Kusler, 1972; Sunger et al., 2012). In some cases of overcrowding, displacement is likely to occur with boaters dispersing to other lakes or reservoirs (Gyllenskog, 1996; Kuentzel & Heberlein, 2003; Robertson & Regula, 1994; Tseng et al., 2009). Recreation managers should therefore strive to understand visitor experiences and attempt to determine appropriate management responses to both prevailing and predicted experiences.

Recreational experiences have been measured by satisfaction models, whereby it has been assumed that there is a level of visitor use and encounters beyond which quality experiences starts to decline (Heberlein & Shelby, 1977). Therefore, crowding is examined as a “negative and subjective evaluation of use level with psychological meaning” (Manning 2011, p.105). As such, crowding is assumed to occur when use level in a certain amount of space is perceived to interfere with people’s activities or intentions (Manning, 2011; Russell, 2005).

Previous studies have suggested that visitor perceptions of crowding are affected by many variables that interact with individual's perceptions of the number of people at a recreation setting (Manning, 2011). Social interference theory (Schmidt & Keating, 1979) suggests that crowding occurs when the number of people present in the setting interferes with one's goals or desired activities. For instance, the number of boaters (especially motorized) present at fishing areas at any given time is likely to interfere with the goals of boaters primarily engaged in fishing. Additionally, stimulus overload theory suggests that crowding is the result of being overwhelmed by the presence of others, for example, high use levels of recreational boaters at any given time and space (Manning, 2011).

Development of Boating Thresholds

In relation to environmental and experiential impacts, it is necessary for water-based recreation managers and relevant stakeholders to have deliberate and well-informed thresholds for recreational boating to protect both natural resources and recreational experiences. Potential threats to the safety of boaters may result in the displacement of some recreational boaters and also negatively influence boaters' satisfaction levels (Titre et al., 2010). This has led to calls for action by certain interested parties to regulate access (Grossmann et al., 2006), which might be implemented with crowding-based boating thresholds.

In recreational boating carrying capacity studies, public land and resource organizations and consultants have often examined the use characteristics and the usable area of the water-based recreation area (WBRA). Use characteristics include information that indicate how the WBRA is being used, and by whom (Bosley 2005; Kopke, O'Mahony, Cummins & Gault, 2008). The usable area proposes the section of the reservoir or lake that is likely to undertake significant use taking into account restrictions or features of the site. For example, established safety or environmental protection zones (Kopke et al., 2008; Lake Ripley Management District [LRMD], 2003) might not allow boating and be excluded from the WBRA.

Crowding-related thresholds for boating measured in surface acres of water per watercraft may be considered to be a fundamental component of the carrying capacity estimation process. Some studies provide aggregate densities, applicable to the entire WBRA, while others specify a density for each type of watercraft (Aukerman et al., 2011; ERM, Inc., 2004; Haas et al., 2004; Kusler, 1972). Therefore, thresholds for boating capacity vary widely, from 1 to over 3,000 surface acres of water allowed per boat (Table 2.1).

The perception of crowding among visitors has seldom been used to determine recreational boating thresholds (Diedrich et al., 2011; Manning et al., 2010). This is despite the fact that overcrowding of recreational boats, and perceived crowding, can affect the well-being and safety of boaters (Ashton & Chubb, 1972; Tseng et al., 2009). Measuring boaters' perception of crowding would also be instrumental to providing data about the level of use beyond which visitors perceive recreational boating as being unenjoyable. However, most of the thresholds developed and shown in Table 2.1 lack empirical consideration of boaters' perspectives regarding safe and enjoyable levels of boating use. In many cases the thresholds developed might be outdated (e.g., EDAW, 2000; Warren & Rea, 1989) or their bases of determination are unspecified (e.g., Aukerman et al., 2011; Fogg, 1981, 1990).

Perceptions of crowding are to a large extent influenced by activity type and the setting in which they occur (Tseng et al., 2009). For example, recreational boaters weigh encounters with other boaters and recreational users quite differently depending on the nature of the encounter. Speeds and activities of boaters (e.g., fishing), along with waiting times at launch sites and availability of parking spots may explain more variation in perceived crowding than numbers of boats on water bodies (e.g., reservoirs) (Powell, 1998; Tseng et al., 2009). Innately, one unsafe incident may have a greater influence on perceived satisfaction than overall numbers of boats (Falk, Graefe, Drogin, Confer, & Chandler, 1992). Further, different activity types may require more space. For example, a boat pulling a skier may require more space than a boat alone because of the additional length over the overall craft and skier, and the additional safety consideration of the skier.

Normative theory and methods developed in sociology have guided research on recreational thresholds (Manning, 2007; Vaske & Whitaker, 2004). Norms are defined as thresholds that individuals and groups use for evaluating environmental and social conditions (Shelby & Vaske 1991). Using Jackson’s (1965) methodology to measure norms, personal norms of individuals are aggregated to derive social norms (Manning, 2007; Vaske & Whitaker, 2004) that are often presented graphically in the form of social norm curves (Manning et al., 2010).

Previously, narrative and numerical approaches have been used to measure norms. For example, respondents are asked to evaluate the acceptability of alternative use levels, such as a range of boats encountered per day in a water-based recreational area. The resulting data are then aggregated to determine social norms. Presently, computer generated visual simulations have been used to depict a range of recreation use levels (Manning & Freimund, 2004; Manning et al., 2010).

The normative approach to carrying capacity has increasingly been used in many outdoor recreational sites including national park systems (Diedrich et al., 2011; Kainzinger, et al., 2015; Manning, 2007; Manning et al., 2010). In the current paper, this approach will be extended to develop recreational boating thresholds at the Priest Rapids Hydroelectric Project (PRHP/the project). This will include consideration of both on-the-water boat densities (i.e., surface acres per boat) and boat launch times. The application of norm-based methods will allow for the development of updated, empirically-based thresholds that help manage for safe and enjoyable boating on the project. It will also demonstrate a method by which context-specific boating thresholds that are inclusive of boaters' perspectives may be developed and applied in other contexts.

(INSERT TABLE 2.1 HERE)

Methods

Study Area

The PRHP consists of the Wanapum and Priest Rapids Reservoirs, which are located on the Mid-Columbia River in Central Washington State, USA. This paper will refer to Wanapum Reservoir as Wanapum, and Priest Rapids Reservoir as Priest

Rapids. Wanapum is approximately 38 miles long and is characterized by publicly accessible lands, steep topography, highway access, private ownership and other restricted access, agricultural activity, and park development. Vantage, the largest town on the reservoir has a population of less than 100 people (US Census Bureau, 2010), and much of the undeveloped western shore of the reservoir and portions of the eastern shoreline is managed by the Washington Department of Fish and Wildlife.

Outside the study area is The Gorge Amphitheater located on a high bluff above Wanapum northwest of George, Washington. The Gorge Amphitheater draws large crowds of concert goers, thereby contributing significantly to the recreation use of the PRHP (FERC, 2006).

Priest Rapids is located approximately 24 miles south of Vantage and 200 miles downstream from the Grand Coulee Dam. It is characteristically different than the Wanapum Reservoir because of the shorter length of the reservoir (approximately 18 miles), and lack of wide basins and sandy beaches open to public recreation use (EDAW, 2000). Additionally, it is farther from the I-90 transportation corridor and the Gorge Amphitheatre as compared to the Wanapum Development. Therefore, this reservoir experiences lower use levels compared to the Wanapum (Hallo et al., 2016).

The study area has 16 river access locations and includes a total of 17 boat launches (Wanapum-10 & Priest Rapids-7) and 2 marinas along the Wanapum Reservoir (Grant PUD, 2015). There are a variety of amenities available at these boat launches, such as single-lane to triple-lane boat launches, boarding floats that are compliant with the Americans with Disabilities Act (ADA) and toilet facilities. In

2015, the total number of visitors to the PRHP, measured using FERC's terminology of recreation days, was approximately 350,000 (Hallo et al., 2016). A 'Recreation Day', is defined by FERC as "each visit by a person to a development for recreation purposes during any portion of a 24-hour period." The methods applied in developing the current study have been updated to reflect substantial changes in technology and approaches for determining boating thresholds since the previous carrying capacity determination that was conducted by EDAW in 2000.

Boater Survey

The target population for this study was individuals visiting one of the two study reservoirs for recreational boating. Boater surveys, as a part of a broader survey of all recreational users, were administered at 17 recreation sites within the PRHP. Approximately equal effort was placed into data collection on each reservoir. Data collection occurred on both week and weekend days during the peak recreational use season of June through September, 2015. All surveys were self-administered and conducted onsite. Survey data collection began at 11 a.m. and ended at 5 p.m. This was meant to recognize the busiest time of day for recreation in the study area. The survey was distributed as recreationists were exiting the lakes.

The survey consisted of questions relating to boaters' experience, acceptable boat launch wait times, and perceived and expected crowding in the study area. Some questions asked boaters to evaluate the quality and number of boat launches on the reservoir and how problematic safety and security were during their visit. In addition, survey questions asked boaters to evaluate simulated photos depicting boat densities of

27.4, 13.7, 9.1, 6.9, 4.6, and 3.4 surface acres of water per boat. As illustrated on Figure 2.1, these values correspond to pictures showing a typical area of the reservoirs - representing 27.4 surface acres of water – with 1, 2, 3, 4, 6, and 8 boats shown, respectively. Survey respondents evaluated each photo based on a 9-point scale of -4 (‘very unacceptable’) to 4 (‘very acceptable’). Also, respondents were asked to indicate the photo that showed 1) the highest number of boats that should be allowed on the reservoir without them feeling too crowded and unsafe, and 2) the number of boats that they typically saw on the reservoir they used. These questions were intended to develop and update norm-based crowding thresholds and assess carrying capacity of boating on the reservoirs. The questions used in the survey apply well-tested wording and practices (i.e., photo displays) for the development of thresholds based on a normative approach (Manning, et al., 2010; Manning, 2007).

(INSERT FIGURE 2.1)

A simple random sampling method was used to select boaters at the sites. A researcher positioned himself near a primary exit or parking location and asked the first available group leaving from the site at that location to participate in the survey. This use of exit surveys (rather than entry or intercept surveys during a recreation user’s experience) ensured that responses were as well informed and accurate as possible. One member from each exiting boating group (selected using the ‘most recent birthday’ technique) was asked to complete the survey. If the individual or the entire group declined the next available individual or group was asked to complete a survey.

Data analysis

Completed surveys were entered into SPSS version 20 and MS Excel for analysis. The Near feature in ArcGIS was used to estimate the distance visitors travelled to the project. It calculates distance and additional proximity information between the input features (i.e., visitors' residential ZIP codes collected from survey data) and the closest feature in another layer or feature class (the project boundary).

Response frequencies and descriptive statistics were determined for each survey question. Norm-based questions were analyzed and presented graphically in the form of social norm curves. Potential for Conflict Index (PCI_2), with scores ranging from 0 (representing complete agreement) to 1 (representing no agreement), were determined for points on the social norm curves (Vaske, Beaman, Barreto & Shelby, 2010) as a measure of norm crystallization (i.e., dispersion). Additionally, analyses were conducted to examine if a potential relationship exists between perceptions of crowding and issues with safety.

Results

A total of 748 surveys were completed between June 18 and September 10, 2015. After data cleaning, 627 surveys were used in the study for questions related to general crowding at PRHP. Approximately 88% of the surveys were collected from Wanapum and the remainder from Priest Rapids. A subset of the above sample was used for questions related to boating thresholds at Wanapum (N=170) and Priest Rapids (N=21).

The difference in survey numbers per reservoir were a reflection of use levels at each reservoir, not the level of effort in collecting survey data.

Visitor Profile

An estimated 53% of the survey respondents at the project participated in recreational boating. A majority of these respondents (84%) participated in motorized boating, whereas only 16% of the respondents participated in non-motorized boating (i.e., canoeing, kayaking or paddle boarding). The average group size for respondents engaging in both motorized and non-motorized boating was four boaters.

Based on survey respondents' residential ZIP codes, 95.5% were in-state visitors who travelled an average of 71 miles to the project (see Figure 2.2). Also the largest portion of survey respondents were overnight visitors (53.8%), with 41.5% of them staying at the project for 3-4 days, followed by those who stayed 1-2 days (25.1%). A plurality (42.7%) of overnight visitors stayed in campgrounds, while the rest stayed at various rented or owned accommodation types such as cabins, hotels and homes. For day visitors, the largest portion spent 1- 4 hours (55.2%), and the smallest portion spent less than 1 hour (4.2%) at the project.

(INSERT FIGURE 2.2 HERE)

General Perceptions of Crowding at PRHP

Visitors were asked two questions to examine their general perceptions about crowding issues at the project. First, visitors were asked whether they felt that the project was crowded by using the 9-point scale developed by Heberlein and Vaske (1977) that ranged from 1 (Not at all crowded) to 9 (Extremely crowded). Results were treated by dichotomizing the scale into values 1 and 2 (defined as not at all crowded), and scale values 3 through 9 (defined as some degree of crowding) (Manning, 2007). Close to three-quarters of visitors (72.7%) felt that the project was not at all crowded. However, when the visitors were asked how crowded they expected to feel prior to visiting the project, more than half of the visitors (60.3 %) felt they would experience some degree of crowding.

The relationship between the perceived levels of crowding and visitors' perception of safety were explored. A simple linear regression was calculated to predict visitors' perception of safety and security based on perceived levels of crowding at the project. A significant regression equation was found ($F(1,625) = 53.826$, $p < .001$), with an R^2 of .078. Perceived level of crowding explained only a small proportion (close to 8%) of the variance of a visitor's perception of safety and security at the project. This can be attributed to generally low levels of crowding experienced at the area of study. Overall, increasing levels of crowding by 1 unit (in a scale of 1-9, with 1 representing not crowded) would result in a .27 unit decrease in the level visitors' perceived the project to be safe and secure.

Experiential Capacity - Boat launch wait times

Survey respondents were asked several questions related to waiting times to launch a boat. The largest portion of respondents (84.2%) did not have to wait to use boat launches at the project. At Wanapum 17.6% of the respondents had to wait to use boat launches compared to 3.2% at Priest Rapids. The average wait times at Wanapum and Priest Rapids were 6.7 (SD = 7.8) and 12.5 (SD = 3.5) minutes, respectively. The average wait times for all people who reported launching a boat was 6.7 minutes. However, when the people who reported not having to wait to launch a boat are included the average wait time is 1.4 minutes. Responses to the visitor survey showed that, on average, visitors felt waiting 11.2 minutes to launch a boat was acceptable. This value represents an experiential threshold for boat launch waiting times.

Experiential capacity - Boats at one time (BAOT)

Crowding thresholds for the number of boats per surface acre of water at the project were measured using a series of six photos as described before. The number of boats ranged from 1-8 depicting densities of 27.4 to 3.4 surface acres of water per boat (see Figure 2.1). The social norm curves derived from the data for both the Wanapum and Priest Rapids are illustrated in Figure 2.3 and Figure 2.4 respectively. Mean acceptability ratings and numeric PCI_2 scores, to illustrate the crystallization, are provided for each image.

In general, the results show that for boaters the acceptability decreases as the number of boats per surface acre of water increases. As shown in Figure 2.3, as the number of boats increased at Wanapum from 1 to 8 in the study photos, mean ratings for acceptability decreased from 3.3 to 1.9 on the response scale. For Priest Rapids, as the number of boats increased from 1 to 8 in the photos, mean ratings for the range of acceptability decreased from 3.1 to 0.2 (Figure 2.4). However, in both reservoirs, all the boating densities shown were deemed acceptable, on average (i.e., a mean greater than zero).

Crystallization (agreement) of norms as measured by PCI_2 for each image ranged from 0.1 to 0.31 for Wanapum, and from 0 to 0.38 for Priest Rapids. Crystallization was higher for the images representing 1 to 3 boats for both reservoirs than other images representing more boats. Reasonably, this means that there were higher levels of consistent agreement regarding the norm that 27.4 to 9.1 surface acres of water per boat was quite acceptable. The norms are less crystallized, though still showing a high level of agreement, for 4 to 8 boats in Priest Rapids compared to Wanapum. Priest Rapids is much shorter in length and has narrower basins compared to Wanapum. Therefore, despite study photos examining the same surface acres of water per boat between reservoirs, it is likely that site specific characteristics influence respondents' evaluations.

(INSERT FIGURES 2.3 & 2.4 HERE)

Visitors were also asked which photo, among the series of six photos, showed the number of boats typically seen on the reservoir. At Priest Rapids and Wanapum, the average number of boats typically seen were 2.4 (SD=1.4) and 3.9 (SD=1.8) BAOT, respectively. This was an indication of differences in use levels between the two reservoirs. Further, visitors were asked which photo showed the point at which boats should be restricted from using the reservoir because it is too crowded and unsafe. On average, the maximum boat density before use should be restricted for Priest Rapids and

Wanapum were 6.9 (SD=1.5) and 5.1 (SD=1.4) surface acres of water per boat, respectively. However, the proportion of survey respondents who reported that none of the photos, illustrated on Figure 2.1, show a high enough number of boats to restrict use at Priest Rapids and Wanapum were 58.8% and 68.2%, respectively. This response could be indicated instead of selecting a photo.

To test for significant differences in crowding thresholds for boating, a repeated measures ANOVA was conducted on survey responses that indicated participation in boating and evaluated the six simulated photos shown in Figure 2.1. The assumption of sphericity was not met, and Wilks' Lambda was used to interpret the results. There were significant differences in the acceptability of the number of BAOT among the respondents, $F_{(5,162)} = 13.261$, $p < .001$.

A pairwise comparison between the six simulated photos used in the study, indicated that with the exception of Photo 1 and Photo 2, there were significant mean differences in the acceptability of ratings of boaters for the number of BAOT (Table 2.2). Visitors found Photo 1 and Photo 2 representing 27.4 and 13.7 surface acres of water per boat respectively to be similar. This may suggest that there was negligible influence in visitors' perceptions of crowding and safety when boaters have over 14 surface acres of water per boat.

(INSERT TABLE 2.2 HERE)

Discussion and conclusion

Increasing popularity in recreational boating has resulted in multiple U.S. states recording rising participation levels. Washington had a total of over 230,000 registered motorized boats in the year 2016, making it one of the states with the highest number of registered boats in the nation (USCG, 2016). Adverse social conditions resulting from increased boating levels raise safety concerns, diminish boaters' experiences, and strain infrastructure such as boat launch sites (Itami, Gimblett & Poe, 2017). This may necessitate waterway managers to develop regulations for the number or types of boats allowed at one time. Therefore, the objective of this study was to update and provide context-specific thresholds for boating density at two reservoirs based on boaters' perceptions and normative methods.

Density-related thresholds for boating, measured in surface acres of water per watercraft, depend on users' preferences and waterbody characteristics, which may be site-specific. Thresholds for boating capacity often vary widely and many of them lack empirical evidence or public input that demonstrate well-established practices. For example, PRHP previously adopted a conjectural boating capacity of 15 to 20 acres of water per boat (EDAW, 2000). This threshold was largely inferred from boating capacity estimates from other waterways and to a certain extent the physical characteristics of the Priest Rapids and Wanapum reservoirs. The current study addressed the lack of a robust evidence-based process in the development of an updated boating density threshold for use at PRHP.

The findings above suggest that a boating capacity standard of 15 to 20 surface acres of water per boat, as previously applied to the Project, is unsupported by empirical data and may be too restrictive. A boating density of 3 acres of water per boat is, on average, acceptable to boaters of both the Priest Rapids and Wanapum Reservoirs. Also, 7 acres of water per boat was reported, on average, as the maximum boat density before use should be restricted because it is too crowded and unsafe. However, it should be noted that both of these potential thresholds for boating density (i.e., 3 and 7 acres per boat) are based on the most restrictive, conservative interpretation of the above results. Specifically, a majority of survey respondents felt that boating use should not be restricted even when boat densities are greater than 3 acres per boat, and users of Wanapum also found such boat densities still acceptable. However, to protect the visitor experience for an overwhelming majority of boaters, a threshold of 5 acres per boat is recommended.

The current study also informed PRHP's requirement (as a FERC licensee) to report the boating capacity utilization of each of its reservoirs. Based on the survey results reported above, boaters typically experienced 11.9 and 7.1 acres per boat on the Priest Rapids and Wanapum Reservoirs, respectively. By comparing these with a threshold of 5 acres per boat, it suggest that the Priest Rapids and Wanapum Reservoirs are utilized for boating, on average, at 42.2 % and 70.4% of their capacity, respectively. By combining these findings, it suggests that PRHP is being utilized for boating, on average, at 56.3% of its capacity.

Visitors' perceived level of crowding was a significant predictor of perception of safety and security at the reservoirs. Also, a negative relationship exists between perceived threats to the safety and security of visitors and level of crowding ($r = -.28$, $p < .001$). Although the relationship was moderate in strength, potential threats to the safety of boaters may negatively influence their satisfaction levels and lead to displacement (Titre et al., 2010). Therefore, there is a safety-related need for waterway managers to determine and implement crowding-based boating thresholds derived from visitor perceptions.

In addition to the number of boats at the reservoirs, boat launch wait times were used as another indicator of crowding. Boat launch wait times provide crucial information to waterway managers. By comparing this threshold to the average reported wait time (i.e., 1.4 minutes), it can be suggested that boat launch amenities on the project are, on average, utilized at 12.5% of their capacity based on wait times to launch a boat. With only 12.5% of boat launch capacity being utilized based on acceptable wait times, the project's managers can make informed decisions whether to temporarily or permanently close some of boat launch sites in order to reduce maintenance costs. Also, by comparing the average capacity utilization of PRHP and that of boat launch wait times, it seems reservoir capacity would reach before launch capacity.

Further, the level of parking occupied at launch sites can be used as an indicator of crowding. Parking lots are an important transportation resource, as they provide visitors convenient access to the reservoirs. While real time parking data for PRHP was collected, capacity based on parking occupancy was beyond the scope of this article.

This study had several limitations and related opportunities for future research. First, other than perceived levels of crowding, there is need to identify other variables that may influence boaters' perception of safety and security. The study did not take into account the noise, speed and type or size of motorized boat. These indicators may have a significant effect on boating density thresholds. However, under power versus stationary boats were balanced in the study photos. Next, the study did not take into account non-motorized boats in the development of the survey instrument. Specifically, no non-motorized boats were included in the simulated photos because of their low proportion of use at both reservoirs.

Future research should consider systematically varying the distribution levels of both motorized and non-motorized boats to estimate crowding-related thresholds for boating. Additionally, future research may explore if the proximity to other boats rather than boating density may influence boaters' perception of safety and security.

The determination of thresholds associated with boating may simply be developed using logic and professional judgement to estimate what level of change in prevalent conditions would prompt more management attention and investment. However, where the potential for controversy and the consequences of capacity decisions (e.g., safety concerns) are high, there is a need to use empirical, well accepted, scientific methods. By applying normative approaches to estimate utilization of boating amenities at PRHP, the study not only determined evidence-based thresholds for boating, but addressed FERC Form 80's fundamental issue of not describing to licensees how they should determine an amenity's capacity. The use of normative approaches are likely to enhance the consistency, objectivity and accuracy of estimation of boating capacity and the utilization of this capacity.

Social norms have been widely applied in park and outdoor recreation management to determine acceptable levels of use and establish thresholds (Manning, 2007; Vaske & Whitaker, 2004). Despite the fact that perceived visitor crowding can influence the well-being and safety of visitors in a recreation area, it has seldom been used to determine recreational boating thresholds. Measuring boaters' perception of crowding can be instrumental in providing data about the level of use beyond which visitors perceive recreational boating as being unenjoyable and unsafe.

Previous boating density-related studies failed to specify the extent to which recommended thresholds may applied. By focusing on crowding thresholds for boats on the water actively engaged in recreation, not boats docked, moored, or beached on land, the current study addressed this deficiency. Therefore, the estimated boating density thresholds are applicable to boats actively in use. Additionally, previous studies suggested boating thresholds that were too high and did not consider public input. These thresholds may be subjective and restrictive and can adversely affect boaters' experiences.

Fogg's (1990) suggested threshold of 2.5 to 3 surface acres per boat was identified to be somewhat comparable to the current study's recommended threshold. However, the bases of its determination were unspecified. Therefore, by providing context-specific thresholds for boating, the current study contributes to the body of knowledge by applying empirical evidence that demonstrate well-established practices in the determination of boating capacity.

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Table 2.1 Recommended optimum densities for boats and other watercraft to emerge from different studies

Source	Suggested surface acres of water per boat	Boating users
Ashton (1971)	5 to 9	All uses in Cass Lake
	4 to 9	All uses in Orchard Lake
	6 to 11	All uses in Union Lake
Aukerman et al. (2011)	1 to 10	Urban
	10 to 20	Suburban
	20 to 50	Rural developed
	50 to 110	Rural natural
	110 to 480	Semi-primitive
	480 to 3200	Primitive
BOR (1977)	9	Motorized
	1.3	Non-motorized
EDAW (2000)	15 to 20	All uses
Florida Department of Environment Protection (n.d.)	5 to 10	<10 Horsepower (HP) boats
	10 to 20	Unlimited HP
	20 to 50	Waterskiing, Sailing
Kopke et al., (2008)	8	Sailing
Kusler (1972)	40	Waterskiing – all uses combined
	20	Waterskiing
	15	Coordinated waterskiing
Lake Ripley Management District (2003)	10	100% Idle speed /stationary boats
	15	75% Idle/stationary & 25% fast moving
	20	50% Idle/stationary & 50% fast moving
	25	25% Idle/stationary & 75% fast moving
	30	100% Fast moving
Fogg (1981, 1990)	2.5 to 3	Motorized
	0.5	Non-motorized
Radomski and Schultz (2005)	20	High-speed watercraft
	9	Low-powered watercraft
Wagner (1991)	25	All recreational activities
Warbach, Wyckoff, Fisher, Johnson and Gruenwald (1994)	30	All motorized uses >30 HP
Warren and Rea (1989)	9	Motorboats
	1.3	Fishing from boat, Canoes & Kayaks
	4.3	Sailboats
	12	Waterskiing

Table 2.2 Comparison of mean differences in visitor responses between six simulated photos measuring the acceptability of the number of BAOT

(I) Photo	(J) Photo	Mean Difference (I-J)	Std. Error	*P*- value[b]
1	2	.020	.045	.653
	3	.168*	.081	.039
	4	.507*	.149	.001
	5	1.347*	.222	.000
	6	2.086*	.286	.000

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Photo 1

27.4 surface acres of water per boat

Photo 2

13.7 surface acres of water per boat

Photo 3

9.1 surface acres of water per boat

Photo 4

6.9 surface acres of water per boat

Photo 5

4.6 surface acres of water per boat

Photo 6

3.4 surface acres of water per boat

Figure 2.1 Study photos of boat density. All images were originally displayed in a large-scale format and in color.

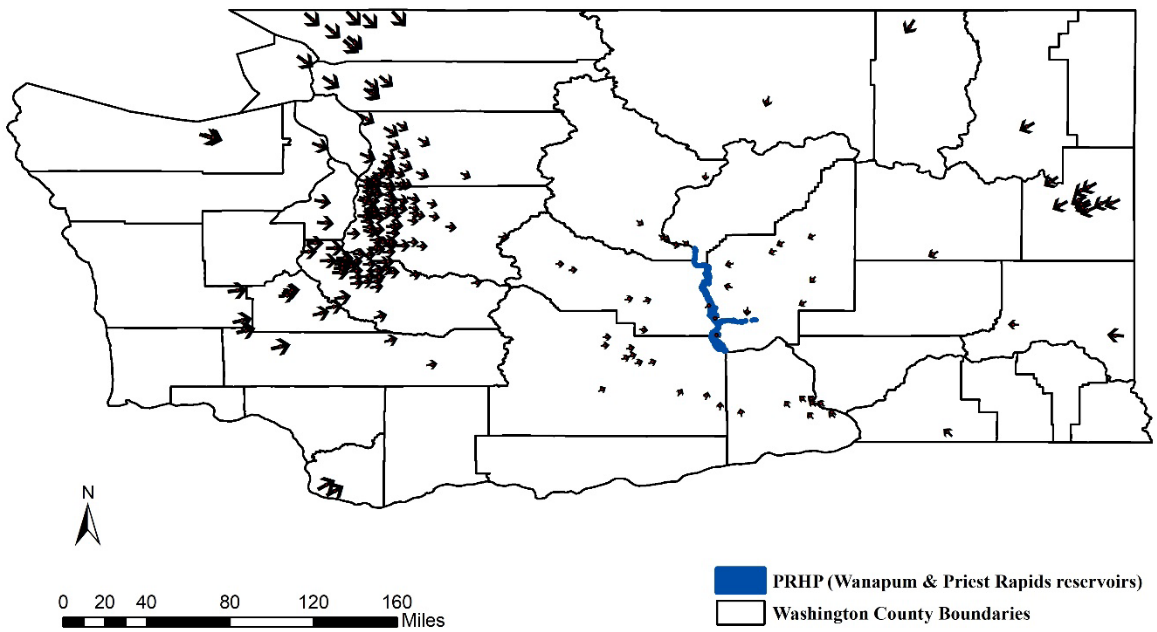

Figure 2.2 Direction of in-state travel to PRHP using residential ZIP codes. The larger the size of the directional arrow, the further away the visitor had to travel to get to PRHP.

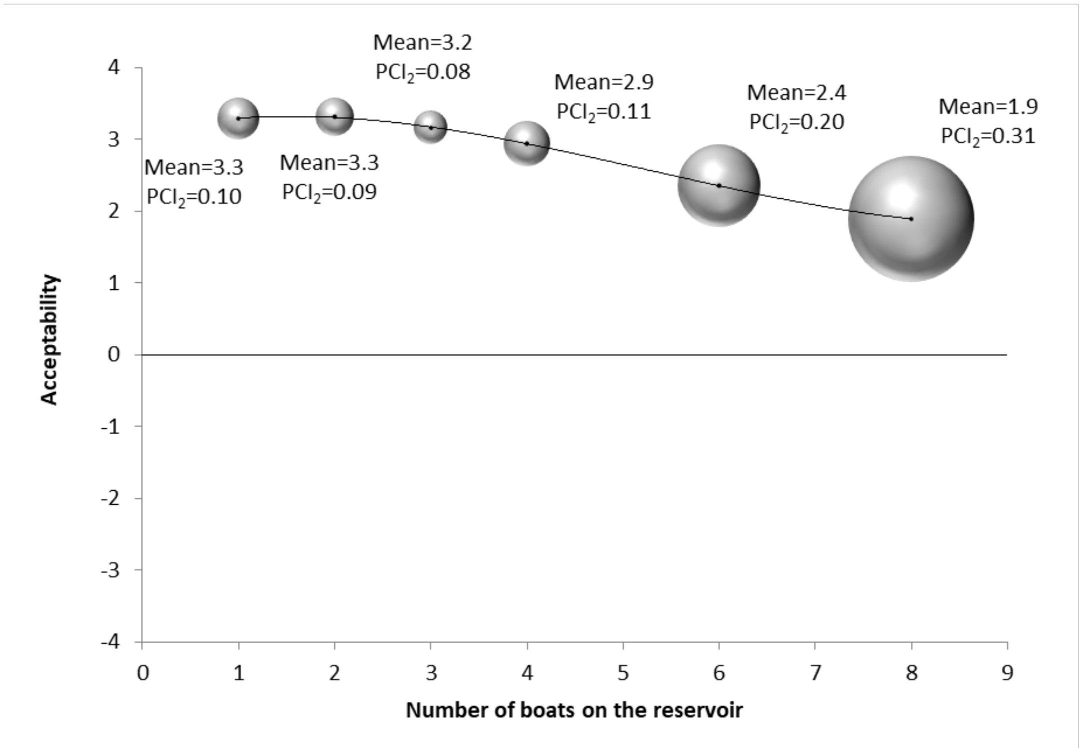

Figure 2.3 Social norm curve for the acceptability of number of boats without feeling too crowded and unsafe at Wanapum. The bubbles represent, PCI_2, with smaller bubbles showing more crystallization (agreement). The line that connects the bubbles is the social norm curve.

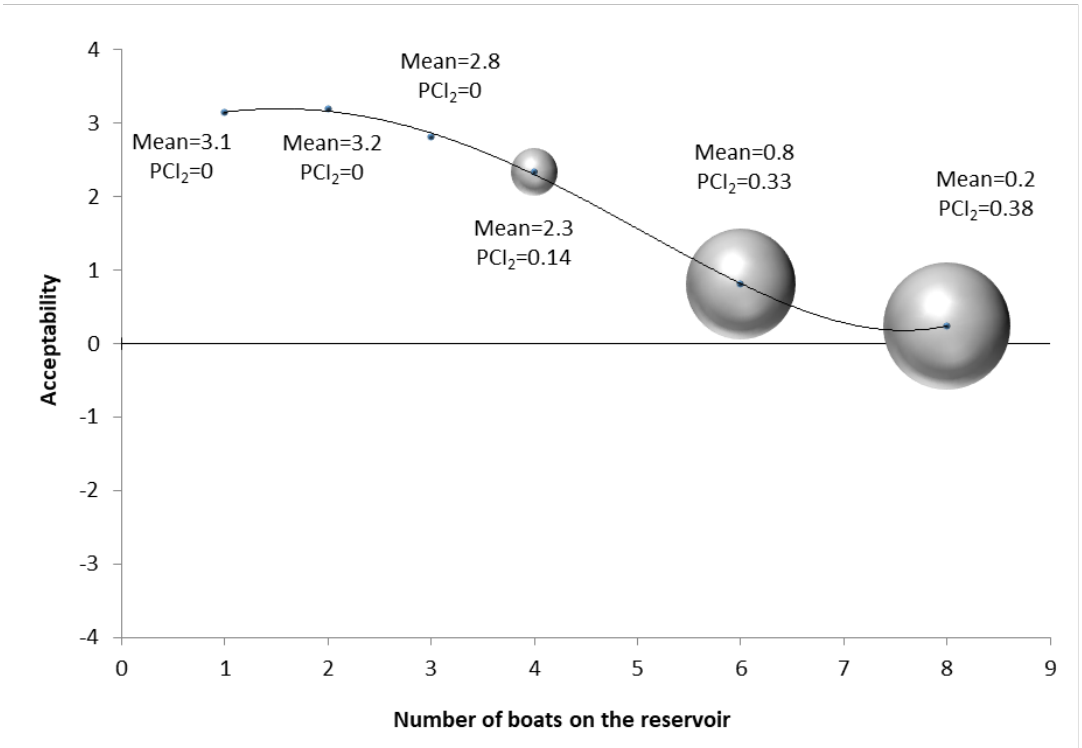

Figure 2.4 Social norm curve for the acceptability of number of boats without feeling too crowded and unsafe at Priest Rapids. The bubbles represent, PCI_2, with smaller bubbles showing more crystallization (agreement). The line that connects the bubbles is the social norm curve.

CHAPTER THREE

Analyzing and simulating experiential capacity at a wild and scenic river

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Abstract

Recreational boating is one of the major water-based activities in the U.S. Visitors enjoy a multitude of public navigable rivers for boating, but what is the capacity of these waterways to accommodate use? An agent-based simulation model of a popular Wild and Scenic River was developed to determine the river's social carrying capacity. The findings show that the current boat use levels for an average non-peak were well within acceptable thresholds for boating. Also, at current boat use level for an average peak day, very few cases of boating thresholds being violated were recorded. However, increasing boat use levels by over 25% may result in "acceptability" and "displacement" thresholds to be exceeded at certain portions of the day. The study identified that one of three river use zones may experience a larger proportion of crowding-related threshold violations. Also, by applying perceived crowding thresholds for boating derived from a 800m viewshed across river segments that were not uniformly sized, the study examined the practicality of applying crowding thresholds for boating in terms of boat density or merely the number of boats that are within the line of sight of visitors at any given time. The results show that there were no significant differences in simulation outcomes for crowding thresholds for boating between the river segments (i.e., viewsheds that were 800m and smaller sized ones). Therefore, the maximum number of boats that are within the line of sight of visitors at any given time may be a more logical threshold to apply across an entire river because viewsheds are likely to change with the river's morphology. The study demonstrated a proof of concept in simulating recreational boating and makes significant contribution to the body of knowledge by applying norm-based approaches to determine acceptable boating conditions. Also, the study findings can inform the development of visitor use management plans for public

waterways and assist managers who seek to promote a high quality recreational boating experience.

Key words: Recreational boating, simulation, agent-based model, NetLogo, carrying capacity, thresholds

Visitation to protected areas (PAs) has steadily increased with countries like the U.S. National Park System recording visitation at over 330 million visits in 2017 (National Park Service [NPS], 2018). With a significant portion of navigable waterways located in PAs, recreational boating (RB) has also experienced a steady increase. For example, paddle sports such as stand-up paddling and whitewater kayaking reported increasing average participation by 26% and 10%, respectively, from 2012 to 2015 (Outdoor Foundation, 2016).

Increased boating levels raise safety issues, can create shoreline erosion, and strain infrastructure and facilities such as boat ramps and parking areas (Itami, Gimblett & Poe, 2017). Therefore, determining acceptable levels of impact from visitor use (i.e., carrying capacity) is a perennial issue on waterways such as rivers due to: 1) increasing boating participation rates that may jeopardize the integrity of natural resources and the quality of the visitor experience (Manning, 2011), and 2) regulatory or planning requirements such as the Wild and Scenic Rivers Act of 1968 that mandates federal agencies managing rivers designated as wild, scenic or recreational to address resource and experiential impacts associated with visitation, specifically including setting capacities. Additionally, enabling legislation such as the Organic Act of 1916 indicate that the NPS must provide for public opportunities to *enjoy* a park unit's natural and cultural resources. This has spurred a need to consider the visitor experience, its management, and the related issue of carrying capacity as a core element of any park's efforts.

To effectively manage PAs and plan for their future, a basic understanding of a park's resources, values, uses, and users is needed. For the latter two, the development of a visitor use management plan provides detailed overall guidance on management strategies, including capacities, associated with particular visitor use facilities, visitor activities, and visitor use issues. Planning frameworks such as the Visitor Use Management (VUM) framework are designed and intended to help guide all visitor use management on federal agency lands and waters (Interagency Visitor Use Management Council [IVUMC], 2016). In the face of increasing visitor use, the VUM framework is aimed at maintaining the quality of the visitor experience while protecting natural and cultural resources. As a part of the VUM framework, PA managers should strive to understand visitor experiences and attempt to determine appropriate management responses to both prevailing and predicted conditions.

The VUM framework contains critical processes designed to allow PA managers to make more informed and defensible decisions. First, the framework emphasizes understanding who PA visitors are. For instance, a better understanding of visitor motivations would help PA managers match recreation opportunities with recreation needs. Also, knowledge about visitors' travel behavior is essential to understanding what types of visitor uses are occurring where. Some of the most basic but vital data on outdoor recreation consists of the places people visit, their travel routes, and the amount of time spent at each location (Hallo et al., 2012). Visitors' movement patterns affect infrastructure and transportation development, the design and maintenance of facilities and services and destination planning (Hallo & Manning, 2010; McGehee et al., 2013). In order to balance various societal demands and protect natural resources, tracking visitor movement patterns is necessary (Beeco & Brown, 2013). For example, areas where the most use occurs require more intense management, including facility development and redistributing use (Hammitt, Cole & Monz, 2015).

Second, the VUM framework can help determine acceptable levels of impact from visitor use. PA managers need to understand the point(s) where conditions in a recreation area are perceived to be undesirable or degraded. The two critical steps in determining this point(s) include: 1) the identification of indicators (i.e., measurable and manageable variables such as the number of boat encounters per hour) to help define the quality of desired natural/cultural resource conditions and the visitor experience, and 2) defining the acceptable condition of indicator variables (i.e., thresholds). Social science studies to support planning with the VUM framework, or its predecessor frameworks like the Limits of Acceptable Change (LAC) and Visitor Experience Resource Protections (VERP), have most often applied a norm-based approach to model the impact of visitor use on the quality of outdoor experiences (Kuentzel & Heberlein, 2003; Manning, 2011; Needham, Vaske, Whittaker & Donnelly, 2014). Norms are defined as expectations that individuals and groups use for evaluating ecological and social conditions, and these norms can be useful as a means of formulating indicators and thresholds (Shelby & Vaske 1991).

Because visitor use fluctuates, but is most often increasing, understanding how a range of visitation levels affects both resources and experiences is helpful for current and future planning. Computer simulations are dynamic and adaptable representation of real situations that often include consideration of time and/or space (Lawson, Hallo & Manning, 2008). For example, visitor data collected in 2015 at a visitation level of 100,000 can inform planning efforts for 2020 when visitation is expected to be 150,000 by modelling estimated effects at this visitation level.

Simulation modelling studies that assess social carrying capacity in PAs have to a large extent focused on trails (D'Antonio et al., 2010), attraction sites (Birenboim, Reinau, Shoval, & Harder, 2015; Bolshakov & Merkuryeva, 2016), and scenic roads (Hallo & Manning, 2010). However, there is limited research that has used simulation modelling in the context of RB (Lowry, Laninga, Zimmerman & Kingsbury, 2011).

Most boat-related simulation studies have examined commercial boating traffic (GeoDimensions, 2006, 2011; Verstichel & Berghe, 2016). Other studies have simulated the capacity of an urban waterway (Itami, 2008) and the potential for vessel collision with large marine wildlife such as whales (Conn & Silber, 2013). Simulation modelling has been used as a tool to evaluate economic and technical issues, risk and accident probabilities, and to perform scenario and policy analyses such as the impact of deepening a river channel (Almaz & Altiok, 2012).

The potential application of simulation modelling to address visitor use issues in the context of RB has been relatively under explored. Yet, simulation research in RB is capable of providing managers with detailed information on both the current and projected boating traffic volumes and densities on specific waterways, and related boating capacities (Itami et al., 2017). By incorporating GPS tracking to collect both motorized and non-motorized boat travel route data, managers can identify "hot spots"

(Lawson, Itami, Gimblett, & Manning, 2006; Beeco & Hallo, 2010). Simulation modelling may use such data to identify areas capable of accommodating additional use, and also to evaluate risk of possible boating-related accidents or incidences at specific areas.

This paper describes the outcome of a study that applied simulation modelling and the core elements of the VUM framework to the determination of social carrying capacities on the Middle Delaware Scenic and Recreational River within the Delaware Water Gap National Recreation Area (DEWA). The purpose of this study was guided by the following research questions:

1. What are the indicators and thresholds for quality experiences for RB in DEWA?
2. How do current perceived and observed RB use levels compare to the determined thresholds?
3. Where and at what point would crowding-related thresholds for RB be violated?
4. Are there differences in the model outcomes for perceived crowding thresholds for boating applied on uneven viewsheds?

Literature review

The Wild and Scenic Rivers Act (the Act)

The National Wild and Scenic Rivers System (National System) was created by Congress in 1968 to preserve certain rivers or segments of rivers with Outstandingly Remarkable Values (ORVs) — scenic, recreation, geologic, fish and wildlife, historic, cultural, or other similar values — in a free-flowing condition for the enjoyment of present and future generations (www.rivers.gov). To maintain free flowing status, the construction of dams is prohibited.

Eligible rivers or segments are designated either through an act of Congress or through approval from the Secretary of the Interior if a state governor requests designation. The latter option requires the river to be first designated as wild, scenic, or recreational (or the equivalent thereof) at the state level by, or pursuant to, an act of the legislature of that state (www.rivers.gov).

Each river is administered by either a federal or state agency. Section 2 (b) of the Act defines the criteria for classification according to the level of development at the time of designation of the shoreline, channel and access as wild, scenic, and/ or recreational (Interagency Wild and Scenic Rivers Coordinating Council [IWSRCC], 2017).

> *(1) Wild river areas — Those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted. These represent vestiges of primitive America.*
>
> *(2) Scenic river areas — Those rivers or sections of rivers that are free of impoundments, with shorelines or watersheds still largely primitive and shorelines largely undeveloped, but accessible in places by roads.*
>
> *(3) Recreational river areas — Those rivers or sections of rivers that are readily accessible by road or railroad, that may have some development along their*

> *shorelines, and that may have undergone some impoundment or diversion in the past.*

The Act protects the integrity of these rivers while also recognizing the potential for their use and development by promoting cross boundary river management. For example, sections of the Delaware River (i.e., Upper, Middle and Lower) are included in the National System and span across three states, namely, New York (NY), Pennsylvania (PA) and New Jersey (NJ). A wild and scenic river designation

> "seeks to protect and enhance a river's current natural condition and provide for public use consistent with retaining those values. Designation affords certain legal protection from adverse development, e.g., no new dams may be constructed, nor federally assisted water resource development projects allowed that are judged to have an adverse effect on designated river values" (IWSRCC, 2017, p.14).

As of January 2017, some 12,734 miles of 208 rivers have been afforded protection in the National System (IWSRCC, 2017). The Act mandates managing agencies to protect and enhance the ORVs along designated rivers. Therefore, managing agencies must conduct baseline studies, either as part of the process of studying a river for inclusion in the National System or as part of the river management plan drawn up for the river after designation (McGrath, 2014). This has spurred a need to consider the visitor experience, and its management. For example, with 40 miles of the Middle Delaware Scenic and Recreational River within DEWA, boating use studies are essential to guide decision-making.

Visitor management frameworks

The world is biophysically finite, so there is need to have sustainable strategies to limit its use (Hardin, 1968). Measuring carrying capacity is one such strategy. For the past 50 years, outdoor recreation research has adapted and developed the concept of carrying capacity to tackle concerns related to visitor use. Early studies focused on evaluating the number of visitors a recreation area could accommodate before its natural qualities were significantly compromised (Whittaker, Shelby, Manning, Cole & Haas, 2011). Subsequent definitions of capacity introduced the social (i.e., experiential) component by focusing on the quality of the recreation experience (Manning, Lime & Hof, 1996). An expansion of the capacity concept applied to outdoor recreation led to a three-dimensional approach, comprised of three components: resource, social and management components. These components are interrelated and affect the quality of recreation experiences (Manning, 2011). Incorporating a physical or facility component (i.e., restrictions imposed by limits of physical space) may give a more holistic representation in determining the capacity of a recreational area (Kim, Shelby & Needham, 2014). However, the physical component is less often emphasized in the management of outdoor recreation (Manning, 2011; Needham, Ceurvorst, & Tynon, 2013).

Outdoor recreation management frameworks developed to support PAs management of capacity-related issues include the LAC (Stankey, Cole, Lucas, Petersen & Frissell, 1985), the Carrying Capacity Assessment Process (CCAP) (Shelby & Heberlein, 1986), Visitor Impact Management (VIM) (Graefe, Kuss, & Vaske, 1990), VERP (NPS, 1997) and the VUM framework (IVUMC, 2016). These frameworks employ a management-by-objectives approach to identify and develop indicators and thresholds of quality experiences. They also track the effects of management practices or actions (Manning 2011; Manning, Rovelstad, Moore, Hallo, & Smith, 2015).

The more recent VUM framework, incorporates lessons learned from agency experience (including legal challenges) to allow flexibility in the planning process (Marion, 2016). The framework is divided into four major elements: (1) build the foundation; (2) define visitor use management direction; (3) identify management strategies; and (4) implement, monitor, evaluate and adjust. Regardless of the managing agency, these basic elements are applicable across many visitor use management plans. Included in each element are steps that provide more detailed direction on the various management topics. For example, when 'defining visitor use management direction' (i.e., element 2), PA managers need to 1) define desired conditions for the PA, 2) define appropriate visitor activities, facilities and services, and 3) select indicators and establish thresholds.

The core elements of the VUM framework have been used to guide the development of DEWA's Visitor Use Management Plan (VUMP). Specifically, this study addresses the framework's process of selecting indicators and establishing thresholds in DEWA for the Middle Delaware Scenic and Recreational River.

Normative theory applied to outdoor recreation

In defining the quality of the recreation experience, it is necessary to determine the variables important to visitors. Researchers have given attention to the identification of these potential indicators of quality for a variety of use types and recreation settings (Manning, 2011). For recreational boating potential indicators may include: the number of boats at one time (BAOT) at attraction sites, number of boats encountered per day, litter, and noise levels (Manning, 2011).

The threshold associated with a particular indicator may simply be developed using logic and professional judgement to estimate what level of change in conditions would prompt more management attention and investment (Cole & Carlson, 2010). However, where the potential for controversy and the consequences of capacity decisions are high, it might be necessary to use empirical methods.

By using quantitative methods like visitor surveys (Hallo, Brownlee, Hughes, Fefer, & Manning, 2018; Manning et al., 2015), qualitative methods such as conducting interviews (Glaspell, Watson, Kneeshaw, & Pendergrast, 2003) or mixed method approaches (Hallo & Manning, 2009), managers can obtain data about level and type of use, indicators, users' personal thresholds and also estimate acceptable conditions in a recreation setting (Manning, 2011).

Studies have often applied a norm-based approach to model the impact of visitor use on the quality of the outdoor experience (Kuentzel and Heberlein, 2003; Manning, 2011; Needham et al., 2014). Normative theory and methods developed in sociology have guided research on evaluating recreational thresholds (Manning, 2013; Pierce & Manning, 2015). Norms are defined as thresholds that individuals and groups use for evaluating ecological and social conditions (Shelby & Vaske 1991). Using Jackson's (1965) Return Potential Model (RPM), personal norms of individuals (e.g., boaters) are aggregated to derive social norms (Manning, 2013) that are often presented graphically in the form of social norm curves as illustrated in Figure 3.1.

Crystallization is a concept for measuring the degree of consensus about recreation-related norms or the amount of dispersion around a social norm (Krymkowski, Manning, & Valliere, 2009). The vertical line marked by bars at the ends in Figure 3.1 represents crystallization at a single measured point along the norm curve. Standard deviation and variance are some of the most commonly used measures of dispersion. However, because these measures can make a skewed distribution appear similar to one where there is a uniform agreement and variables can be measured on different scales, concepts like standard deviation are often not comparable across different studies (Krymkowski et al., 2009). The Potential for Conflict Index (PCI_2) not only addresses the above issues, it also simultaneously describes a variable's central tendency, dispersion and shape using a graphic display (Manfredo, Vaske & Teel, 2003).

(INSERT FIGURE 3.1 HERE)

PCI_2 scores range from 0 to 1. Scores closer to zero indicate higher levels of crystallization or more agreement. The lowest amount of crystallization (agreement) occurs when responses are equally divided between two extreme values such as where 50% of the responses are highly unacceptable and 50% highly acceptable (Engel, Vaske, Bath, & Marchini, 2017). However, there is complete agreement or the highest level of crystallization if all responses (100%) were at any one point on the scale (Engel et al., 2017). Studies have often used PCI_2 for reporting crystallization (Marin, Newman, Manning, Vaske & Stack, 2011; Miller & Freimund, 2017). Also, programs for calculating and graphing PCI_2 values are freely available from http://welcome.warnercnr.colostate.edu/.

A normative approach and related empirical methods have increasingly been used to formulate thresholds in PAs such as DEWA (Brownlee, Sharp, Peterson, & Cribbs, 2018; Hallo, Fefer & Riungu, 2017). Narrative/numerical description of ecological or experiential conditions have been used to measure norms. For example, respondents are asked to evaluate the acceptability of alternative use levels, such as a number of groups encountered per day. The resulting data are then aggregated to determine social norms. However, narrative/numerical approaches often require respondents to imagine the resource and experiential conditions after reading long descriptive narratives.

Visual-based methods are also commonly used for investigating normative evaluations of recreation settings (Gibson et al., 2014). Studies have used computer generated photo simulations (Gibson et al., 2014), moving images (Kim & Shelby, 2009), video (Freimund, Vaske, Donnelly & Miller, 2002), and images and sound (Grau & Freimund, 2007) to simulate resource and social conditions for evaluation. These methods are robust and can easily and effectively capture variables that would be awkward to describe using narrative methods (Manning & Freimund, 2004).

Visual-based methods have been used for more than 25 years (Shelby & Harris, 1985) and studies have often supported the validity of these methods to evaluate quality standards at recreation sites (Manning, 2011). Therefore, this paper used computer generated photo simulations to determine the thresholds for quality boating experiences at DEWA's portion of the Delaware River.

Thresholds for boating may vary depending on users' preferences, activity type, or other considerations, all which may be site-specific. Studies have often used boat density, measured in surface acres of water, to determine the acceptable number of boats per acre of water. Additionally, some density-related thresholds are aggregated to apply to an entire waterbody, while others specify a density for each type of watercraft. However, little is known about how these thresholds are related to how boaters space themselves particularly in rivers. Typically research using simulated photos to help develop thresholds evenly distributes use throughout a site's space (Manning & Freimund, 2004; Manning, 2011). For recreational boating such an approach may unrealistically allow a greater number of boats to be present than would naturally occur. This may result in thresholds that are too restrictive. Also, flowing waterways such as rivers may have a dynamic morphology. Because boaters' viewsheds may be constantly changing, this study tested for differences in the model outcomes for perceived crowding thresholds for boating at different viewsheds.

Tracking and simulating recreational boating

Studies in parks and protected areas have often tracked visitor travel patterns on roads (Manning & Hallo, 2010), formal and informal hiking trails (Beeco & Hallo, 2014; D'Antonio & Monz, 2016), or both roads and trails (Wolf, Hagenloh & Croft, 2012). Despite the growing popularity of boating and its associated risks, few studies have examined how recreational boaters travel through space and time (Cui, & Mahoney, 2015; Lowry et al., 2011).

In the U.S. boating is one of the major water-based activities. Participation is considered to be substantial and an estimated 36% of U.S. households participate in it annually (National Marine Manufacturers Association [NMMA], 2017). Waterways are a finite space of surface area and entail many different uses along its edges (e.g., river banks) and also on the open water. Therefore, high level of participation in boating may lead to undesirable conditions to not only boaters, but to other users.

Overcrowding in public waterways may result in displacement with boaters dispersing to other lakes or reservoirs (Gyllenskog, 1996; Kuentzel & Heberlein, 2003; Tseng et al., 2009). Recreation managers should therefore strive to understand visitor experiences so as to decide on appropriate management responses like scheduling put-in times for commercial boat liveries or expanding boating facilities (e.g., boat ramps and parking) to reduce congestion and wait times.

Due to growth in the number of boats and their usage, the potential for injuries and incidents also increase (Virk & Pikora, 2011). Studies have demonstrated that perceptions of boating safety have been significantly correlated with crowding among recreational boaters (Titre, Gilbert, Cherokee CRC & Jones, 2010; Tseng et al., 2009). GPS data can be used to measure movement of boaters and the level of exposure to risks associated with boating activity (Manning, Valliere & Hallo, 2010; Wu, 2007). Studies have simulated boating traffic in waterways to perform risk analysis (Pelot & Wu, 2007; Wu, 2007).

Simulation modelling can be used to describe and understand existing visitor use conditions that are inherently difficult to observe. For example, simulation models can incorporate both social data collected from visitor surveys and spatial data from GPS-based tracking methods to predict the potential impact of recreational behavior on visitor experiences (Manning & Hallo, 2010). It can be also be used in hotspot analysis and for identifying areas of crowding and areas capable of accommodating additional use (Lawson, Itami, Gimblett, & Manning, 2006; Beeco & Hallo, 2010). Simulation modeling can allow PA managers to “experiment” with different management actions and visitor use scenarios (Lawson et al., 2003).

Among other simulation techniques, agent-based models (ABMs) have been shown to be an effective option to handle the complexity of tourism and recreation (Nicholls, Amelung & Student, 2017). For example, park visitors move across large landscapes and along distributed networks; hence, their transportation choices may be driven by a number of conditions such as infrastructure design, cost, frequency of public shuttle services, and level of traffic. Because ABMs afford the agent the ability to gather data from their environment and make decisions based on the information, ABMs build representations of recreation use that are more realistic than probabilistic models (Skov-Petersen & Gimblett, 2008).

ABMs are a class of computational models simulating a system as a collection of autonomous agents that interact with the environment and each other, and make decisions based on a set of rules defined by the user (Bonabeau, 2002). ABMs are robust tools for modeling visitor behavior as a variety of agent decisions and actions can be modelled in a single ABM (D'Antonio, 2015). The rules and actions that drive the agent's behavior in the ABM are built using a series of assumptions derived from observed visitor behaviors (often using monitoring techniques such as visitor counts). These ABM rules, often formed as "if-then" statements, govern the behavior of the agents in the model and certain rules can be triggered by changes in the agent's social or physical environment (Crooks & Heppenstall, 2012; Nicholls et al., 2017). Additionally, the possibility to integrate ABMs and spatial information (e.g., through ArcGIS), enables PA managers to efficiently simulate real-world environments.

This paper presents an agent-based model to estimate the maximum number of boats that can use DEWA's portion of the Delaware River without violating crowding-related thresholds.

Methods

Study Area

DEWA contains significant natural, cultural, and recreational resources, including the Middle Delaware National Scenic and Recreational River (referred to as 'DEWA River'). Mostly due to its proximity to big cities in NJ, PA, and NY, DEWA recorded over 3,400,000 visitors in 2017, many of which congregate at popular recreation sites (NPS, 2018). Visitors are drawn to the area by its unique natural and cultural resources and the recreational opportunities they provide, such as the Delaware River.

The preservation of scenic and resource values of the Delaware River was a major factor in designating DEWA as a park unit in 1965. The DEWA River was designated thereafter in 1978. The river spans 331 miles, 40 of which are included in the national wild and scenic rivers system and are located within DEWA (IWSRCC, 2017).

The National Park Service's mission, DEWA's enabling legislation and the Wild and Scenic Rivers Act of 1968 indicate that recreation opportunities must be provided for the public whilst protecting the park's natural and cultural resources. Managing visitor use and experiences are considered as core elements of DEWA's efforts. High quality visitor experiences are not only a legislative mandate for DEWA, but they are essential to ensuring public support and stewardship of the park, and for continued visitation to a region that has a large portion of the local economy rooted in nature-based tourism (Hallo et al., 2017).

DEWA provides opportunities for motorized and non-motorized boating, river angling and river-based camping. DEWA's section of the Delaware River has many quiet pools and a few short riffles making it ideal for beginning paddlers. Therefore, changes in paddling use levels at a broader scale are likely to be reflected at DEWA.

Simulation model data collection

Three types of data inputs for the simulation model of boating on DEWA River were collected during the peak use season in 2016: 1) boat counts, 2) thresholds for quality boating experiences, and 3) boat travel routes.

Boat counts. Counts of boats on the river were collected using automatic time-lapse field cameras placed at four selected sites along DEWA River. The cameras collected data from June 18 to August 14, 2016 (61 days). The selected camera locations provided elevated and unobstructed views of RB use on the river. Except for one site (i.e., Riverview near the McDade Trail), cameras were placed on bridges connecting PA to NJ. They included the Milford–Montague Toll Bridge (also known as the US 206 Toll Bridge), Dingmans Ferry Bridge, and the Delaware Water Gap Toll Bridge which carries Interstate 80 across the Delaware River near Kittatiny Point Visitors Center (see Figure 3.2).

(INSERT FIGURE 3.2 HERE)

The cameras are both reliable and field-tested for the purposes of automatically recording recreation use at a site. Specifically, Hallo, Brownlee and Fix (2013) used field cameras for conducting counts of both people and vehicles in parking lots at Pinnacles National Park. Additionally, field camera images have been used to determine the use and capacity of recreation facilities at both Priest Rapids Hydroelectric Project, Washington and three Tennessee State Parks (Hallo, et al., 2016; Hallo, McGuiness, Dudley & Fefer, 2017).

The Moultrie D-555i field cameras utilized in the study were relatively inexpensive ($120 each) and allowed high resolution photos (8 MB) to be taken. The camera’s programmable time-lapse function allowed photos to be taken at specified intervals and during specified hours. This function has also been used to conduct recreational use assessments of water-based activities in Philadelphia, US (Sunger, Teske, Nappier & Haas, 2012). The cameras were programmed to capture photos every

30 minutes between 8 a.m. and 7:00 p.m. This time period was selected because it was recognized as the busiest time of day for recreation activity in the study area.

The cameras gathered photographic data on the number of watercraft and boats on the river, rather than put-ins and take-outs. This was done to estimate the average number of boats on the river at one time. *Timelapse2* image analysis software and trained research assistants were used to count boats to establish the levels of RB use at half hour intervals. In contrast, some studies have used qualitative visual count methods, which is hinged on the ability of an observer to identify patterns based on the dynamic inspection of an image bank (Martínez-Ibarra, 2011). For example, an observer estimates the use level of a beach from images taken of the site at specified times based on a predetermined visitor density range (i.e., 0- null density, 0.5, 1, 1.5, 2, 2.5, 3- maximum density). Each image is then assigned a specific density level (Gómez-Martín & Martínez-Ibarra, 2012). This process is subjective, therefore, using *Timelapse2* provides a more objective approach.

Boater thresholds and travel routes. Data on visitor-based thresholds for boating on the river and boaters' travel routes were collected by surveys and GPS units (i.e., Globalsat DG100), respectively. The Globalsat DG100 GPS data logger costs approximately $40, and has acceptable accuracy and reliability in estimating distances and speeds in outdoor research (Noury-Desvaux et al., 2011; Hallo et al., 2012). The GPS units were set to record boaters' locations every 30 seconds.

The GPS units and surveys were distributed from June 1 to August 15, 2016 with research staff administering surveys on site at DEWA. Sampling efforts occurred on randomly selected days (stratified by weekday versus weekend). The survey was administered to boat-based users present at the following locations: Milford Beach boat launch, Namanock canoe launch, Dingmans Ferry boat launch, Eshback canoe launch, Bushkill boat launch, Poxono boat launch, Smithfield Beach boat launch, and Kittatinny Point canoe launch (see Figure 3.2).

A water-proof packet containing a GPS unit and a survey were handed to boaters who were about to launch on to the river. To facilitate the return of both the GPS unit and completed survey to researchers, a stamped pre-addressed envelope was included in the packet. This allowed participants to fill out the survey after exiting the sample site and avoided interfering with their on-site recreation experience.

Surveys were conducted by contacting all groups present at boat put-ins. In groups consisting of more than one person, one user per group who was 18 years or over was asked to complete the survey. In groups consisting of members who were not personally affiliated, such as with livery-based canoe trips, multiple qualified users per group (age 18 or over, and not from the same family and/or friend subgroup) were asked to complete a survey.

Survey questions asked boaters to evaluate 8 simulated photos depicting different levels of RB use on an estimated 800-meter (m) view shed. The total number of watercrafts in the photos ranged from 0-15 (see Figure 3.3). Survey respondents evaluated each photo based on a 9-point scale of -4 (‘very unacceptable’) to 4 (‘very acceptable’). A total sample of 196 boaters completed the survey, with a response rate of

96%. Survey respondents were also asked to indicate the photo showing the level of use that they found so unacceptable that they would no longer boat on the DEWA River.

(INSERT FIGURE 3.3 HERE)

Completed surveys were entered into SPSS version 20 for analysis. Response frequencies and descriptive statistics were determined for each survey question. Norm-based questions were analyzed and presented graphically in the form of social norm curves.

Designing the model

The model, developed using NetLogo version 6.0.3 (Wilensky, 1999), is described below following a simplified version of the Overview, Design concepts, Details protocol (Grimm et al., 2010). NetLogo is a programmable modelling environment for simulating natural and social phenomena. It was selected for this study because of its wide application in agent-based modelling research (e.g., Guerin et al., 2009; Li, Xiao, Zhang, Kong & Sun, 2017; Orsi & Geneletti, 2016; Student, Amelung & Lamers, 2016), its supportive community of users and access to high quality tutorials and textbooks.

The GPS tracks that were collected at DEWA were uploaded into ArcGIS as point features. Each GPS track (visualized as a series of points) was assigned a unique ID number to allow for each unique boater track to be examined individually from the overall dataset.

DEWA’s portion of the Delaware River was divided into 3 ‘river use zones’ (see Figure 3.2). These zones were created as sections between where automatic time-lapse field cameras were placed to collect boat count data along the river. This delineation of the river into 3 zones provided a better visualization of boating movement and created locations in the river that the ‘agents’ (boaters) could feel “crowded” while moving in the model. The river use zones data layer was also used to determine the average speed (and standard deviation) of boaters for specific zones.

Rule building

The primary component of the model encompasses boater movements within the DEWA River. This results in two main phases that boaters pass through during a simulation run, namely river access location choice (i.e., entry and exit) and boating speed selection. From survey responses non-motorized watercraft formed the largest proportion (83.2%) of boat use at DEWA. Therefore, the model was specifically designed to simulate non-motorized boating. Also, boat ‘agents’ were designed to travel downstream by following the rules outlined and justified in Table 3.1 (also see green boxes in Figure 3.4). The output file from the model was saved as a comma separated value (csv) file for analysis.

(INSERT TABLE 3.1 HERE)

a) River access location selection

A combination of travel guides, Google Earth, ArcGIS shapefiles (from the NPS and the Delaware River Basin Commission) and GPS tracks used in the study were used to determine river access locations. A total of 17 boat put-in areas were identified with one site often comprising of multiple boat put-in areas (see Figure 3.2). For example, Milford, Smithfield and Kittatiny sites each had 2 put-in areas, whereas Bushkill site had 3 put-in areas. After visually inspecting all boat launches, the put-in (start) and take-out (exit) areas were randomly selected based on a predetermined distance between launch areas. Boat launches that were greater than 600m apart in distance were selected to be start and exit locations. This was to avoid boaters launching and exiting at the same site. Then the selection of river access locations was randomly drawn from a list of all possible combinations for put-in and take-out locations.

b) Boat speed, frequency of boats launching and duration of boating

By using the average boat speed from GPS tracks collected in the study, the random-normal function in NetLogo was used to create a normal distribution of boating speed for the population of agents for each zone. The absolute values for speed were used in the model. Decisions on the time spent boating were based on the river access location and boating speed, and assigned boating duration. The assignment of boating duration followed a normal distribution from field survey work. Therefore, when the assigned boating duration elapses the agent travels to the nearest take-out location. Then the agent is removed from the model.

To determine the number of boats being launched at each zone, the hourly average BAOT for non-peak and peak days (see Table 3.2) was used to assign a distribution for each boat launch area. By using the random-poisson function in NetLogo, a Poisson-distributed random integer was assigned for all boat launched in each zone. This function uses the mean BAOT for each zone to map the distribution of boats being launched every hour between 8 a.m. to 7 p.m. at specified locations. Also, a distribution of the average wait time was applied to all river access locations where more than one boat was launched at a specified time of day. This represented a scenario where groups or solitary boaters may be launching.

(INSERT TABLE 3.2 HERE)

Running the model

When the simulation starts, the boat distribution is set to either a non-peak (weekday) or peak (weekend or holiday) distribution (see grey boxes in Figure 3.4). Also, all the agents are initialized with parameters such as the put-in and take-out locations and the speed of travel. In the NetLogo environment, time is discrete and simulated by ticks where one tick is a unit of time (Beheshti & Sukthankar, 2015). One tick in the current model represents 1 second in reality and simulations are run for 39,600 ticks, equivalent to 11 hours (between 8 a.m. and 7 p.m.).

The current model only simulates non-motorized watercraft. Therefore, agents are instructed to move south from respective put-in locations. In reality the DEWA River flows southwards, hence a boater's take-out location will be south of where they put-in. Also, an agent is removed (exits) upon arriving at the assigned destination. Additionally, Kittatiny was the southernmost boat launch site in the simulation environment, therefore it was only used as a take-out location and was not assigned to agents as a put-in location.

To measure the level of encounters and estimate crowding levels, the river was divided into 101 segments. To represent the viewshed used to determine perceptions of crowding in the boater survey, the studied attempted to apportion the river into 800m segments. However, due to the morphology of the DEWA River, 62.4% of the segments had an 800m viewshed and the rest were smaller. Each river segment had a unique ID and its corresponding X and Y coordinates. For simulation purposes, the above parameters were used to determine the number of boats found at each viewshed from the start to end of the simulation (i.e., 8 a.m. to 7 p.m.) at a 5-minute interval.

A tutorial of the final model can be viewed at the following link. https://youtu.be/q3BiIwRmRN8

Results

A total of 196 surveys were completed with a response rate of 96% at representative boat launch sites throughout DEWA. Non-motorized watercraft (83.2%) were the most frequently used types of watercraft and included kayaks, canoes and tubes; the rest were motorized boats (16.8%). Therefore, the current study examined non-motorized boating levels to determine where and when experiential capacities may be exceeded along the DEWA River.

Experiential Capacity - Boat launch wait times

Survey respondents were asked questions related to waiting times to launch a boat. The largest portion of respondents (95%) did not have to wait to use boat launches at the project. The average wait time was 7.9 (SD = 4.5) minutes. Responses to the visitor survey showed that, on average, visitors felt waiting 12 minutes to launch a boat was acceptable. This value represents an experiential threshold for boat launch waiting times.

Experiential capacity - Boats at one time (BAOT)

Crowding thresholds for the number of BAOT were measured using a series of eight photos as described before. The number of boats ranged from 0-15 with even proportions of motorized and non-motorized boats. However, Photos 7 (6 non-motorized, 3 motorized) and 8 (6 motorized, 3 non-motorized) represented a change in the proportion of motorized vs. non-motorized boats. The social norm curve derived from the data is illustrated in Figure 3.5. Also, the mean acceptability ratings and Potential for Conflict Index (PCI_2) scores, to illustrate the crystallization, are provided for each image.

In general, the results show that for boaters the acceptability decreases as the number of boats increases. As shown in Figure 3.5, as the number of boats increased from 0 to 15 in the study photos, mean ratings for acceptability decreased from 3.7 to -1.5 on the response scale. Photo 1 received the highest rating of acceptability from the study sample indicating that the optimum condition for boating is when there are no other boats. Survey responses suggested than on average 11.5 boats in the study photo was the maximum acceptable number (“acceptability”). Changing the proportion of boat types (motorized vs. non-motorized) brought the mean “acceptability” threshold down, where 9 boats of close to equal proportions is acceptable, yet 9 boats of uneven proportions is unacceptable (see Figure 3.5).

Crystallization of norms as measured by PCI_2 for each image ranged from 0.02 to 0.45. The size of the bubbles represents the level of agreement from responses for a particular norm rating. The smaller the bubble the higher the agreement. Crystallization was higher for the images representing 0 to 6 boats than other images representing more boats. The PCI_2 values indicated that there is modest variation in the acceptability evaluations, especially when the evaluations go into the unacceptable range (i.e., 12 to 15 boats).

Further, at a use level of 14.1 boats in the study photos, respondents reported that they would no longer boat at the DEWA River (“displacement”). Responses to both the acceptability and displacement evaluative dimensions of boating represent a range of potential crowding thresholds to guide evaluation of the DEWA River’s social carrying capacity.

(INSERT FIGURES 3.5 HERE)

Simulated data validation

To verify that the simulation output provides a realistic depiction of boat use levels on the DEWA River, the following steps were undertaken. First, baseline data were determined from the field data. Because the simulation used a Poisson distribution (derived from the field camera data) to assign the number of boats being launched at every hour, the total number of boats is likely to vary every time the simulation is run. Therefore, to validate the output the simulation was run 62 times to represent the duration in days (i.e., non-peak and peak) that the actual study was conducted. An independent-sample t-test was conducted to compare boat counts per day for actual and simulated conditions. There was no significant difference in the boat counts for actual (M=35.4, SD= 35.6) and simulated (M= 31.3, SD= 21.6) conditions, t (121) = 0.802, p > .05.

Second, the researcher examined the areas or zones traversed by unique agents (boats) in the simulation and compared this information with field data and logic. For example, by determining the actual distance between two points along the DEWA River and applying a known average boating speed, the duration of travel can be estimated. The length of the river from Milford beach boat launch (the start of Zone 1) to Kittatiny boat launch (the end of Zone 3) is approximately 34 river miles (54,718 meters). The average speed of boaters calculated from GPS tracks collected through survey work was approximately 1 meter per second (m/s). Therefore, for a boat to move non-stop from Milford to Kittatiny it would take approximately 15 hours. Conversely, it would take close to 12 hours (non-stop) to get from Milford to Poxono, which is the closest boat launch in Zone 3 and 26 river miles away. The current simulation was programmed to run from 8 a.m. to 7 p.m. (11 hours) and the model output indicated that no boats moved across all three zones in this timeframe. This was considered to be a realistic representation of the actual pattern of boat movement on the DEWA River.

Lastly, the researcher identified five participants to rigorously test the simulation on NetLogo by applying different input parameters. The participants visually analyzed where and when boats were being launched, the pattern of boat movement, the relative speed of boats and what happened when the boats reached their destination. Any issues or ‘bugs’ that were identified during this process were addressed.

Simulating current boating levels

A total of 40 simulation runs of the model for both non-peak and peak days were conducted. The resulting data were then examined to determine cases where the recorded number of BAOT was approaching the “acceptability” threshold (i.e., 11 BAOT) or had violated the “acceptability” and “displacement” thresholds across the entire river.

For the simulated average non-peak day, 38.6% of the boats were found in Zone 3, the next 22.1% were found in Zone 2, and 8.9% were found in Zone 1. The boats that moved from Zone 1 to 2 and Zone 2 to 3 were 19% and 11.4%, respectively. For the simulated average peak day, the largest proportion of boats were found in Zone 3 (51.9%), the next 18% were found in Zone 2, and 5.9% were found in Zone 1. The boats that moved from Zone 1 to 2 and Zone 2 to 3 were 11.1% and 13.1%, respectively.

The maximum number of BAOT for both non-peak and peak days were compared to “acceptability” and “displacement” thresholds. For non-peak days both thresholds were not violated for any portion of time at current use levels. However, for peak days, there was one case where “acceptability thresholds” were violated between 11 a.m. and noon. Additionally, there were two cases where the number of BAOT were approaching the “acceptability” threshold from 9 to 10 a.m. There were no cases where “displacement thresholds” were violated (see Table 3.3).

Projected increase in boating levels

The study also tested the effect of increasing current boat use levels at DEWA. By increasing the boat use levels by 25, 50, 75 and 100 percent, the simulation examined where and when the "acceptability" and "displacement" thresholds may be violated. A total of 40 simulations runs were conducted for each percentage increase in boat use levels. Because the average boat use level for a non-peak day were three times lower than that of a peak day, the effect of increasing boat use levels was only tested for peak days.

The simulated outputs were then examined to determine cases where the recorded number of BAOT was approaching the "acceptability" threshold (i.e., 11 BAOT) or had violated the "acceptability" and "displacement" thresholds.

For a 25 percent increase in boating, out of the total cases identified above, 33.0 % and 14.9% had violated the "acceptability" and displacement" thresholds, respectively (see Table 3.3). This occured between 10 a.m. and noon. For a 50 percent increase in boating use levels, 33.7% and 17.1% of the total cases identified had exceeded the "acceptability" and "displacement" thresholds, respectively. Also, "displacement" thresholds were violated from 10 a.m. to 1 p.m. Similarly, over 75% of "acceptability" thresholds were violated at this time (see Table 3.3).

For a 75 percent increase in boating levels, 37.9% and 21.7% of the total cases identified above had violated the "acceptability" and "displacement" thresholds, respectively. A large proportion (95.1%) of violations to "acceptability" thresholds occurred as from 9 a.m. to 2 p.m., and "displacement" thresholds were exceeded as from 10 a.m. to 1 p.m. (see Table 3.3).

At a 100 percent increase in boating levels, 42.7% and 22.2% of the total cases identified had exceeded the “acceptability” and “displacement” thresholds, respectively. A large proportion (91.7%) of the violations to “acceptability” thresholds occurred as from 8 a.m. to 2 p.m. Other violations were between 3 p.m. to 6 p.m. “Displacement” thresholds were exceeded from 9 a.m. to 1 p.m. (Table 3.3).

(INSERT TABLE 3.3 HERE)

Testing for differences in perceived crowding thresholds for boating across river segments

To determine the number of BAOT and estimate instances where crowding thresholds were being violated in the simulation, the DEWA River was divided into 101 segments. With 37.6% of the segments being smaller than the 800m viewshed used to determine perceived crowding levels for boating, one-way analysis of variance (ANOVA) was used to test whether the size of the segments show differences in crowding thresholds being violated for boating. The results show that there were no significant differences in crowding thresholds for boating between river segments, $F_{(1, 1146)} = 3.344$, $p > .05$.

Discussion

Results from the model runs suggest that the current boat use level for non-peak days on the DEWA River did not violate crowding thresholds for boating for any portion of time. Also, the maximum number of BAOT for an average non-peak were well within the boater-reported crowding threshold across all river use zones. For peak days, violation to “acceptability” thresholds were limited and “displacement” thresholds were not exceeded for any portion of time.

Simulation model results also provide estimates regarding the degree to which boater-reported thresholds would be violated if the boat use levels along the DEWA River were to increase. Because DEWA is one of the most frequently visited national park units and rising boat sales are often reported by trade associations such as the National Marine Manufacturers Association, it is reasonable to assume that use level along the DEWA River may increase. If boat use level for peak days were to increase by 25 to 100 percent, the simulation model estimates that boaters’ experiences may be diminished for given portions of time. Also, diminished experiences may result in some visitors changing locations or pursuing different recreational activities.

Overall, increasing boating use may result in higher cases of use levels approaching “acceptability” thresholds or “acceptability” and “displacement” thresholds being violated. As boat use levels increase from 25 percent to 100 percent, there was an increase in the proportion of “acceptability” and “displacement” thresholds being violated. Additionally, there were more portions of time that thresholds were exceeded. For example, at a 100 percent increase in boat use levels, “acceptability” and “displacement” thresholds were violated as from 8 to 10 a.m. Also, increases in boat use levels may result in boating thresholds being violated during take-out specifically in the evening as from 4 p.m.

By examining boat use levels that are approaching "acceptability" thresholds waterway managers may identify areas and specific portions of time that are likely to experience boating thresholds being violated in the not too distant future. This would help in the development of strategies that maintain boating conditions within the minimum acceptable level. For example, as from 3 p.m. to 7 p.m., a total of 20.8% and 13.8% of the cases were approaching "acceptability" thresholds after boat use levels were increased by 75 and 100 percent, respectively. Therefore, boaters' may be more likely to experience diminished experiences at the end of their trip hence managers might plan to maintain positive experiences at take-out times.

Boater-reported crowding thresholds were more likely to be exceeded in Zone 2 than any other zone. This was because Zone 2 was the largest (43.2%) and located between the two river-use zones, hence more likely to experience higher boat use levels. Also, because of the duration of travel, boats from Zone 1 are more likely to exit the DEWA River from Zone 2 rather than float to Zone 3.

The average acceptable BAOT for an 800m viewshed on the Delaware River is 11.5 boats. However, changing the proportion of boat types (motorized vs. non-motorized) brought the mean acceptability level down, where nine boats of close to equal proportions is acceptable, yet nine boats of uneven proportions is unacceptable. Interestingly, the acceptability of uneven proportions of boats did not change based on which type of boat (motorized vs. non-motorized) was seen more frequently in the photo. This is surprising because feelings of being crowded on the river are generally perceived as higher in the presence of motorboats than non-motorized boats (Hallo et al., 2017).

By applying perceived crowding thresholds for boating derived from a 800m viewshed across river segments that were not uniform in size (i.e., demarcated river segments that were less than 800m in size), the study examined whether model outcomes for perceived crowding thresholds for boating are manifested in terms of boat density or merely the number of boats that are within the line of sight of visitors at any given time. Studies have often used boat density, measured in surface acres of water, to determine the acceptable number of boats per acre of water. However, questions may be raised about how boaters space themselves.

Boaters may naturally use navigable portions of a river while providing adequate spacing from other boaters or use groups. Therefore, by using simulated photos to evenly distribute boats throughout a site's space may unrealistically allow a greater number of boats to be present than would naturally occur. This is currently considered a best practice in research using photos to help develop thresholds (Manning & Freimund, 2004; Manning, 2011). For waterway managers to accurately apply boat density thresholds they may need to constantly adjust thresholds to match existing viewsheds. For example, if the acceptable boat density threshold for a particular river is 2 boats per 1,000m of river channel and due to the morphology of the river the viewshed is halved, then a threshold of 1 boat per acre of water might be applied for that specific river section. This approach may not be realistic and can result in crowding thresholds for boating being too restrictive. Another approach may be using the number of BAOT within a visitor's line of sight irrespective of a river channel's length. This approach may lead a person to evaluate portions "available" for use, based on river channel viewsheds, and develop more realistic boating thresholds.

By applying boating thresholds derived from a fixed viewshed to uneven river segments of the DEWA River, the current simulation study tested for any significant differences in simulation outcomes between crowding thresholds for boating based on their interpretation as a density (boats/meter) or as based on a number of boats in view. The results show that there were no significant differences in simulation outcomes for crowding thresholds for boating between the river segments. Therefore, the average "acceptability" thresholds may be applied across the entire river irrespective of the boat density. The current study creates a foundational piece to further probe a fundamental concept in developing boating thresholds. This line of research may warrant more investigation.

"In recent years, areas within DEWA have experienced changes in the amounts and patterns of use by visitors and residents. This use is affecting park natural and cultural resources in ways unanticipated since the finalization of the park's General Management Plan in 1987" (NPS, 2015). To maximize the ability of park managers to provide recreational opportunities and protect DEWA's natural and cultural resources, the park has adopted a portfolio planning approach. The Delaware Water Gap National Recreation Area and Middle Delaware National Scenic River Visitor Use Management Plan is currently being developed to examine the current and potential visitor opportunities and develop long-term strategies for providing access, connect visitors to experiences, and manage visitor use. Also, DEWA was the first park unit identified by the NPS to develop a comprehensive visitor use management plan.

To inform the development of this visitor use management plan, resource managers may need to gain a better understanding of boaters and their needs, experiences, and preferences to help identify and cater for existing or new needs while also protecting the resources and experiences. One way agencies managing public waterways may perform this dual role of providing for recreational boating opportunities and protecting the integrity of resources and visitor experiences is by developing acceptable boating thresholds and evaluating the effect of implementing these thresholds over an entire waterway.

To get a better understanding of how visitors move across the DEWA River, an agent-based simulation model was developed to not only provide a visual display of boat use levels but also assist waterway managers to identify where and when crowding-related thresholds for boating may be violated across different use levels. The current study applied camera-based use estimates to simulate the current amount of use on the DEWA River and compare use levels to the selected thresholds of “acceptability” and “displacement” for boats seen at one time.

A limitation of the study was that adequate empirical GPS data was not available to support boat use distribution between specific boat launch sites. Also, boat counts from and to specific boat launch sites were not available. However, in the current study, strategically placed field cameras along the entire river were used a reasonable proxy to estimate boating use levels. Therefore, within a zone use was randomly apportioned to boat launches within that zone. This represented a conservative approach to the determination of crowding within each zone. Field surveys were also used to develop boaters' pattern of use such as boaters' length of stay and boat launch wait time to support model development.

In addition to boat counts on the DEWA River, boat launch wait times were used as another indicator of crowding. Boat launch wait times provide crucial information to waterway managers. A large proportion (95%) of boaters at DEWA did not have to wait launch a boat. By comparing the average reported wait time to an empirically-based acceptable wait time, it can be suggested that boat launch amenities at DEWA were, on average, utilized at levels well within their capacity to launch boats. By evaluating the boat launch utilization capacity waterway managers can make informed decisions whether to temporarily close some boat launch sites in order to reduce maintenance costs.

Future simulation research should consider incorporating management action alternatives such as closing boat launch sites and evaluate how such actions will affect experiential capacities. Additionally, future research may include motorized boats due to their ability to go upstream. Such a study may provide a more holistic view of how "acceptability" and "displacement" thresholds compare and better inform the planning process.

The level of parking occupied at launch sites can be used in the future as an indicator of crowding. Parking lots are an important transportation resource, as they provide visitors convenient access to waterways. Parking lots often dictate where a boat trip for a particular waterway commence and end. Therefore, future studies may simulate parking patterns and how parking lots can be efficiently managed to ensure a more even distribution of boats along the entire DEWA River. It is possible that even when on-water crowding “acceptability” and “displacement” thresholds are currently not being exceeded, visitors’ experiences may be diminished due to limited parking spaces.

Conclusions

The current study demonstrates a proof of concept that social science can be integrated with spatial patterns of boaters to determine where and when perceptions of crowding may be violated. Traditionally, the use of surveys and visitor feedback have been used to determine visitor satisfaction levels at specific sites within a recreational area. The use of a computer simulation model to not only map existing boat use levels on the DEWA River but also identify potential areas where visitors’ experiences may be diminished demonstrate the novel application of ABMs in recreational boating.

Simulation modelling may be viewed as a versatile tool that recreation managers may adopt in the management of public waterways to predict visitor responses to different management scenarios. Specifically, due to budget constraints, agencies may use open source tools like NetLogo to advance human dimensions research in public spaces. To the authors’ knowledge, there is only one study that has applied ABM to examine boat traffic using NetLogo. Guerin et al. (2009) developed an autonomous agent model to simulate boat and pedestrian traffic that operate along Venice’s canals and move on the city’s bridges and walkways, respectively. The autonomous agent boat model was used to simulate effects of changing the directionality of canals, closing certain canals and changing speed limits.

The Venice study examined the transportation system of the city hence the boat traffic was composed of both recreational and non-recreational boats. However, the current study was not only limited to recreational boating but integrated social science data. Therefore, the current study addresses some of the fundamental challenges of incorporating spatially-related social science data into the study of human dimensions of outdoor recreation (Beeco & Brown, 2103).

With many waterways located in protected areas, managers need to develop and implement comprehensive visitor use strategies that cover various boat types and address a wide range of possible impacts on resources and visitor experiences. To help guide this process, researchers may seek to identify ways to incorporate simulation modelling into current management frameworks like the VUM Framework. A boating management plan may consider potential issues and associated management options. Therefore, waterway managers and stakeholders may better understand current conditions and expected impacts of future boat use volumes (Itami, Gimblett, & Poe, 2017). A set of alternative management scenarios may then be evaluated and selected based on model outcomes.

The current study has also begun to query the process of developing boating thresholds and the practicality of implementing boat density thresholds along an entire waterway. Rivers, unlike oceans and reservoirs, often have a dynamic channel. Therefore, the application of boat density thresholds along an entire river may not be realistic because the viewshed used to develop these thresholds may be constantly changing. The study proposes the development of thresholds based on the number of BAOT within a visitor’s line of sight. This approach may lead a person to evaluate portions “available” for use and develop more realistic boating thresholds. Further empirical research is needed to test and validate this line of research, and in by so doing provide a concept useful to managers who seek to promote a high quality recreational boating experience.

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Table 3.1 Summary of ABM rules that an agent will follow

Order	Rule	Justification
1	The agent will move in a southerly direction in the model.	Non-motorized boaters often go downstream with the flow of the river.
2	The agent will move to the particular river use zone that was assigned.	River use zones were identified as the sections between where automatic time-lapse field cameras were placed to collect boat count data along the river.
3	Once in a river use zone, the agent will move randomly at assigned speed for that zone	Each zone may be characterized by different features like islands that influence boat speed.
4	The agent will estimate how many times crowding-related thresholds were violated for each river segment in a specific zone.	Crowding-related thresholds were used to estimate the frequency of violations in RB experiences for each river segment.
5	If the agent moves into another river use zone, then steps 3 and 4 are repeated.	Represents a boater using a put-in and a take-out site located in different zones.
6	The agent will move to the assigned take-out X/Y coordinates.	Boaters usually have a designated take-out location with a variety of transport options like liveries, public transport or private cars.
7	Once an agent reaches its take-out X/Y coordinates then the run of that agent is complete.	Represents the boater leaving the recreation site.

Table 3.2. The hourly average BAOT for a non-peak and peak day for respective DEWA River zones

Zone	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
1	0.1(0.1)	0.1(0.3)	0.3(0.7)	0.3(1)	0.4(1.3)	0.4(1)	0.2(1)	0.3(0.7)	0.2(0.4)	0.2	0.1(0.1)	0.1(0.1)
2	0(0)	0(0)	0.1(0.1)	0(0.1)	0.1(0.1)	0.1(0.1)	0.1(0.1)	0.2(0.2)	0.1(0.1)	0.1	0.1(0.2)	0.1(0.2)
3	0(0)	0.1(0)	0(0.1)	0(0.1)	0.1(0.3)	0.1(1)	0.2(1)	0.2(1.3)	0.3(1.3)	0.3	0.1(0.4)	0.1(0.4)

-The figures in parenthesis indicate hourly average BAOT for a peak day

Table 3.3 Results from the simulation model showing the time when portions of the DEWA River violate crowding thresholds for boating at varying use levels

Percent increase in current boat use levels	Evaluative Dimension (threshold)	8-9am	9-10am	10-11am	11-12 noon	12-1pm	1-2pm
0% (current use)	Approaching	-	2(100%)	-	-	-	-
	Acceptability	-	-	-	1(100%)	-	-
	Displacement	-	-	-	-	-	-
25%	Approaching	-	7 (14.3%)	17 (34.7%)	14 (28.6%)	4 (8.2%)	2 (4.1%)
	Acceptability	-	-	19 (61.3%)	12 (31.7%)	-	-
	Displacement	-	-	6 (42.9%)	8 (57.1%)	-	-
50%	Approaching	-	2 (2.2%)	36 (38.7%)	24 (25.8%)	8 (8.6%)	11 (11.7%)
	Acceptability	-	-	20 (29.9%)	19 (28.2%)	12 (17.9%)	6 (9%)
	Displacement	-	-	18 (54.5%)	14 (42.4%)	1 (3.1%)	-
75%	Approaching	-	7 (5.4%)	33 (25.4%)	36 (27.7%)	19 (14.6%)	5 (3.8%)
	Acceptability	-	3 (2.5%)	47 (38.5%)	41 (33.6%)	20 (16.4%)	5 (4.1%)
	Displacement	-	-	32 (45.7%)	31 (44.3%)	6 (8.6%)	-
100%	Approaching	-	17 (9.1%)	63 (33.5%)	51 (27.1%)	21 (11.2%)	10 (5.3%)
	Acceptability	2 (1.0%)	31 (13.5%)	74 (32.3%)	61 (26.6%)	34 (14.8%)	8 (3.5%)
	Displacement	-	12 (10.1%)	56 (47.1%)	45 (37.8%)	4 (3.4%)	-

Table 3.3 (cont.,) Results from the simulation model showing the time when portions of the DEWA River violate crowding thresholds for boating at varying use levels

Percent increase in current boat use levels	Evaluative Dimension (threshold)	2-3pm	3-4pm	4-5pm	5-6pm	6-7pm	Total (8 a.m. to 7 p.m.)
0% (current use)	Approaching	-	-	-	-	-	2(66.7%)
	Acceptability	-	-	-	-	-	1(33.3%)
	Displacement	-	-	-	-	-	-
25%	Approaching		3 (6.1%)		2 (4.9%)	-	49 (52.1%)
	Acceptability		-		-	-	31 (33.0%)
	Displacement		-		-	-	14 (14.9%)
50%	Approaching	4 (4.3%)	5 (5.4%)	1 (1.1%)	1 (1.1%)	1 (1.1%)	93 (48.2%)
	Acceptability	6 (9%)	3 (4.5%)	-	1 (1.5%)	-	67 (34.7%)
	Displacement	-	-	-	-	-	33 (17.1%)
75%	Approaching	3 (2.3%)	7 (5.4%)	3 (2.4%)	2 (1.5%)	15 (11.5%)	130 (40.4%)
	Acceptability	-	1 (0.8%)	-	-	5 (4.1%)	122 (37.9%)
	Displacement	-	-	1 (1.4%)	-	-	70 (21.7%)
100%	Approaching	-	9 (4.8%)	1 (0.5%)	16 (8.5%)	-	188 (35.1%)
	Acceptability	-	5 (2.2%)	5 (2.2%)	9 (3.9%)	-	229 (42.7%)
	Displacement	-	-	-	2 (1.7%)	-	119 (22.2%)

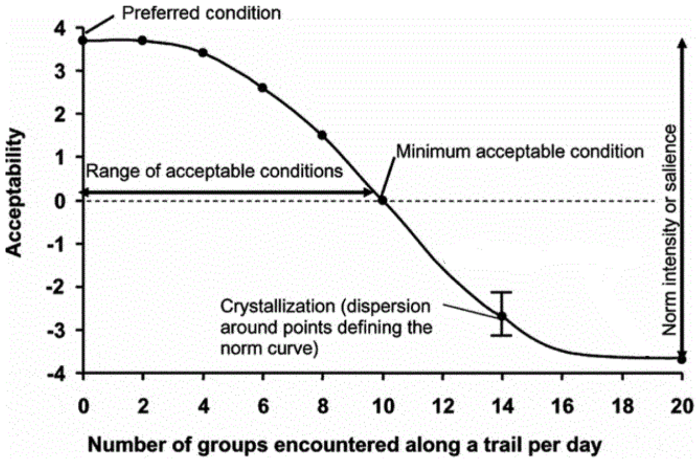


Figure 3.1 Hypothetical social norm curve (Adapted from Manning, 2011, p.138).

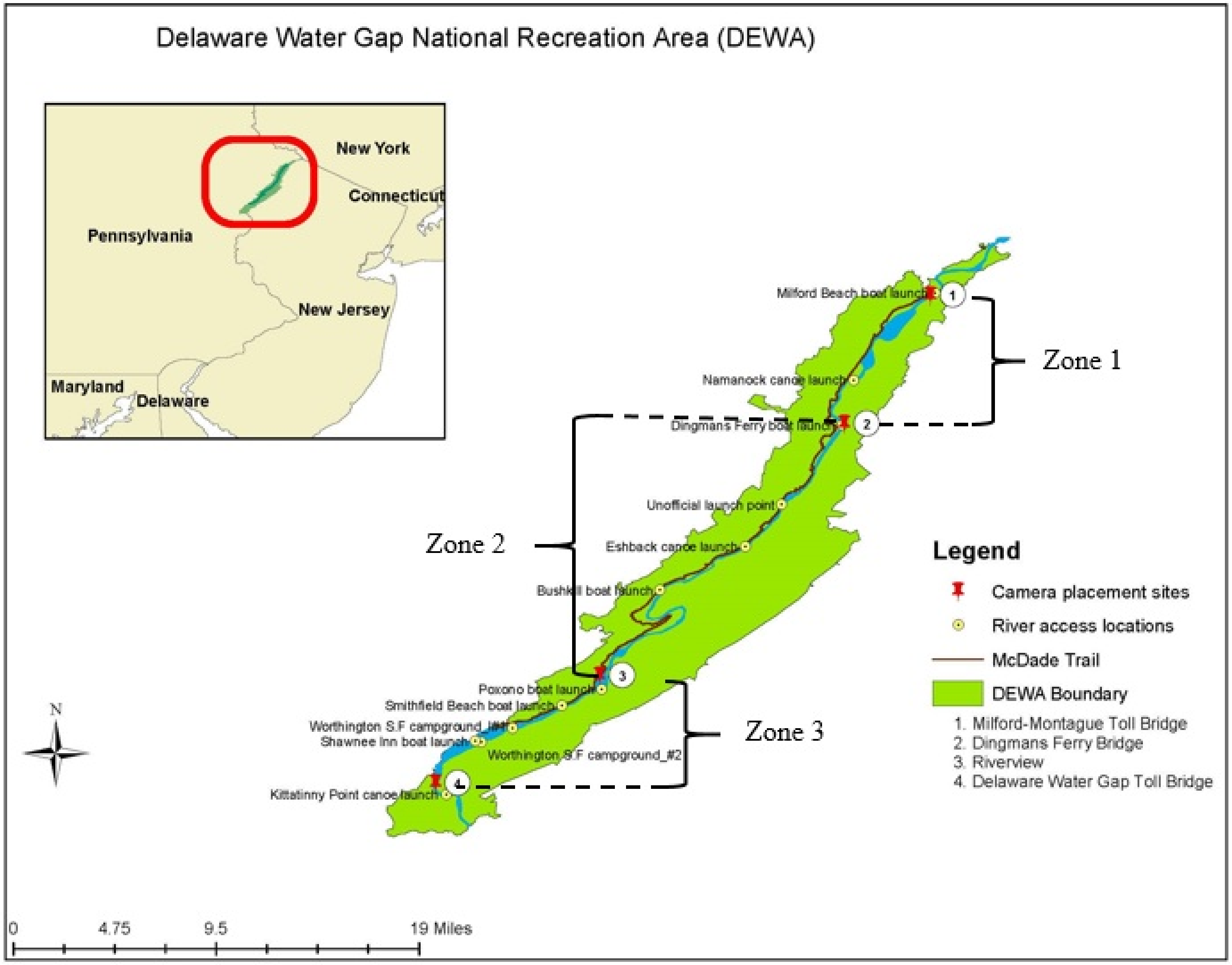


Figure 3.2 Map of Delaware Water Gap National Recreation Area

Photo 1 (zero boats)

Photo 2 (2 non-motorized, 1 motorized)

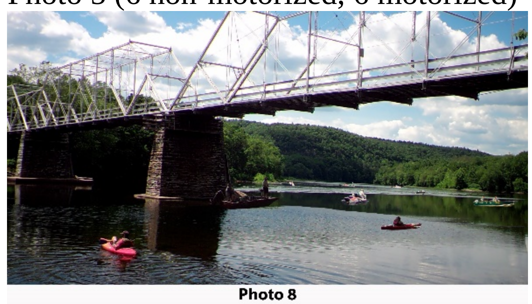
Photo 3 (3 non-motorized, 3 motorized)

Photo 4 (5 non-motorized, 4 motorized)

Photo 5 (6 non-motorized, 6 motorized)

Photo 6 (8 non-motorized, 7 motorized)

Photos 7 (6 non-motorized, 3 motorized)



Photos 8 (3 non-motorized, 6 motorized)

Figure 3.3 Study photos. All images were originally displayed in a large-scale format and in color

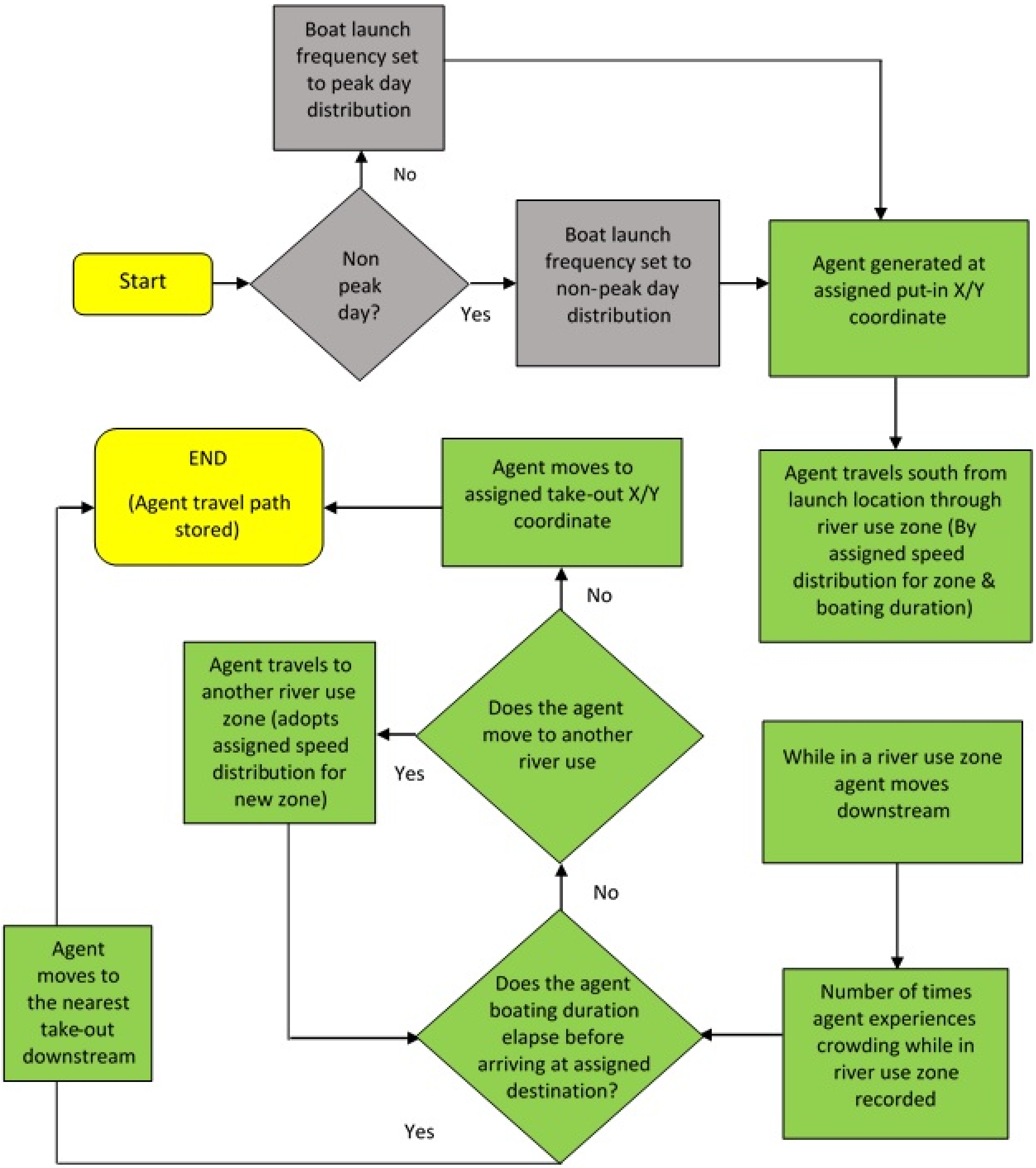


Figure 3.4 Framework for developing agent and the rules for the agents in an ABM.

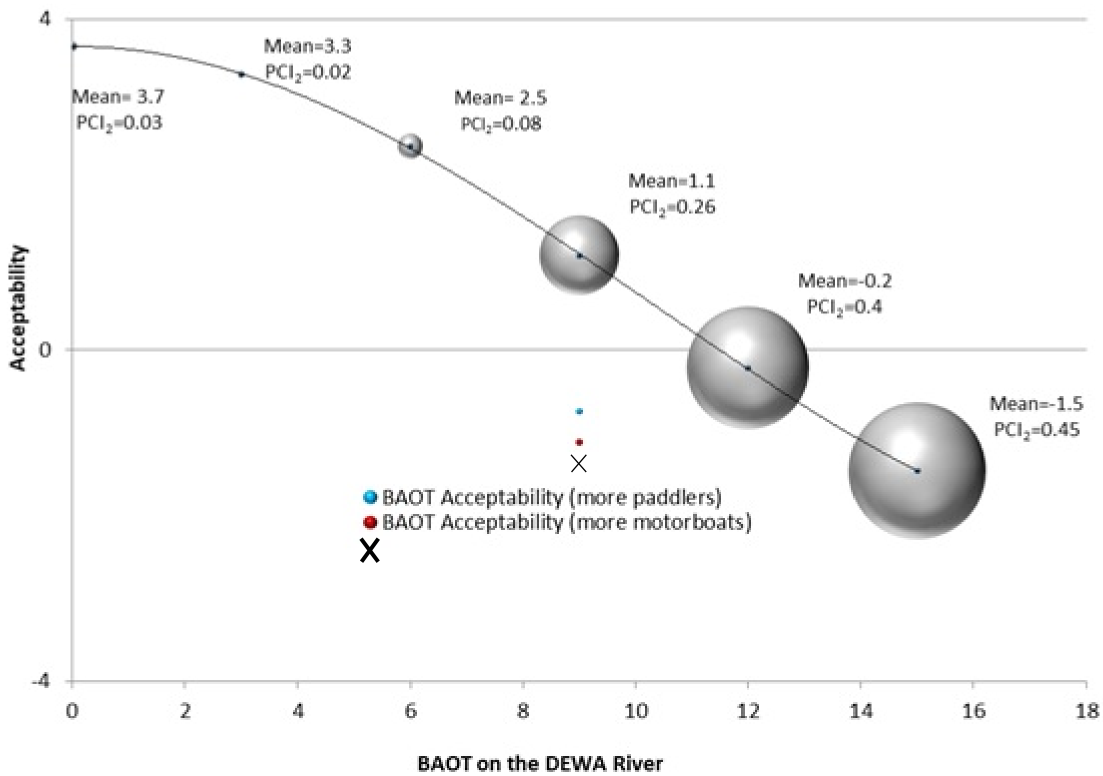


Figure 3.5 Social norm curve for the acceptability of number of BAOT at DEWA. The bubbles represent PCI_2, with smaller bubbles showing more crystallization (agreement). The line that connects the bubbles is the social norm curve.

CHAPTER FOUR

The influence of weather on real-time hourly recreational boating use levels

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Abstract

This paper evaluates the impact of actual weather encountered and streamflow on the level of boat-related arrivals and departures at a section of a Wild and Scenic River in the eastern United States. The data consists of hourly 1) boat counts collected by field cameras set up at one of the study area's river access location, 2) weather data from the nearest hourly-data National Weather Service (NWS) Automated Surface Observing Systems (ASOS) station, and 3) streamflow data from the United States Geological Survey's gauge located on the river. Recreational boating may be weather dependent, and waterways often report higher use levels in the summer. This study determined that prevailing weather conditions did not greatly influence the arrival and departure of non-motorized boaters in the summer. Results using Poisson Regression show weather had limited influence on boating levels. In the study, weather explained close to 2% of the variance for both arrivals and departures. For arrivals, wind speed had the largest effect size followed by precipitation and modified Physiological Equivalent Temperature (mPET) index. Visibility had a small effect size. Also, at above acceptable streamflow, there was a negative and significant relationship between streamflow and boat arrivals (r = - .16, p <.01). These finding can inform management actions to improve visitor access and experiences by providing real-time wind gage information for the Delaware River on the National Park Service website or Hotlines.

Key words: Recreational boating, river, weather, climate, streamflow, camera

Changing climate continues to impact parks and recreation resources. Therefore, understanding environmental influences on outdoor recreational activities is necessary for the sustainable and effective management of protected areas as well as visitor experiences (Kim & Shelby, 2011). Weather and climate are two major factors that influence recreational behavior (Scott & Lemieux, 2010). The National Oceanic and Atmospheric Administration (NOAA) describe weather as the state of the atmosphere at a particular location over the short-term. Therefore, weather is what a visitor gets or experiences at the destination. It can affect recreation activities and transportation choices. For example, a few 'nice' sunny days may draw a large number of people to the beach leading to parking congestions (Sabir, van Ommeren & Rietveld, 2013) , while 'poor' weather may lead to lower levels of use. Climate is often what the visitor expect at the destination (e.g., a hot summer), and it is described as the average long-term pattern of weather in a particular location usually taken over 30 years (http://www.noaa.gov/).

The weather and climate at the destination can be a key attraction or pull factor (Caber & Albayrak, 2016; Hamilton & Lau, 2004; Moreno, 2010). Tourism and recreation pull factors emphasize the appeal of destination attributes and are considered to be external, situational, or cognitive motivations. They typically include a combination of natural features, local culture and leisure infrastructure (Wu & Pearce, 2014; Yoon & Uysal, 2005). Also, outdoor recreation activities typically rely on particular weather and resulting conditions. For example, it may be ideal to go skiing in the Swiss Alps when it freezes (in the winter). This is commonly referred to as weather dependency (Verbos &

Brownlee, 2017). Therefore, weather and climate can influence the timing of travel and choice of destination for outdoor recreation activities (Scott & Lemieux, 2010).

Weather and climate can also be constraints to outdoor recreation. For example, if a destination experiences inclement weather or is too hot, visitors' experiences may be adversely affected, with some substituting outdoor recreation activities for indoor ones. However, weather and climate may also affect participation levels for indoor activities. For example, visitor attendance at the Smithsonian museums fluctuates with seasonal changes. The prevailing temperatures and precipitation significantly influences visitation levels with periods of comfortable weather accounting for more visitors (Karns & Pekarik, 2007).

The relationship between weather, climate, and tourism has been studied for over 40 years (e.g., de Freitas, 2001, 2003; Fisichelli, Schuurman, Monahan & Ziesler, 2015; Mieczkowski, 1985; Perry, 1972; Ploner & Brandenburg, 2003; Rutty & Scott, 2015; Smith 1993). These studies have examined the interaction between weather, climate and tourism in predicting tourism demand. Tourist flows have also been examined in response to climate change concerns and changes in destination attractiveness. Additionally, some studies have developed indices that can be used to derive the levels of thermal comfort or discomfort experienced by tourists (de Freitas, Scott & McBoyle, 2008; Mieczkowski, 1985; Scott, Rutty, Amelung, & Tang, 2016). However, these studies have largely focused on tourism with limited studies examining recreation. It is widely acknowledged that weather and climate affect key aspects of outdoor recreation, but little is known about how outdoor recreationists' process and integrate weather and climate information (Verbos, Altschuler, & Brownlee, 2017).

The role of weather and climate in determining the suitability of a destination for recreation is often assumed to be "self-evident" (de Freitas, 2003, p.45) or intuitively obvious (Brandenburg, Matzarakis & Arnberger, 2007) rather than demonstrated (Machete, Lopes, Gómez-Martín & Fraga, 2014). Understanding the weather and climate conditions that influence destination choice and activity satisfaction is important in the development of products and services for tourism and recreation (De Urioste-Stone, Scaccia & Howe-Poteet, 2015). Weather and climate play an important role in the planning of special events such as the annual Albuquerque International Balloon Fiesta, outdoor music concerts, and sporting events. For example, the 2022 World Cup in Qatar will be held in the winter, rather the summer, for the very first time due to the predicted heat that would occur during June or July.

A better understanding of visitors' responses to various weather and climatic conditions can help recreation managers better manage short-term visitor demand and adapt to long-term climate changes in visitor use patterns (Perkins & Debbage, 2016). Weather and climate thresholds depend on individual value judgements and personal health (Scott et al., 2008), therefore assessing recreationists' perceptions and use levels will inform approaches to visitor management, education and outreach programs.

Studies have typically examined the influence of weather and climate on outdoor recreation activities such as skiing (Dawson & Scott, 2013; Shih, Nicholls, & Holecek, 2009), hiking (Li & Lin, 2012), biking (Böcker, Dijst, & Prillwitz, 2013; Brandenburg et al., 2007) and beach visits (de Freitas, 2015; Sabir et al., 2013). However, there is limited research on recreational boating (RB) despite an estimated 36% of U.S. households participating in it annually (National Marine Manufacturers Association [NMMA], 2017). In contrast, some studies have focused on competitive boating (e.g., at the Olympics) where the influence of weather conditions have been examined on the performance of boaters (e.g., finish times) and also their effect on boating events such as delays or postponement of rowing and sailing events (Diafas, Kaloupsis, Bachev, Dimakopoulou, & Diamanti, 2006; Morris & Phillips, 2009).

Recreational boaters are generally exposed to the elements of weather with minimal protection. Therefore, air temperature, relative humidity, wind speed, precipitation and cloud cover are likely to influence both their participation and satisfaction levels. Additionally, prevalent weather conditions directly influence the water temperature and wave height (Zhang & Wang, 2013). These variables are extremely important for the safety and comfort of boaters. For instance, non-tornadic convective winds account for an estimated 15% of boating fatalities in the U.S. (Black & Ashley, 2010). Therefore, a prerequisite for safe and enjoyable boating involves a better understanding of preferred weather conditions.

Most studies investigating the relationship between weather and climate, and recreational activities have relied on aggregated secondary meteorological and visitation level data (i.e., relating monthly, quarterly or yearly level participation rates to corresponding averages of weather indicators) (Liu, Susilo & Karlström, 2015; Perkins & Debbage, 2016). At a macro level, these studies indicate the influence of weather and climate on seasonal tourist arrivals and the impact it has on the sustainability of a destination. However, at a micro level, the influence of weather on both visitor attendance decisions and how recreational managers and businesses forecast visitor demand is less conspicuous. Yet this is the temporal scale at which recreation decisions are often made.

Also, to estimate the level of use for recreational facilities, recreation managers often rely on the number of visitor arrivals. For departures, most destinations do not report this statistic (Hamilton, Maddison & Tol, 2005). It is typically assumed that the number of arrivals will be the same as departures, hence some destinations fail to record departures. For recreational sites having multiple access points, departures may not necessarily be equal to the number of arrivals. Therefore, policies developed by relying only on arrivals data may be deficient.

The collection of both arrival and departure data may be time consuming and involve additional costs. Therefore, by determining the relationship between weather, visitor arrivals and departures, recreation managers may make informed decisions to either collect both arrival and departure data or opt for one over the other.

Despite weather being known to change quickly (i.e., both temporally and spatially), there is limited research examining how weather influences hourly visitor activity at a particular recreational area (Aylen, Albertson & Cavan, 2014; Becken, 2013). Studies that assess real-time changes in on-site visits (i.e., arrivals and departures) to recreational areas in relation to variations in weather are likely to contribute to the body of knowledge (Verbos et al., 2017). Specifically, the current study addresses the research question: Do hourly weather conditions influence RB use levels?

Based on this research question, the following hypotheses were tested:

1. There is a significant relationship between hourly weather conditions (e.g., wind, temperature, and rain) and real-time boat arrivals.
2. Boat arrivals are a better measure of the influence of hourly weather conditions on boating levels compared to boat departures.

Literature review

A number of key areas within the current literature were reviewed to provide the study context and have been presented under relevant heading to illustrate important knowledge gaps within the current understanding of weather and climate thresholds for outdoor recreation.

The relationship between weather, climate and outdoor recreation

The popularity of nature-based outdoor recreation among people in the U.S. is notable. Over 140 million people, almost half of all Americans, participated in some form of outdoor activities in 2015 (Outdoor Foundation, 2016). Therefore, in order to come up with appropriate resource and visitor management practices such as handling recreational demands or user conflicts, it is important to understand the factors affecting recreation behavior (Manning, 2011). Determinants of recreation behavior may include personal, social, and environmental factors (Mansfield, Ducharme & Koski, 2012). Weather and climate form a significant part of the environmental context in which recreation and nature-based tourism takes place. The interaction between weather, climate, and tourism is considered to be “multifaceted and highly complex” (Scott & Lemieux, 2010, p.147).

Weather and climate influences different subsectors of tourism (e.g., source markets, travel motivations, transport systems), either directly or indirectly. The weather and climate experienced, and recreational opportunities at the place of tourist origin and destination are relevant motivators for tourism (Scott, Hall & Gössling, 2012). Weather and climate may be viewed as enablers or deterrents for visitors seeking to engage in certain tourism or recreational activities at a particular destination (Becken & Wilson, 2013; Hübner & Gössling, 2012). For example, wind can be a major attraction especially for water-based recreation activities such as surfing, kiteboarding, sailboarding, and sailboating. However, for beach users wind speeds in excess of 8 m/s (18 mph) are perceived as unpleasant (Matzarakis, 2014). Activities like walking, hiking, swimming, sunbathing, and cycling have higher participation (i.e., use levels) with increase in temperatures (Wolff & Fitzhugh, 2011).

Technological advances to outdoor equipment and gear make it possible for recreationist to engage in outdoor activities in less than ideal weather conditions. For example, ski operators and resorts use snowmaking machines during winter periods that experience low amounts of snowfall. Additionally, advances in hunting gear create opportunities for recreational hunting during wet or cold periods. However, high amounts of precipitation may negatively affect activities such as hunting. For example, in Netherlands and Germany the number of hunting bags recorded for European hares and rabbits harvested was lower in years with high amounts of precipitation (Rödel & Dekker, 2012).

Relevance of weather and climate information to tourism/outdoor recreation

The tourism industry is to a large extent weather-sensitive and climate-dependent; accurate weather and climate information is invaluable. Inaccurate information or adverse weather warnings may deter visitation and can have far reaching consequences to the tourism industry (Scott, Lemieux & Malone, 2011). In the United Kingdom (UK), after the National Meteorological Service forecast ‘unusually warm, dry weather with heat waves’ in 2009, there was a marked decrease in demand for foreign holidays. However, after a revised forecast, there was a reported 40% increase in travel bookings (Hill, 2009).

Tourists’ decision-making often involves destination and time period choice, and tourists (e.g., domestic and international tourists) often respond differently to weather and climate conditions. For example, in the UK, outbound tourists are more responsive to climate variability of the preceding year, whereas domestic tourists are more responsive to variability within the year of travel (Agnew & Palutikof, 2006). Therefore, climatic information is most applicable for tourism at the planning phase of trips (Scott & Lemieux, 2010). However, for recreationists and day visitors weather information is most useful. This is because plans can be adjusted in the short-term (McEvoy et al., 2006). Studies suggest that encountered weather (Denstadli, Jacobsen, & Lohmann, 2011), coupled with prior and simultaneous engagement with weather information, often resulted in recreation behavioral changes (Becken & Wilson, 2013).

In many destinations, advances in computing and satellite technologies have resulted in weather forecasted with considerable accuracy. Additionally, the development of early warning systems (e.g., real-time smartphone apps) are of significant interest to outdoor recreation. Early warning systems inform people engaged in recreation about potential weather hazards to reduce the safety risks associated with these events. Therefore, effective warnings need to provide timely and accurate forecasts and "nowcasts" (i.e., a forecast for zero to six hours of an occurring event) (World Meteorological Organization [WMO], 2010).

The presentation of weather and climate data should relate to individuals' physiological or psychological needs. According to de Freitas, (2001, p.5) "data should give an impression of the likelihood of occurrence of the climate/weather conditions (events)" rather than just offer averages. Therefore, weather/climate data output should be readily interpreted and understood by the user. The weather/climate data should also be representative of the recreation setting (i.e., the micro climate of a particular area such as mountain peaks or beaches) rather than just the standard climate station data (de Freitas, 2001).

Weather, climate and RB

RB involves the use of watercraft (i.e., motorized and non-motorized) that are operated out on the water for recreation, not for commercial purposes. The United States Coast Guard (USCG, 2012, p.9) identifies recreational boats to include: "outboard, inboard and stern-drive power boats, jet boats, pontoon boats, houseboats, rowboats, canoes, kayaks, personal watercraft (e.g., jet skis), inflatable boats, kiteboards, sailboards, stand-up paddleboards and various types of sail boats." The classification also includes rented boats, with the exception of captained charter or party boats, ferries, cruise ships or toy boats.

Participation in RB in the U.S. steadily increased during the 1960's to the early 1990's, but has since started to level off (Mahoney & Stynes, 1995; USCG, 2014). Even though participation in recreational boating is steady, it is considered to be substantial. RB facilitates other forms of offshore water-based activities such as fishing, swimming, snorkeling and diving. In 2017, the total expenditures on boats, engines, accessories and related costs in the U.S. totaled $37 billion (NMMA, 2018). Therefore, understanding the relationship between weather, climate and RB is important.

Despite recreational boaters typically being exposed to the elements of weather for extended periods, there is limited research on the influence of weather and climate on boaters' satisfaction and participation levels. Weather information and weather warnings are extremely important for the safety and comfort of boaters (Saltzer, 2002). For instance, severe wind (having measured gusts of over 25 meters per second (m/s)) can result in fatalities while engaging in outdoor activities like boating. Such fatalities occur in both offshore waters and inland lakes and rivers when boats are capsized by the waves (Black & Ashley, 2012). Therefore, a prerequisite for safe and enjoyable boating should involve a better understanding of preferred weather conditions.

Research on the relationship between weather, climate and RB will provide insights into boaters' responses to weather and climate variability, therefore exploring their adaptive capacity. A better understanding of recreational boaters' behavior will help recreational managers improve the safety and comfort of boaters. For example, through relevant education and outreach programs, boaters can be informed on how to reduce exposure to changes in weather conditions and undesirable weather at a particular destination.

Three approaches are commonly used to evaluate preferred weather and climatic conditions by tourists (Scott, Gössling & de Freitas, 2008). First, those based on expert consultations and opinions; second, those that measure tourism demand (e.g., visitation levels) and determine its relationship to weather and climate conditions (i.e., *revealed tourism climate preferences*); and finally, those that use questionnaire surveys to establish tourist weather and climate preferences. This study adopts the second of these approaches. Specifically, it examines the relationship between boat launch occupancy levels and weather conditions. Unlike most studies it uses hourly use counts and weather conditions to determine preferences.

Quantification of Weather and Climate for Tourism/Recreation

The relationship between the weather and recreational activities may be a function of on-site atmospheric conditions. The Tourism Climate Index (TCI) developed by Miekzowski (1985) is the most widely known quantification of climate information. TCI has commonly been used to assess the climatic elements most relevant to tourism experiences for general activities such as sightseeing (Perch-Nielsen, Amelung, & Knutti, 2010; Scott & McBoyle, 2001). Studies have critiqued the TCI and highlighted a number of limitations. They include:

"(1) the subjective rating and weighting system of climatic variables; (2) it neglects the possibility of an overriding influence of physical climatic parameters (e.g., rain, wind); (3) the low temporal resolution of climate data (i.e., monthly data) has limited relevance for tourist decision-making; and (4) it neglects the varying climatic requirements of major tourism segments and destination types (i.e., beach, urban, winter sports tourism)." (Scott et al., 2016, p.2)

An alternative index is the Temperature-Humidity index (THI) also referred to as the heat index. In determining THI, the mean of dry bulb temperature (i.e., temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture) and relative humidity are used (Schoen, 2005). For example, if the air temperature is 32 °C (89 °F) and the relative humidity is 60%, the heat index (i.e., how hot it feels) is 37 °C (99 °F). THI was determined by experimentally subjecting a sample of people to varying levels of temperature and humidity and then interviewing them as to the discomfort they experienced (Ruffner & Blair, 1977). According to NOAA people engaged in physical activity should be cautious when the index is above 27 °C (80 °F) (https://www.weather.gov/ama/heatindex). However, THI may be deficient if used alone as it relies on only two variables.

The major facets to consider when investigating the influence of weather and climate on tourism include the physical (e.g., precipitation), the thermal (e.g., air temperature) and the aesthetic (e.g., cloudiness) characteristics (de Freitas, 2017). The thermal comfort of tourists (i.e., air temperature, wind, solar radiation, humidity and metabolic rate) is regarded as the main factor determining the desirability of a location

(Perch-Nielsen et al., 2010). A popular approach to describe the thermal component of climate in relation to outdoor tourism is the Physiologically Equivalent Temperature (PET) (de Freitas, 2001).

The PET provide a more accurate representation of the physiological conditions a person may experience at a destination (Perkins & Debbage, 2016; Ploner & Brandenburg, 2003). PET has been used when considering the energy balance of the human body in an outdoor setting and initially created to characterize and evaluate the human bioclimate in a physiological setting (Höppe 1999). Secondary meteorological parameters such as air temperature, air humidity, wind speed and mean radiant temperature of the surroundings are considered in determining PET categories (Matzarakis, Rutz & Mayer, 2007; Matzarakis, Endler & Nastos, 2014). PET can be calculated using the radiation and energy balance model RayMan (Matzarakis, Rudel, Zygmuntowski, & Koch, 2010). As illustrated in Table 4.1, a PET of approximately 18-23 °C equates to thermal comfort.

(INSERT TABLE 4.1 HERE)

Studies have incorporated PET to investigate the influence of thermal comfort on visitation levels at destinations. For example, a study of Phoenix and Atlanta zoos paired daily visitor attendances at each zoo from 2001 to 2011 with the PET to help measure the thermal conditions most likely experienced by zoo visitors and its influence on attendance. Findings indicated that optimal thermal regimes for peak attendance occurred within “slightly warm” and “warm” PET-based thermal categories. Consequently, zoos may use the “slightly warm” and “warm” thermal categorizations as a preliminary basis for predicting high-volume attendance days (Perkins & Debbage, 2016).

Constraints to using PET include: 1) it is related more closely to air temperature and wind speed, but less sensitive to the changes in humidity (Chen & Matzarakis, 2014), and 2) it fails to consider behavioral adaptation of clothing insulation in response to prevailing environmental air temperature. PET uses a standard clothing insulation (clo = 0.9) for the evaluations of the thermal conditions during summer conditions (Blazejczyk, Epstein, Jendritzky, Staiger, & Tinz, 2012; Chen & Matzarakis, 2017).

A new thermal index, the modified physiological temperature (mPET) has been developed to address some of the weaknesses of the original PET. The mPET has improved the original physiologically equivalent temperature (PET) by enhancing evaluation of the humidity and clothing variability (Chen & Matzarakis, 2017). The mPET uses clothing behaviors study recommendations (e.g., Havenith et al., 2012) to implement an auto changing of clothing insulation based on environmental air temperature conditions to serve as a standard of modern clothing behaviors (Chen & Matzarakis, 2017). This study is the first to apply the mPET within an outdoor recreation context to examine the bioclimatic conditions recreational boaters would experience.

Streamflow

In addition to atmospheric factors the amount of water in a river may have a direct effect on the quality, timing and safety of RB. Streamflow, measured in cubic meters per second (cms), influences opportunities to engage in river-related recreation such as kayaking, whitewater rafting and fishing. Releases from dams and reservoirs often manipulate streamflow. However, free-flowing rivers like the Middle Delaware National Scenic and Recreational River are likely to be affected by the prevailing weather conditions both onsite or through tributaries.

Different flow levels offer varied boating opportunities. The rise in streamflow from low to high often corresponds with the level of difficulty and challenge in boating. Further, optimum flow levels may be site specific and may depend on the type of boating or social value provided (Whittaker & Shelby, 2000). Studies have applied norm-based approaches to define acceptable flow ranges based on boaters' evaluations. For example, Stafford, Fey and Vaske (2017) surveyed commercial and non-commercial boaters in the Cataract Canyon of the Colorado River, Utah. They determined the lowest acceptable flow for the river was 113.27 cms (4000 cfs). Also, flow levels above 1,415.84 cms (50,000 cfs) would lead to a decline in boating experiences, but were within acceptable levels. However, Fey and Stafford (2016) found that the full range of acceptable flows for the San Miguel River Basin, Colorado ranged from 14.16 to 141.58 cms (500 to 5,000 cfs). Additionally, Whittaker & Shelby (2015) reported that the standard flow ranges for whitewater opportunities for all crafts was 56.63 to 283.17 cms (2,000 to 10,000 cfs).

Estimating visitation- arrivals vs. departures

To estimate tourism demand and the level of use for tourist/recreational facilities, tourism and recreation managers typically collect the number of tourist/visitor arrivals. Visitation data can be collected through active (e.g., physical observations and surveys) and passive (e.g., cameras and road-tube counters) methods. Studies have used visitor arrivals data to assess the impact of tourism promotion efforts (Seetanah & Sannassee, 2015), destination web search queries (Liu, Tseng & Tseng, 2018; Rosselló & Waqas, 2016), greenhouse gas emissions between destinations (Gössling, Scott & Hall, 2015), weather (Perkins & Debbage, 2016; Falk, 2014 & 2015) and climate change (Amelung & Nicholls, 2014). Departures are often unreported (Hamilton et al., 2005).

Countries of origin often record departures as the number of tourists leaving their country for other countries. Generally, destinations describe departures as the number of tourist arrivals who are at the end of their stay and are leaving. For example, Chatterji and Sridhar (2005) examined the main causal factors of delay on air transportation. Using data from the National Airspace System (NAS), they estimated that over 60% of aircraft departures are delayed due to weather. For protected area managers, monitoring departures can provide crucial information that can be used to better serve visitors. For example, by determining the time most visitors leave specific sites and their length of stay, managers may develop suitable hours of operation and facilitate making informed decisions on park issues such as implementation of time restrictions to mitigate against recreational conflicts. Additionally, managers may be able to determine which on-site factors influence visitors to not only visit, but stay at a specific site.

With most studies relying on secondary meteorological and high-level arrival aggregate data (i.e., monthly, quarterly or yearly levels) to investigate the relationship between weather and climate, and recreation activities, there is limited research examining how weather influences hourly visitor activity at a particular recreational area (Aylen, Albertson & Cayan, 2014; Hewer & Gough, 2016). Therefore, this study examines the influence of hourly weather conditions on RB-related arrivals and departures at a section of the Middle Delaware River. Findings from the study may have direct implications for adaptive strategies and decisions that recreation managers' will likely face with regards to the potential impacts of climate change on boating in the future.

Methods

Study Area

Delaware Water Gap National Recreation Area (DEWA) extends across a stretch of the Delaware River on the New Jersey (NJ) and Pennsylvania (PA) border in the eastern United States. It contains significant natural, cultural, and recreational resources, including 64 km (~ 40 miles) of the Middle Delaware National Scenic and Recreational River. Mostly due to its proximity to big cities in NJ, PA, and New York, DEWA recorded over 3,400,000 visitors in 2017, many of which congregate at popular recreation sites (NPS, 2018). Visitors are drawn to the area by its unique natural and cultural resources and the recreational opportunities they provide, such as the Delaware River.

DEWA provides opportunities for motorized and non-motorized boating, river angling and river-based camping. DEWA has several river access locations that are both primitive and developed. The estimated distance between Milford Beach, one of the developed boat launch sites located in the northern end of DEWA, and Kittatiny Point at the southern end is approximately 54 river km (34 miles). The river has many quiet pools and a few short riffles making it ideal for beginning paddlers. Therefore, changes in paddling use levels at a broader scale are likely to be reflected at DEWA. The term

‘Milford’ will be used to refer to Milford Beach boat launch, the area of focus in the study.

Boating data

The assessment of boating at Milford was accomplished using counts by a motion sensor field camera placed at the entrance. This non-intrusive method enabled researchers to study the behavior of recreational boaters without inducing changes in their activity. Field cameras are both reliable and field-tested for the purposes of automatically recording recreation use at a site. Specifically, Hallo, Brownlee and Fix (2013) used field cameras for conducting counts of both people and vehicles in parking lots at Pinnacles National Park. Additionally, field camera images have been used to determine the use and capacity of recreation facilities at both the Priest Rapids Hydroelectric Project (PRHP) in Washington State and three Tennessee State Parks (Hallo, Fefer & Riungu, 2017; Hallo, McGuiness, Dudley & Fefer, 2017).

The Moultrie D-555i field camera utilized in the study was relatively inexpensive ($120 each) and allowed high resolution photos (8 MB) to be taken. The camera had both a motion sensor feature and a programmable time-lapse function that allowed photos to be taken at specified intervals and during specified hours. The camera was programmed to take still images when motion was detected. Counts in camera view were recorded between 6 a.m. to 9 p.m.

The field camera was deployed for data collection at Milford between May 20th 2015 and Aug 14th 2015 (87 days). The camera gathered photographic data on the number of vehicles, trailers and watercrafts arriving and departing Milford. *Timelapse2* image analysis software and trained research assistants were used to count these variables to establish the levels of boat-related arrivals and departures. Other studies have typically applied a qualitative visual count method, which is based on the ability of an observer to identify patterns based on the dynamic inspection of an image bank (Gómez-Martín & Martínez-Ibarra, 2012; Martínez-Ibarra, 2011). Therefore, using *Timelapse2* provides a more precise and objective approach.

Weather and streamflow data

Weather data for Milford was obtained from the nearest hourly-data National Weather Service (NWS) Automated Surface Observing Systems (ASOS) station. The Sussex Airport (Sussex, NJ) weather station, approximately 19 km (12 miles) away from Milford, was used as a reasonable proxy for weather experienced at the northern end of DEWA. Further, streamflow data for the river was obtained from the United States Geological Survey's gage located at the study site, the Montague, NJ gage. The weather and streamflow data were converted from an imperial to a metric system of measurement.

Based on three key tourism climatic facets, namely, the *thermal*, *physical* and *aesthetic* conditions (de Freitas, 2017), individual weather variables were examined. In considering the *thermal facet* (i.e., thermal comfort), the RayMan Pro software was used to calculate the hourly mPET values. The input variables include: 1) topographical variables, including latitude, longitude and altitude of Milford, 2) meteorological variables such as temperature (° C), relative humidity (%), and wind speed (m/s), and 3) physiological variables such as sex, age, weight, height, and the levels of thermal stress related to engaged activity and clothing insulation expressed in Watts and clo respectively (Roshan, Yousefi, Kovács & Matzarakis, 2016).

Studies have often used ‘standardized’ measures for sex, age, height and weight to calculate PET and mPET of the study population (Chen & Matzarakis, 2017; Lai et al., 2016). The default personal values of the RayMan program include: male, 35 year old, a height of 1.75m, and a body weight of 75kg. To improve on the accuracy of results, this study used a more representative estimate of input measures. In 2011, an estimated 55.7% of U.S. boating participants were male (USCG, 2012). Also, the Recreational Boating and Fishing Foundation and the Outdoor Foundation (2017) reported that 64.8% of freshwater fishing participants, over 6 years old, were male. Over half of these participants fish using boats. Further, according to NMMA (2008), the median age of boat owners in the U.S. was 45-49 years. For this age group, the average height and weight was 1.76 m and 91.5 kg, respectively (Fryar, Gu, Ogden & Flegal, 2016). Therefore, the personal values specified in the RayMan program include: male, 47 years old, a height of 1.76 m, and a body weight of 91.5 kg.

The *physical facet* recognizes the existence of specific meteorological elements (e.g., precipitation and wind) that directly or indirectly affect participant satisfaction other than in a thermal sense. A classification of two precipitation categories – with and without precipitation – was used in this analysis. An hour with precipitation was defined as any hour with at least 0.25 mm of rainfall. Wind speed was used in the analyses as a continuous variable. The *aesthetic facet* relate to the weather factors associated with the prevailing synoptic condition. The study used visibility, reported up to a maximum of 16,093.4 m (i.e., 10 miles), to measure the aesthetic facet of DEWA.

Statistical Analyses

Analyses of the relationship between meteorological factors and boating were conducted using Poisson regression. The frequency of boat counts for both arrivals and departures were not normally distributed. It demonstrated a highly positively skewed distribution, with low values the most frequent and high values were not often observed (i.e., a Poisson distribution). These type of data are quantified with a count variable that can take on discrete non-negative whole number values. Therefore, modeling a dependent variable following a Poisson distribution using standard ordinary least squares (OLS) regression may produce biased results (Coxe, West & Aiken, 2009). The rates predicted by OLS regression typically do not account for the large number of low or zero scores in the count outcome (Cohen, Cohen, West, & Aiken, 2003). Also, it may not handle the systematic change in the spread of the residuals over the range of measured values. This violates the assumption of OLS regression that all residuals are drawn from a population that has a constant variance; homoscedasticity (Gardner, Mulvey & Shaw, 1995).

Poisson regression uses a maximum likelihood approach to determine the least possible deviation between the observed and predicted values. This departs from OLS regression where the best-fitting line is determined by minimizing the squared residuals (Verma, 2013). In maximum likelihood, the smallest possible deviations or best fit are denoted as -2 log likelihood (-2LL). This is the error remaining after including all predictors in a Poisson model. It is analogous to the sum of squares total in OLS regression. Also, this deviance statistic follows the chi-square distribution. (Cohen et al., 2003).

The measure of efficiency in assessing the suitability of the model in Poisson regression is Hosmer and Lemeshow's measure — R^2_L (Verma, 2013). It is an analogous to R^2 in OLS regression. Therefore, R^2_L is "the proportional reduction in the absolute value of the log-likelihood measure, and as such it is a measure of how much the badness of fit improves as a result of the inclusion of the predictor variables. It can vary between 0 (indicating that the predictors are useless at predicting the outcome variable) and 1 (indicating that the model predicts the outcome variable perfectly)" (Field, 2013, p.1216). The R^2_L value refers to the difference between the total deviance and the deviance of the studied model divided by the total deviance.

In Poisson, the test for model effects provides unique reduction in error due to each predictor in the full model. Therefore, the percent unique reduction in error, or misfit due to each predictor (Sr^2_L) is calculated by dividing the chi-square change for each predictor by the -2 log likelihood (-2LL) of the intercept/null model. Sr^2_L is analogous to the semi-partial r^2 in OLS regression.

To test the hypothesis that meteorological conditions influence boating levels, hourly boat-related arrivals were regressed by controlling for several non-weather variables. Consistent with Cohen et al. (2003), the predictor variables were first mean centered before hypothesis testing. Also, squared terms were created from the centered variables.

First, temporal variables were included in the model. Hour and day of the week may have a significant effect on boating. Protected areas often experience higher levels of use at certain hours and on weekends and federal holidays. This may be attributed to most people being away from their school and workplace. Additionally, to account for school or work-related vacations (i.e., institutional seasonality), month was included in the model. Second, streamflow, measured in cubic meters per second (cms), was included in the model. Streamflow may be affected by prevailing weather conditions away from the study site. It may affect the floatability, rate of travel and safety of recreational boating. Consequently, streamflow rate may compromise the quality of a recreational boating experience. Also, weather variables (i.e., wind, precipitation, and mPET) were included in the model. Last, visibility was included as an onsite weather-influenced variable.

Results

Boater profile

The study focused on estimating hourly boating levels specific to Milford. Data were grouped into non-peak and peak days representing weekday and weekend/holiday, respectively. The term ‘boat’ was used in the study to represent all types of watercraft. A sample of 1,071 and 1,076 records for hourly boat arrivals and departures at Milford, respectively, were used in the study.

Milford is a multi-use area that offers different recreational opportunities. For example, it hosts one of the trailheads to the McDade Trail which extends most the length of DEWA. Therefore, camera counts were limited to vehicles transporting boats using roof racks, truck beds, or trailers. Vehicles towing trailers, but without boats onboard were also included. These vehicles may be directly associated with a boat put-in or take-out. The total counts for vehicles, trailers and boats was 11,137. Boats represented 58.9% of the total counts at Milford, with the remainder being vehicles and trailers. The estimated number of boats per vehicle at Milford was 1.4. Additionally, a large proportion of the boats were non-motorized (93.4%).

The average number of non-motorized boat arrivals was 31.8 and 90.2 for non-peak days and peak days, respectively. For departures, there were 24.4 and 54.1 non-motorized boats on average for non-peak days and peak days, respectively. Additionally, there were 2.6 and 5.5 motorized boat arrivals on average during non-peak days and peak days, respectively. A similar average number of motorized boat departures, 2.5 and 5.2, was determined for non-peak days and peak days, respectively. This is because motorized boaters often use the same put-in and take-out location unlike non-motorized boaters.

For non-peak days, the average number of non-motorized boats per hour was 2.1 (SD=5) and 1.6 (SD=4.1) for arrivals and departures, respectively. Overall, boat arrivals rapidly increased from 8 a.m., and peaked between at 11 a.m. There was steady decline in traffic from midday up to 6 p.m. (see Figure 4.1-A). In contrast, there were little or no departures recorded between 6 to 8 a.m. The level of arrivals was relatively higher compared to departures until late afternoon (3 p.m.). The distribution of motorized boats, on non-peak days, for arrivals was relatively constant between 6 a.m. to 10 a.m. Unlike non-motorized boats, motor boats were recorded leaving Milford in the early morning (see Figure 4.2-A). Decreasing levels of arrivals for motorized boats were observed after

10 a.m., until 2 p.m. when it was at its lowest. Also, departures were higher compared to arrivals during this period. There was a second rise in arrivals and departures at 3 p.m. to 5 p.m. and the highest count for motorized boats was recorded at 5p.m.

For peak days, the average number of non-motorized boats per hour was 5.7 (SD=8.3) and 3.4 (SD=5.1) for arrivals and departures, respectively. Boat arrivals rapidly increased from 8 a.m., and peaked between 10 a.m. to 12 a.m. There was steady decline in arrivals from midday up to 6 p.m. (see Figure 4.1-B). A similar pattern of departures for non-peak days described above was observed for departures on peak days. As illustrated in Figure 4.2-B, there was a rise in the arrival of motorized boats between 6 and 7 a.m. Then a steady decline in arrivals up to 11 a.m. was recorded. There was an increase in arrivals from midday to 1 p.m. coupled with a rapid rise in departures up to 3 p.m. There was a third rise in arrivals and departures at 3 p.m. to 4 p.m. and the highest count for motorized boats was recorded at 4 p.m.

(INSERT FIGURE 4.1& 4.2)

Hypothesis Testing

H1: There is a significant relationship between hourly weather and boat arrivals.

The predictor variables for the regression model included 1) temporal variables like the hour of the day, day of the week, and month, 2) weather variables such as wind, precipitation, and mPET, and 3) weather-influenced variables like visibility and streamflow. The relation of the predictor variables to the number of boat arrivals was studied via the linear term applied in the Poisson models. Poisson regression allows transformations of the predicted outcome, which can linearize a potentially nonlinear relationship between the dependent variable and the predictors. (Coxe, West, & Aiken, 2009). The boat counts, the rate ratios and their significance, and the percent reduction in the misfit of the model (indexed by the R^2_L) were computed.

For boat arrivals, all variables were significant at $p<.05$ except for the interaction between hour and day of the week (see Table 4.2). The percent reduction in error, or misfit due to the predictors in the model was .47 (R^2_L). Further, to determine the significant main non-linear effect for each variable, the study examined the change in boat arrivals at three distinct intervals. These intervals were defined as the lowest, moderate and highest values recorded for each variable in the study.

For example, to determine the significant main non-linear effect for hour of day, the study examined the change in boat arrivals at different time intervals: 6 a.m. to 7am, 1 p.m. to 2 p.m., and 8 p.m. to 9 p.m. (early morning, afternoon and late night values). The number of boat arrivals increases by 0.1 from 6 a.m. to 7 a.m. The predicted number of boat arrivals remains unchanged when the time changes from 1 p.m. to 2 p.m. However, the predicted number of boat arrivals when the time changes from 8 p.m. to 9 p.m. decreases by 0.1 (see Figure 4.3).

(INSERT TABLE 4.2 & FIGURE 4.3 HERE)

In determining the main significant non-linear effect for day of week, the study examined the change in number of arrivals from non-peak to peak days. The predicted number of hourly arrivals when day of the week changes from non-peak day to peak day increases by 1.1. Additionally, during summer the predicted number of hourly arrivals when months change from May to June, June to July, and July to August increases by 0.2, 0.3 and 0.5, respectively.

By examining the weather variables specified in the model, when wind speed changes from 0 to 1 m/s, 4 to 5 m/s and 7 to 8 m/s (low, moderate and high wind speeds) it results in a decrease of predicted number of hourly arrivals by 0.27, 0.1, and 0.05, respectively (see Figure 4.4). The main significant non-linear effect for precipitation on number of arrivals was determined by examining events without precipitation and those with precipitation. The predicted number of hourly arrivals decreased by 0.4 when weather changes from no precipitation to precipitation. Also, the change in the predicted number of hourly arrivals would increase by 0.04, 0.026 and 0.02 when mPET changes from 11.3° to 12.3° (low), 27.8° to 28.8° (moderate), and 35.8° to 36.8° (high), respectively (see Figure 4.5). Finally, in determining the main significant non-linear for visibility, the study examined periods of low, average and high visibility. As illustrated in Figure 3.6, the predicted number of hourly arrivals when visibility changes from 482.8 m to 1,287.47 m (low visibility), 7,242.05 m to 8,046.72 m (moderate visibility) and 15,288.67 m to 16,093.4 m (high visibility) decreases by 0.01, 0.01 and 0.02, respectively.

(INSERT FIGURE 4.4, 4.5 & 4.6 HERE)

In determining the main significant effect for streamflow, the study examined the change in number of boat arrivals using three representative streamflow values; 45.87 to 55.87 cms (low), 260 to 270 cms (moderate), and 522.36 to 532.36 cms (high). The predicted number of hourly boat arrivals decreases by 0.09, 0.06 and 0.04 respectively (see Figure 4.7).

The hourly flow in the study period of DEWA's section of the Delaware River ranged from 45 to 532 cms (1,620 to 18,800cfs). There was no significant relationship between boat arrivals and streamflow levels that ranged from 45 to 142 cms (1,620 to 5,000 cfs). However, at levels beyond 142 cms (5000+ cfs), there was a negative and significant relationship between streamflow and boat arrivals (r = - .16, p <.01).

(INSERT FIGURE 4.7 HERE)

H2: Boat arrivals are a better measure of the influence of meteorological conditions on boating levels compared to boat departures.

To test the hypothesis that hourly boat arrivals are a better measure of the influence of meteorological conditions on boating levels, a Poisson regression model was specified using the variables identified above. However, the dependent variable was set to hourly boat-related departures. The results of the two separate Poisson regressions were then compared.

For boat arrivals, the non-linear term Hour ($Hour^2$) term had the largest effect size, χ^2 (1, N= 1,072) = 0.191, p<.05. Also, it was negatively and significantly related to arrivals (*B* = -.922, *p* < .05). These results indicate a curvilinear relationship between arrivals and hour of day. As illustrated by Figure 4.3, at early hours of day, boat-related arrivals increased as the hour increased. The rate of arrivals began to decrease as hour approached midday and then arrivals decreased at later hours of day.

Among the weather variables, wind and precipitation had the largest unique effect sizes, χ^2 (1, N= 1,072) = 0.008, p<.05 and χ^2 (1, N= 1,072) = 0.006, p<.05, respectively. Streamflow and visibility had small effect sizes in the model, χ^2 (1, N= 1,072) = 0.001, p<.05 and χ^2 (1, N= 1,072) = 0.001, p<.05, respectively (see Table 4.2).

For boat departures, all variables were significant at p<.05 except for mPET and the interaction between hour and day of the week (see Table 4.3). The percent reduction in error, or misfit due to the predictors in the model was .396 (R^2_L). This was lower than the model that specified arrivals as the dependent variable (.47). The non-linear term $Hour^2$ had the largest effect size, χ^2 (1, N=1076) =0.207, p<.05. Also, it was negatively and significantly related to departures (*B* = -.081, *p* < .05). Therefore, holding other predictors at the mean, for every above-average increase in hour, the number of boats departing would decrease 0.081 times. In contrast, for every above-average increase in hour, the number of boats arriving would decrease 0.922 times. Therefore, departures are less sensitive to hour of day compared to arrivals.

As illustrated in Table 4.3, precipitation and visibility had similar effect sizes, χ^2 (1, N=1076) =0.004, p<.05. Wind had the smallest effect size amongst weather variables specified in the departure model χ^2 (1, N=1076) =0.003, p<.05. With the exception of visibility, these effect sizes were lower compared to the ones specified in the arrival model.

Discussion

Despite weather and climate affecting key aspects of outdoor recreation, little is known about how outdoor recreationists' process and integrate weather information (Verbos et al., 2017). Specifically, RB has received little attention from scholars. In this study, boat arrivals and departures were regressed with temporal variables (e.g., hour of day), streamflow and meteorological conditions. The predictor variables explained 47% and 39.6% of the variance in the model for hourly arrivals and departures, respectively. Temporal variables explained the highest model variance for arrivals (45.2%) compared to departures (38.1%). This may indicate that temporal variables are far more important than weather in planning RB. Specifically, boaters who use liveries and outfitters may need to book in advance of visiting boating locations. Also, if local public transport is available, boaters need to be familiar with the hours and schedule of operation. Non-motorized boaters that launch at Milford often use a free public shuttle to get back to Milford, where they parked.

Boaters are often exposed to the elements of weather with minimal protection. High wind speed and precipitation events might negatively influence boating participation and satisfaction levels. However, at DEWA, weather had limited influence on boating levels. Weather explained less than 2% of the variance for both arrivals and departures. This was consistent with Gómez's (2005) assertion that if the day-to-day weather variation is not too extreme, little effect on overall visitation are expected. Yet, with the exception of mPET for departures, weather variables had a significant relationship with boating. For arrivals, wind speed had the largest effect size followed by precipitation and mPET. Visibility had a small effect size. This was contrary to Hewer and Gough's (2016) study that reported temperature was the most influential weather variable in relation to zoo visits, followed by precipitation and, then, wind speed.

Generally, seasonal fluctuations in temperature are thought to affect visitation levels to protected areas. However, the impact of mPET on boating levels at DEWA was minimal. This may be due to little variation in temperature observed in the summer (Scott et al., 2007). A positive non-linear relationship was observed between boat arrivals and changes in mPET until a certain threshold, after which the rate of arrival decreases as mPET rises (see Figure 4.5). In the study the highest calculated mPET was 36.8°. Matzarakis et al., (2010) report that measures above 41° are perceived by people to be very hot and a source of extreme heat stress. Therefore, it is likely that boat arrivals would drastically decrease as mPET approaches and exceeds this level. Similarly, Falk (2014) reported an inverted u-shaped relationship between visitor overnight stays and temperature changes in peak summer periods (i.e., 1960-2012).

Visibility is a measure of the distance at which an object or light can be clearly discerned. Precipitation, fog, mist and haze can inhibit visibility. Unlike other forms of outdoor recreation such as cycling and off-road driving, boating may take place in both low and high visibility. For example, boaters often fish early in the morning and late in the evening. Second, waterways are more expansive than trails or roads, hence has the potential of greatly reducing the risk of collisions. Also, at DEWA the majority of boats were non-motorized. Therefore, the average boat speed is relatively slow, allowing boaters to operate in low visibility. Lastly, the minimum visibility recorded in the study was 482 m. Therefore, with the winding nature of DEWA boaters are capable of seeing their immediate surroundings. The study found a weak negative non-linear relationship between visibility, and boat arrivals and departures. This may be as a result of other variables specified in the model. For example, visibility may be influenced by the time of day and precipitation. However, the influence of visibility on boat arrivals and departures was minimal.

Boating is streamflow-dependent and the quality of boating experiences is often directly affected by floatability, rapids, rate of travel and safety (Whittaker & Shelby, 2002). Dams are commonly used to manipulate stream flows. Consequently, flow management has become one of the most important issues on the river conservation agenda (Whittaker & Shelby, 2002). However, due to the Wild and Scenic River designation of the study area, streamflow was free of impoundments. Streamflow was included in the full regression model and it explained only 0.03% of the variance for both arrivals and departures at Milford. Flows above 142 cms would result in decreasing levels of arrivals because flows may be considered too high to meet preferred boating experiences.

Conclusions

Even as climate and weather studies have largely focused on tourism, research has shown recreational activities such as hunting, cycling, golfing, skiing, scenic flights, swimming, and visits to zoos are particularly weather sensitive and weather dependent. However, in the summer, the peak period for boating, the impact of weather on RB arrivals and departures may be minimal. Among the different facets of weather (de Freitas, 2017), the physical facet was the most influential component for boaters at DEWA, followed by the thermal and aesthetic facets.

It is widely accepted that one of the motivations for travel to holiday destinations is climate and the prevailing meteorological conditions (Becken & Wilson, 2013; Falk, 2014; Scott et al., 2016). However, some studies indicate that the relationship between weather and tourism demand may be weak or non-existent. For example, in examining the impact of climate change on nature-based tourism in the Canadian Rocky Mountains for peak summer months, Scott, Jones & Konopek (2007) regressed temperature and visitation data for the years 1996-2003. They found a weak relationship ($r^2 = 0.01$), indicating that changes in temperature are projected to have minimal impact on visitation. In China, Liu et al., (2018) concluded that precipitation and cloud cover do not impact tourist arrivals to cultural destinations that have natural resources. Also, McKercher, Shoval, Park & Kahani (2015) reported that actual weather conditions encountered in urban destinations have minimal effect on visitor behavior. This may be because the typical length of stay of visitors was short and fixed. Shoval and Raveh (2004) suggest tourists on limited time budgets often set priorities prior to arrival, and rarely change plans once in the destination.

Similarly to these tourism studies, timing may be the most important factor for RB. Specifically in peak use seasons (summer), the use of available leisure time may be a priority to boaters. It is common for people to be away from their workplace or school thereby visiting sites that offer boating opportunities. In contrast, weather may be a secondary concern. In this study boaters were found to be resilient, as actual weather did not greatly affect real-time boat arrival and departure behavior. This may be due to a number of reasons. First, often paddlers go on pre-booked trips. Therefore, boaters may opt to go on the river in less than ideal, but not severe conditions instead of cancelling the trip. By examining non-guided trips the predictability of weather changes on boating levels may be increased. Second, the current study examined boating during the summer. Examining the influence of weather on boating over a whole year, including winter seasons, may allow for different conclusions to be drawn. However, recreational areas such as DEWA experience concentrated use. Therefore, to understand boater experiences during such periods often coincides with peak use seasons. Lastly, it is possible that boaters may access weather information prior to visiting the site. However, there are limited studies that have examined the influence of real-time weather changes in visitors' behavior.

Managing visitor use and experiences are considered as core elements of protected area administration. High quality visitor experiences are not only a legislative mandate for DEWA, but they are essential to ensuring public support and stewardship of the park, and for continued visitation to a region that has a large portion of the local economy rooted in nature-based tourism (Hallo et al., 2017). Therefore, this study reinforces the need for managers to continually provide visitors with adequate weather information that could influence the planning and execution of their trips. For example, the current study identified that wind most significantly affects boating arrivals, followed by precipitation and mPET. River conditions and recommendations for the Delaware River are posted on the NPS website allowing boaters to access up-to-date water levels (streamflow) and temperature readings. However, wind gage measures are not provided. Wind information is necessary to not only ensure boaters make informed decisions prior to visiting a site, but also to be aware of onsite conditions. Additionally, the fact that visitor use levels are not greatly affected by weather at DEWA suggest that staffing levels and programs should also not be altered due to weather.

Future research should consider socio-psychological factors and their influence on boating (Mehmetoglu, 2011). Besides weather and time, boater destination choices may be ‘pulled’ by other destination attributes or ‘pushed’ by multiple socio-psychological factors such as the presence of children on a boating trip. Consequently, future research may consider collecting boaters’ perceptions of destination choice through interviews or conducting surveys. In addition, a similar study should be conducted on open lakes, reservoirs and coastlines to examine if the influence of weather varies across different waterways. Perceptions of crowding may also explain use levels for a waterbody. Future studies needs to examine boaters’ perceptions of crowding and how it affects their experiences and safety, and how boaters distribute themselves on waterways and how this may influence perceived crowding and safety.

There may be key weather thresholds which are required before a majority of people are willing to participate in certain activities like boating. Understanding how weather influences visitor flows (e.g., travel patterns) and resource flows (e.g., streamflow) is key to understanding how visitors engage, utilize, and impact resources within public spaces. This study has started down this path. By examining the influence of weather on real-time arrivals and departures, this research provides a baseline study of recreation climatology specifically for RB during peak use periods. With enhanced information about the influence of weather on outdoor recreation behavior, managers should be able to increase visitor awareness, enhance visitors' experience, and improve safety guidelines as environmental conditions change.

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Table 4.1 Levels of physiologically equivalent temperature (PET) in °C for different levels of thermal perception by human beings (Matzarakis & Mayer, 1996; Matzarakis et al., 2010).

PET	Thermal perception	Level of thermal stress
<4	Very cold	Extreme cold stress
4-8	Cold	Great cold stress
8-13	Cool	Moderate cold stress
13-18	Slightly cold	Slightly cold stress
18-23	Comfortable	No thermal stress
23-29	Slightly warm	Slight heat stress
29-35	Warm	Moderate heat stress
35-41	Hot	Great heat stress
>41	Very hot	Extreme heat stress

Table 4.2 Poisson regression results for arrivals of non-motorized boats

					95% CI for boating		
Predictor	*B*	SE *B*	$\Delta\chi^2_{removal}$	Quadratic slope of predicted counts for boat arrivals	Lower	Upper	Sr^2_L
Constant	1.547	.0322	--	--	--	--	
$Hour^2$	-.082*	.0025	-2026.13*	.921	.916	.925	0.191
Hour	-.241*	.0133	-426.001*	.786	.765	.807	0.040
Day of week	1.030*	.0458	-510.154*	2.802	2.562	3.065	0.048
Month	.387*	.0187	-445.65*	1.472	1.419	1.527	0.042
$Hour^2$ * Day of week	-.005	.0033	-2.202	.995	.989	1.002	0.000
Wind (m/s)	-.244*	.0264	-86.581*	.784	.744	.825	0.008
Precipitation (mm)	-.676*	.0943	-61.272*	.509	.421	.609	0.006
mPET (C^o)	.032*	.0075	-17.732*	.969	.954	.983	0.002
Visibility (m)	-1.41E-05*	5.295E-06	-6.884*	1.000	1.000	1.000	0.001
Streamflow (cms)	-.002*	.0006	-9.417*	.998	.997	.999	0.001

Note **p* < .05, Model χ^2 = 4,972.562, df =10, n = 1072, R^2_L = 0.47. Initial -2 Log Likelihood (-2LL) = 10,579.92, Model with all predictors -2 LL = 5,607.357. Weather variables arranged based on unique effect size

Table 4.3 Poisson regression results for departures of non-motorized boats

Predictor	B	SE B	$\Delta\chi^2_{removal}$	Quadratic slope of predicted counts for boat departures	95% CI for boating Lower	95% CI for boating Upper	Sr^2_L
Constant	1.325	.0374	--	--	--	--	
$Hour^2$	-.081*	.0028	1622.267*	.922	.917	.927	0.207
Hour	-.121*	.0133	91.027*	.885	.862	.908	0.012
Month	.502*	.0237	488.878*	1.652	1.577	1.730	0.062
Day of week	.781*	.0542	205.817*	2.184	1.963	2.428	0.026
$Hour^2$ * Day of week	-.004	.0046	.715	.996	.987	1.005	0.000
Precipitation (mm)	-.621*	.1124	36.201*	.538	.429	.666	0.004
Visibility (m)	-3.864E-05*	6.335E-06	34.452*	1.000	1.000	1.000	0.004
Wind (m/s)	-.136*	.0300	20.576*	.873	.823	.926	0.003
Streamflow (cms)	-.003*	.0007	17.639*	.997	.996	.999	0.002
mPET (C^o)	.005	.0091	.344	1.005	.988	1.023	0.000

Note *p < .05, Model χ^2 = 3,131.45, df =10, n = 1076, R^2_L = 0.396. Initial -2 Log Likelihood (-2LL) = 7,906.363, Model with all predictors -2 LL = 4,774.734. Weather variables arranged based on unique effect size

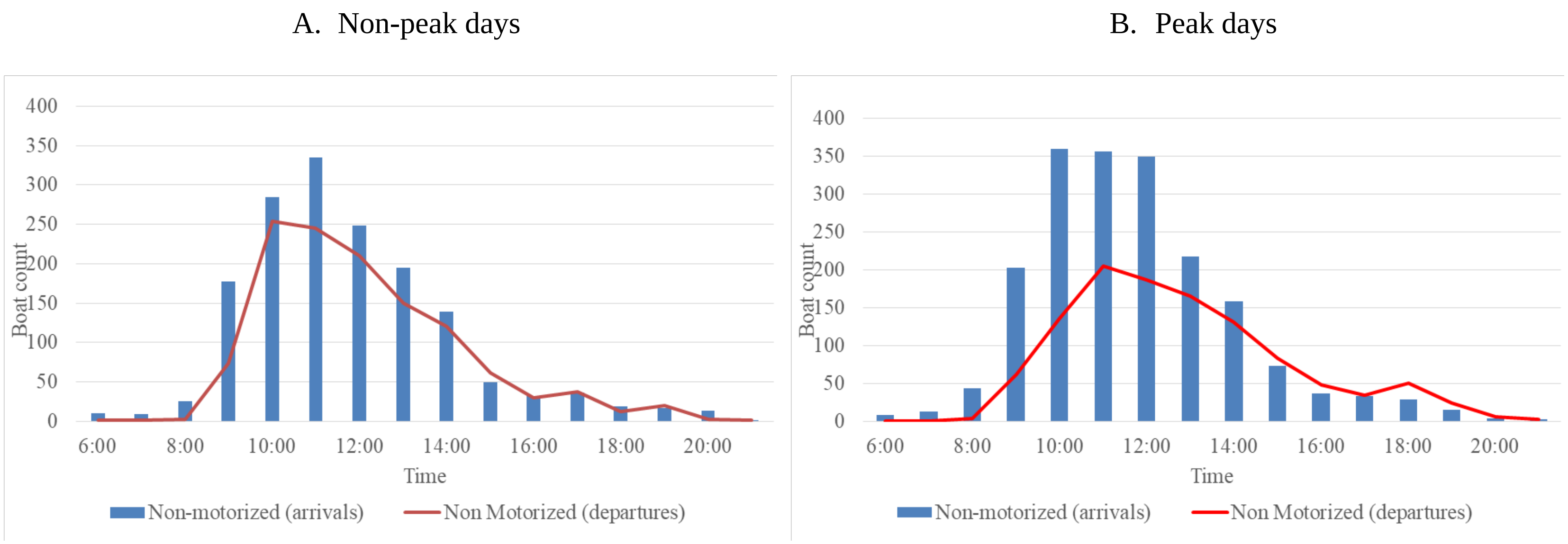

Figure 4.1 Hourly distribution of non-motorized boats during non-peak and peak days

A. Non-peak days

B. Peak days

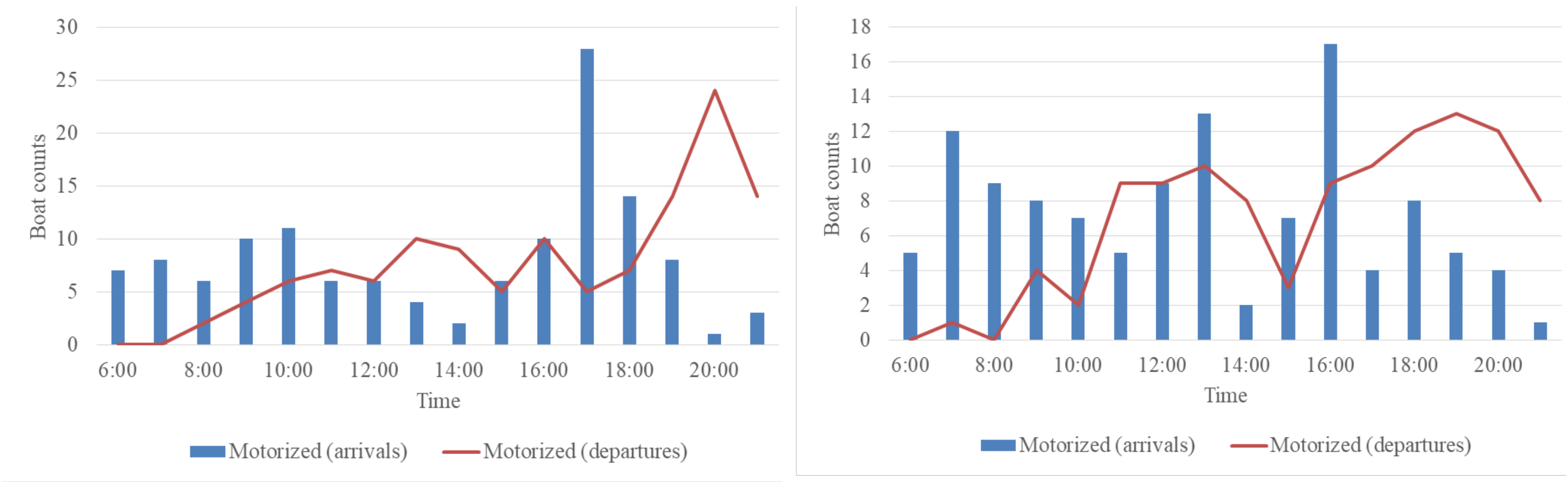

Figure 4.2 Hourly distribution of motorized boats during non-peak and peak days

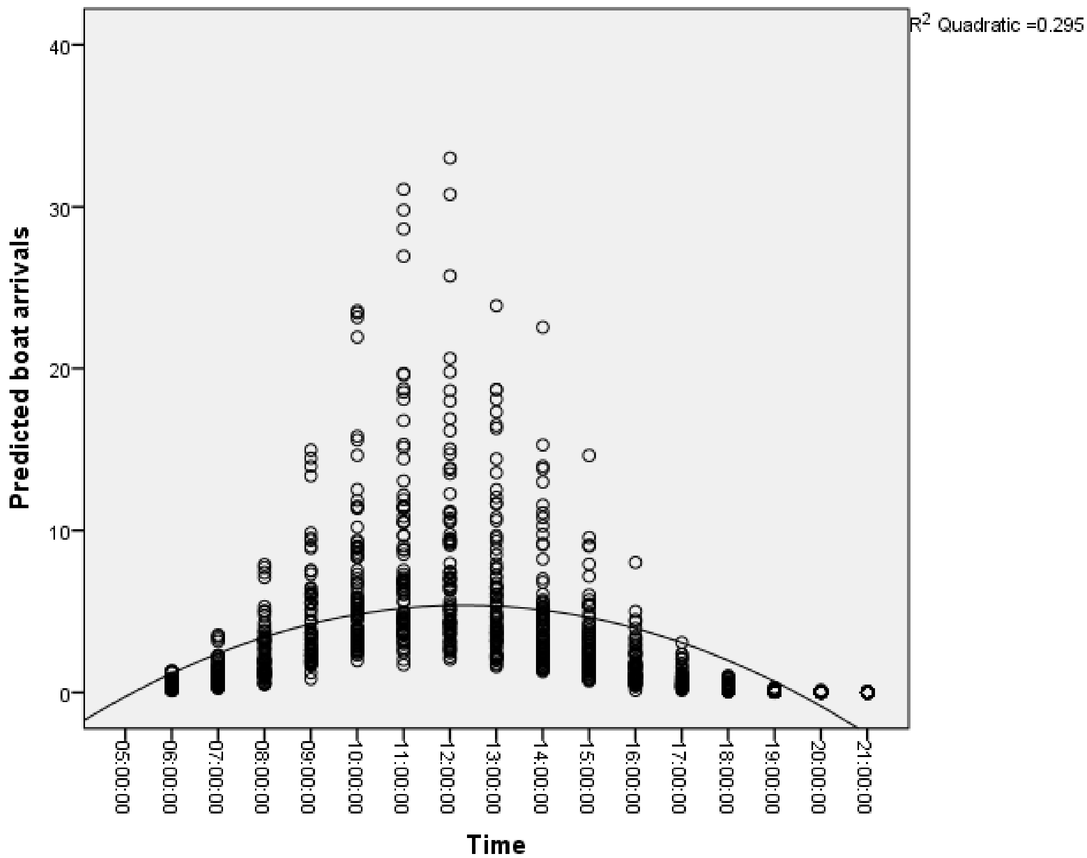

Figure 4.3 The relationship between arrivals (non-motorized boats) and time of day

The figure was created using the predicted values of arrivals from the full regression equation and plotting them against hour of day.

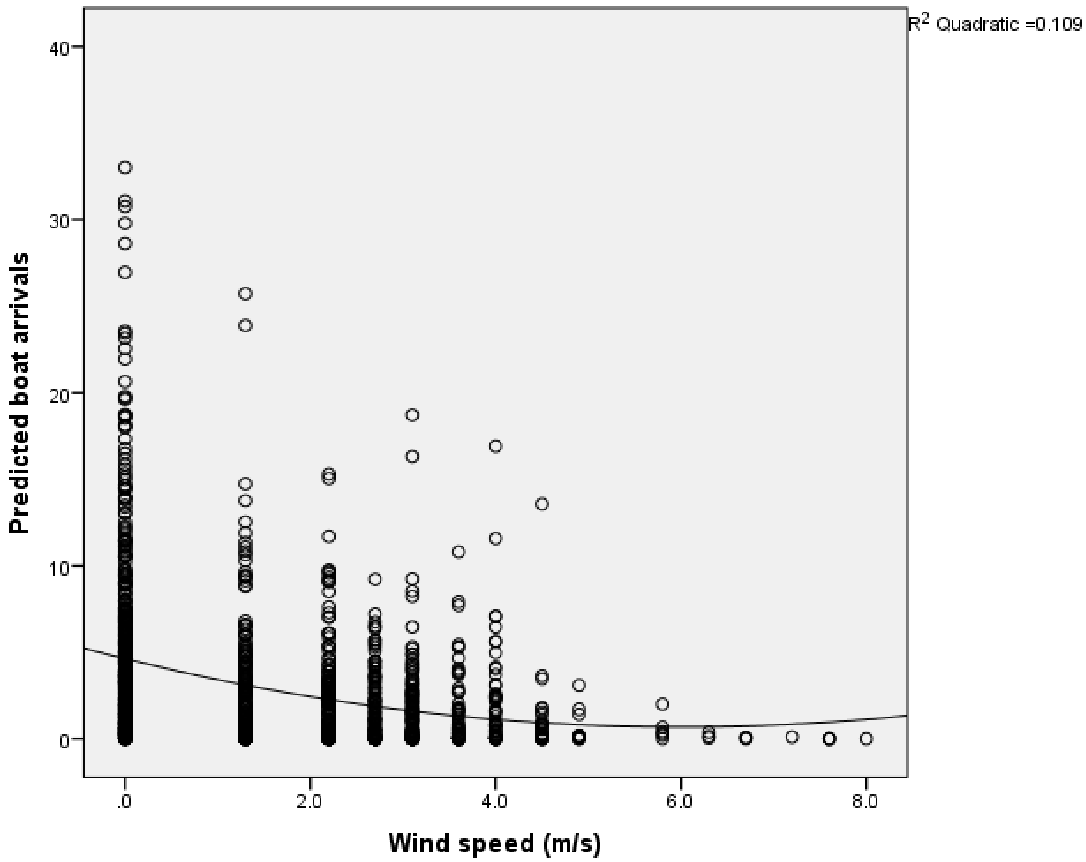

Figure 4.4 The relationship between arrivals (non-motorized boats) and wind

The figure was created using the predicted values of arrivals from the full regression equation and plotting them against wind speed.

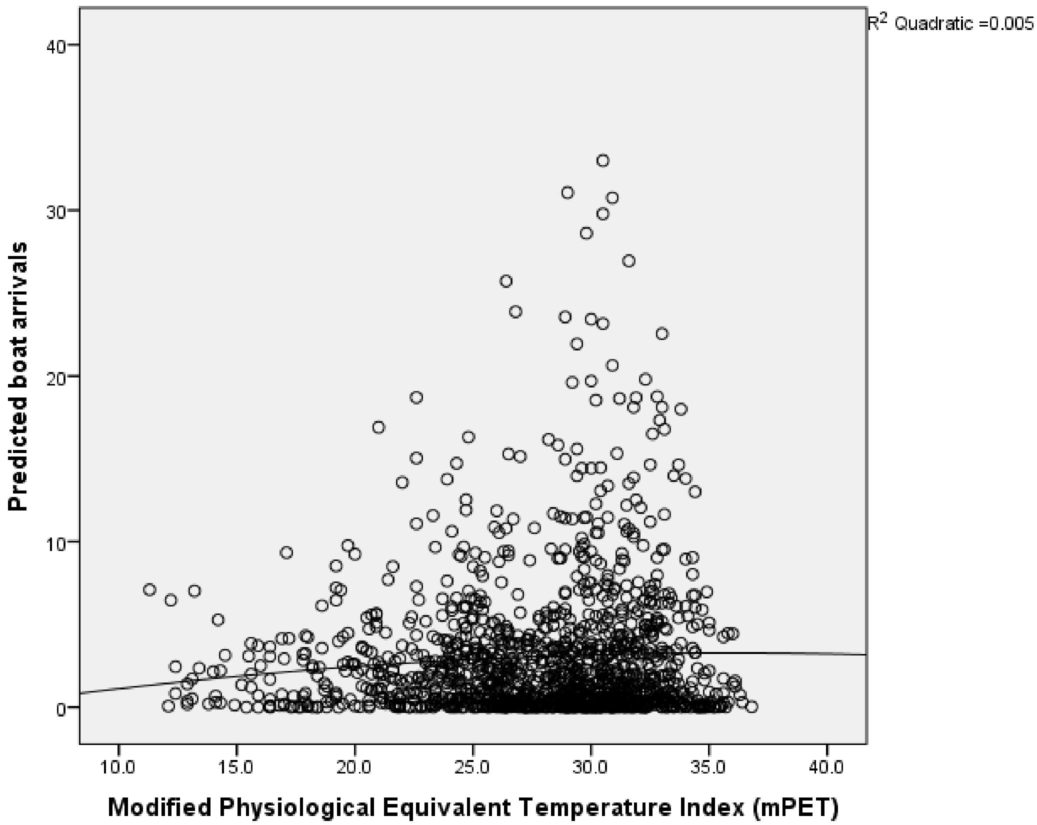

Figure 4.5 The relationship between arrivals (non-motorized boats) and mPET(°C)

The figure was created using the predicted values of arrivals from the full regression equation and plotting them against mPET.

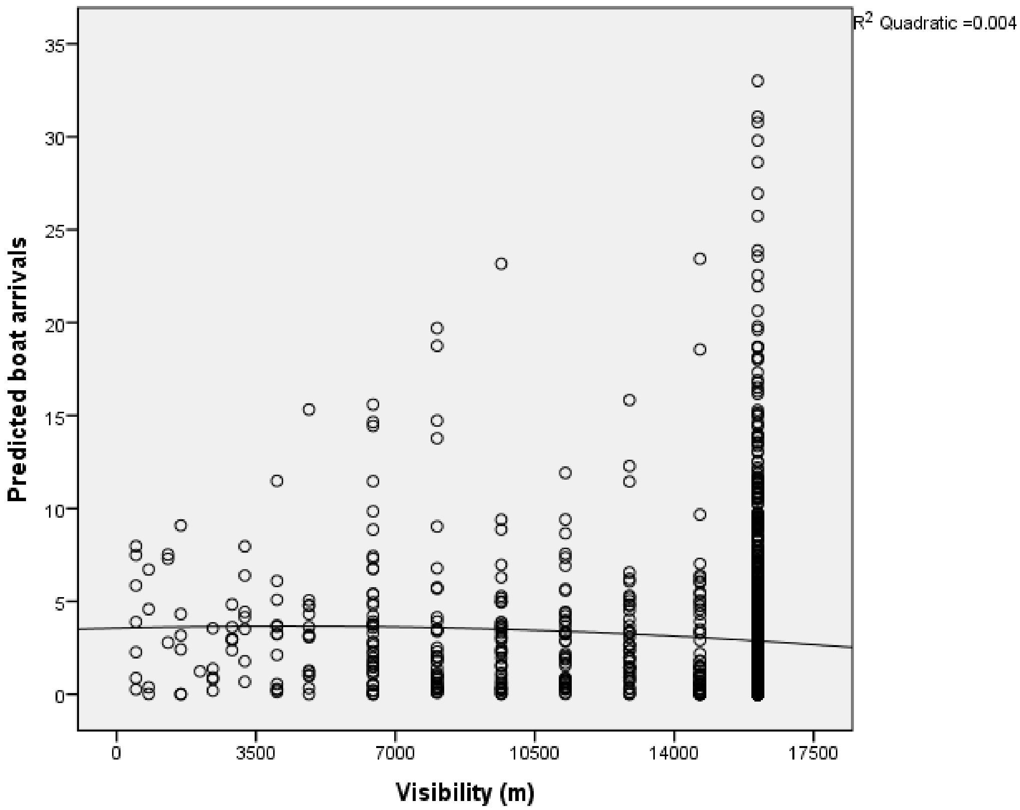

Figure 4.6 The relationship between arrivals (non-motorized boats) and visibility

The figure was created using the predicted values of arrivals from the full regression equation and plotting them against visibility.

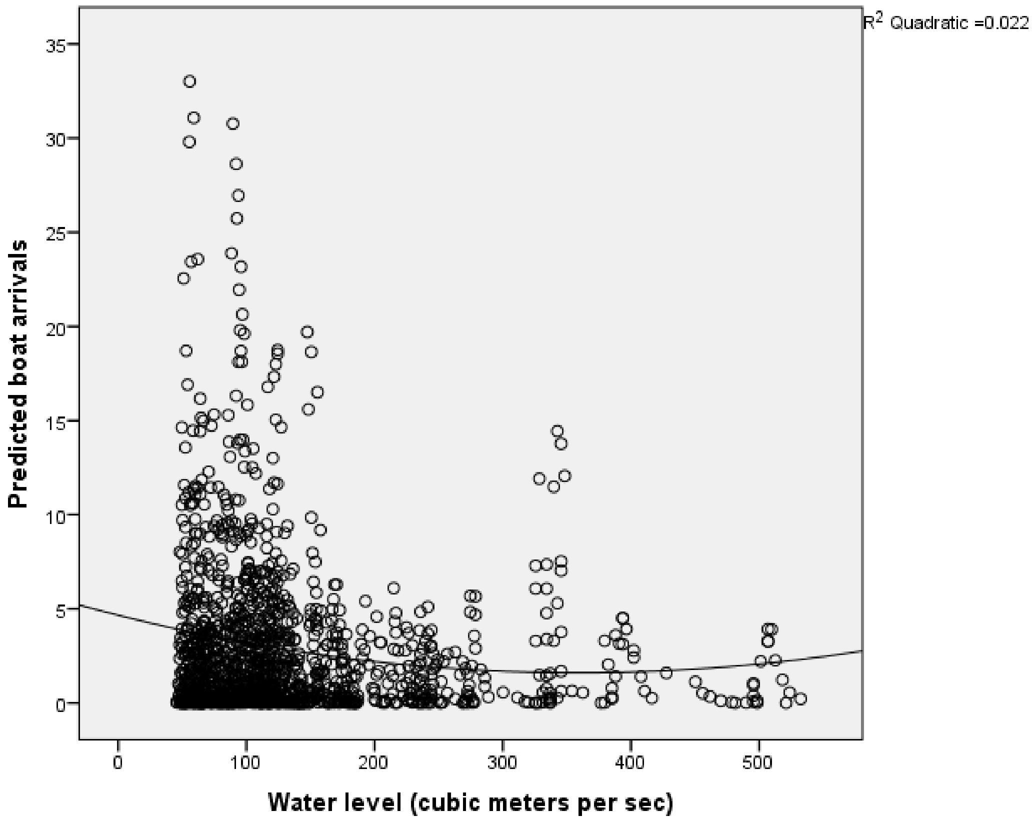

Figure 4.7 The relationship between arrivals (non-motorized boats) and streamflow

The figure was created using the predicted values of arrivals from the full regression equation and plotting them against the river's streamflow.

CHAPTER FIVE

SUMMARY AND SYNTHESIS

The series of articles in this dissertation were intended to address the lack of empirical studies regarding the management of boaters' experiences in public waterways. Specifically, these studies examined the influence of social and environmental conditions on recreational boating (RB). Three overarching goals guided the studies in this dissertation. The first objective was to extend the application of normative approaches to review boating thresholds. Second, to apply agent-based modelling to determine RB capacity. Third, to investigate the relationship between weather conditions and RB use levels. Three distinct studies involving different settings and methods were evaluated. A brief summary of each study and the contributions of this dissertation to methods, theory and practice are provided in the following section. Also included are the author's reflections.

Article one of this dissertation demonstrates a need for empirical approaches to update and establish context-specific thresholds for boating density. Despite thresholds specifying the minimum acceptable conditions for boating, agencies managing waterways often apply thresholds that are not site-specific, evidence-based, and lack public input. Therefore, thresholds for boating capacity vary widely. Additionally, the study investigated the perceptions of crowding and how they relate to the safety of water-dependent activities at reservoirs.

Results from this study indicated that previous boating thresholds established at the same study site but without a robust evidence-based process were unsupported by empirical data and were too restrictive. Additionally, visitors' perceived level of crowding was a significant predictor to their perceptions of safety and security at reservoirs. Therefore, there is a safety-related need for waterway managers to determine and implement crowding-based boating thresholds derived from visitor perceptions.

By applying normative approaches to determine boating thresholds, article two explores the use of agent-based modeling to determine where and when "acceptability" and "displacement" thresholds may be violated along a public waterway. Autonomous agents (non-motorized boaters) were modeled in NetLogo using boat count data and boaters' spatial patterns. The study found that the current boat use levels for an average non-peak and peak day were well within acceptable thresholds for boating. However, increasing boat use levels by over 25% may result in "acceptability" and "displacement" thresholds being violated at certain portions of the day. The study identified that one of three river use zones may experience a larger proportion of crowding-related threshold violations.

Article three investigated the influence of real-time weather on RB levels. Specifically, the study examined the impact of hourly changes in weather on the level of boat-related arrivals and departures at a section of a Wild and Scenic River in DEWA. By regressing weather variables and boating-related arrivals, results show that wind speed had the largest effect size followed by precipitation and a modified Physiological Equivalent Temperature (mPET) index. However, overall their influence was limited. Therefore, weather may be a secondary concern for these boaters because the prevailing weather conditions did not greatly affect real-time boat arrival and departure behavior. In contrast, timing may be the most important factor for RB. In peak use seasons, the use of available leisure time may be a priority to boaters.

The contribution of this dissertation to the body of knowledge can be classified into three dimensions: contributions to methods, theory and practice.

Contribution to methods

i. Applying normative approaches

Article one extended the application of normative approaches to determine recreational boating density thresholds. Recreational boating capacity studies have often been developed using logic and professional judgement. Additionally, some studies calculate boating density thresholds by dividing the section of a waterway that is likely to undertake significant use (i.e., the usable boating area) with the number of boats parked or moored (i.e., the peak use rate). These thresholds may be subjective, misleading, restrictive, and result in multiple interpretations hence making managing agencies more vulnerable to litigation. Therefore, where the potential for controversy and the consequences of capacity decisions (e.g., safety concerns) are high, there is a need to use empirical, well accepted, scientific methods. Article one addresses this methodological gap by applying norm-based approaches to determine perceived crowding thresholds.

The normative approach to carrying capacity has increasingly been used in many outdoor recreational sites including national park systems. However, the perception of crowding among visitors has seldom been used to determine recreational boating thresholds. By measuring boaters' perception of crowding the study estimated the level of use beyond which visitors perceive recreational boating as being unenjoyable. This included consideration of both on-the-water boat densities (i.e., surface acres per boat) and boat launch times. The norm-based approach demonstrates a method by which context-specific boating thresholds that are inclusive of boaters' perspectives may be developed and applied.

ii. Estimating use using field cameras

Articles two and three used field cameras to assess boating levels at DEWA. Field cameras are increasingly being used in carrying capacity studies (e.g., Hallo, Brownlee & Fix, 2013; Hallo, Fefer & Riungu, 2017; Hallo, McGuiness, Dudley & Fefer, 2017). Advances in technology have increased the quality of images, the life of batteries and storage space for cameras, and reduced the cost of implementing them. However, analyzing the large quantity of images is often untenable and costly (Arnberger, Haider, & Brandenburg, 2005).

To ease the burden of counting, tracking, and storing images, software programs have been developed with the potential of being incorporated into camera based assessment protocols to reduce fiscal and temporal constraints to using cameras. In Articles two and three, *Timelapse2* image analysis software and trained research assistants were used to count these variables to establish the levels of boating. In contrast, other studies using field cameras have typically applied a qualitative visual count method, which is based on the ability of an observer to identify patterns based on the dynamic inspection of an image bank (Gómez-Martín & Martínez-Ibarra, 2012; Martínez-Ibarra, 2011). *Timelapse2* provides a more precise and objective approach. In this dissertation, counts in images (e.g., people, vehicles, trailers and watercraft) were converted to actual use estimates by calculating the mean and standard deviation for corresponding hours, days, weeks or months.

iii. Simulating recreational boating

Article two explored two primary methods for incorporating social science data into spatial models outlined by Beeco and Brown (2013). This article extended the utility of GPS tracking of visitor use and recreation simulation modeling. GPS tracks were used in conjunction with survey data to develop an agent-based model of recreational boaters at the DEWA River. By simulating boaters' distribution with respect to the DEWA River, this article demonstrates how the distribution of boaters is influenced by time, speed of travel and built infrastructure (i.e., boat launch areas). Additionally, studies have often simulated recreational activities through closed systems. Closed systems restrict visitor use to trails or roads (Beeco & Brown, 2013). However, this study examined RB patterns on an open system. The DEWA River was conceptualized as an open system that did not restrict visitor movement. Movement patterns were only limited to the flow of the river because a majority of the users were non-motorized.

iv. Applying an updated thermal comfort index

Article three used the modified Physiological Equivalent Temperature (mPET) to investigate the influence of thermal comfort on visitation levels at destinations. Previously, the PET index has been widely used to represent the physiological conditions a person may experience at a destination. The PET index was developed in the late 1990s and there are a few limitations associated with using the index. For example, it is less sensitive to the changes in humidity (Chen & Matzarakis, 2014) and it fails to consider behavioral adaptation of clothing insulation in response to prevailing environmental air temperature (Chen & Matzarakis, 2017). A new thermal index, the mPET has been developed to address the weaknesses of the original PET. This study is the first to apply the mPET within an outdoor recreation context to examine the bioclimatic conditions recreational boaters would experience. Additionally, studies have often used 'standardized' measures for sex, age, height and weight to calculate PET and mPET of the study population (Chen & Matzarakis, 2017; Lai et al., 2016). The default personal values of the RayMan program include: male, 35-year-old, a height of 1.75m, and a body weight of 75kg. To improve on the accuracy of results, article two used a more representative estimate of input measures. The measures were extracted from published secondary sources and used to develop personal values for an average U.S. boater. The values specified in the RayMan program include: male, 47 years old, a height of 1.76 m, and a body weight of 91.5 kg.

Contribution to theory

It is widely accepted that one of the motivations for travel is climate and the expected meteorological conditions at the destination. Destination choices are often linked to environmental conditions. Studies have often examined the relationship between weather and where and when tourists are likely to go prior to them traveling (i.e., at the planning stage). However, the influence of prevailing weather conditions on recreationists when at a destination has not received much empirical attention. Article two, found that timing was the most important factor for RB and that boaters were more resilient to on-site changes in weather. Also, the study findings provide a good foundation for future research to investigate the influence of weather to the heuristic decision-making process for visitors, specifically recreational boaters. For example, how the level of boater preparedness (e.g., appropriate gear and apparel) may influence the way recreational boaters react to changes in weather conditions. Also, studies may examine real-time visitors' arrival and departure patterns when there are lightning events.

Contribution to practice

i. Reporting use and capacity in FERC's Form 80

The Federal Energy Regulatory Commission (FERC) requires many companies holding hydropower licenses (e.g., Priest Rapids Hydroelectric Project) to provide recreation amenities at their project. Licensees through the FERC Form 80 are required to periodically (i.e., every 6 years) report the number and type of recreation amenities, capacity utilization of each amenity, and recreational use levels at the project (Hallo et al., 2016). However, the agency does not describe how an amenity's capacity is, or should be, determined. By applying normative approaches to estimate utilization of boating amenities, article one not only determined evidence-based thresholds for boating, but addressed the fundamental issue of not describing to licensees how they should determine an amenity's capacity. The use of normative approaches are likely to enhance the consistency, objectivity and accuracy of estimation of boating capacity and the utilization of this capacity.

ii. Collecting visitation data

To estimate tourism demand and the level of use for tourist/recreational facilities, tourism and recreation managers mostly collect the number of tourist/visitor arrivals.

Often destinations do not collect or report departures (Hamilton, Maddison & Tol, 2005). Therefore, policies developed by relying only on arrivals data may be deficient. Article two, collected and tested the influence of real-time weather conditions on both boat-related arrivals and departures. The findings show that arrivals and departures are influenced by weather variables differently. For instance, mPET significantly influenced arrivals but not departures. Also, by collecting both the arrival and departure data recreation managers are able to determine the distribution patterns of boating throughout a given period for specific sites. This information can be used to determine the temporal extent to which resources are utilized, and may inform for zoning strategies.

iii. Supplementing traditional methods of research

Simulations can be used to identify potential problem areas along a river system. Article three demonstrates a proof of concept that social science can be integrated with spatial patterns of boaters to determine where and when perceptions of crowding may be violated. Traditionally, the use of surveys and visitor feedback have been used to determine visitor satisfaction levels at specific sites within a recreational area. The use of computer simulation analysis to not only investigate existing use levels at DEWA River but also identify potential areas where visitors' experiences and safety may be diminished demonstrate the novel application of ABMs in recreational boating. Additionally, input parameters may be adjusted to reflect future boating levels and determine how these levels will affect boaters' experiences. Therefore, simulation modelling may be viewed as a robust tool that recreation managers can adopt to enhance the management of public waterways.

Final Thoughts

This dissertation evolved from a need to better understand recreational boating and its management. First, reflecting on applying visual-based social norm methods to determine boat density thresholds may help resolve some of the challenges related to reporting carrying capacity in public waterways and FERC licensees. Past research pertaining to development of boating thresholds was often not based on empirical approaches. Also, with some of these outdated thresholds still being used, this dissertation is an excellent resource that can be adapted by agencies managing waterways to update their existing boating thresholds.

Second, by using normative approaches to determine boat density thresholds, this dissertation extended the application of simulation models to waterway management. Simulation modelling has typically focused on terrestrial landscapes like roads, trails and particular attraction sites. Unlike commercial shipping, the movement of recreational boats are to a large extent unregulated. Therefore, the development of agent-based models for RB may be a complex undertaking. The current study builds upon limited ABM studies that focus on RB specifically using NetLogo, a widely used open source software, to evaluate current and projected use levels and their effects on crowding thresholds for boating. To improve the accuracy of simulation models managers may better define boaters' patterns of use by collecting the following data: put-in and take-out time; the type, number, and speed of watercraft; the typical path or area used; streamflow; and the existing weather conditions.

Third, little was known about the influence of weather on recreational boating. With the various recreational seasons, there are key weather thresholds which are required before a majority of people are willing to participate in certain activities like boating. Understanding how weather influences visitor flows (e.g., travel patterns) and resource flows (e.g., streamflow) is key to understanding how visitors engage, utilize, and impact resources within public spaces. This dissertation has started down this path. By examining the influence of weather on real-time arrivals and departures, this research provides a baseline study of recreation climatology specifically for RB during peak use periods. Therefore, recreational managers are able to identify the effect of particular weather variables on outdoor activities and use this information to increase visitor awareness and improve safety guidelines. For example, waterway management agencies such as the NPS should provide not only streamflow and precipitation data online but the prevailing wind conditions.

Lastly, with many waterways located in protected areas, managers need to develop and implement comprehensive visitor use strategies that cover various boat types and address a wide range of possible impacts on resources and visitor experiences. To guide this process researchers should seek to identify ways to incorporate perceptions of crowding, simulation modelling and weather into current management frameworks like the Visitor Use Management Framework developed by the Interagency Visitor Use Management Council.

While the incorporation of the above parameters in the current recreational carrying capacity frameworks could substantially advance the field of recreation management, it must be acknowledged that future research will likely be constrained by agency budgets that are limited for human dimensions research. Future research must not only show decision-support value, but it must be cost effective. Therefore, this dissertation used open source tools that were robust, had a broad support network, and were generally easy to use. For example, 1) *Timelapse* image analysis software was used to count people or objects captured by field cameras, 2) RayMan Pro software was used to calculate mPET. It also can be used to calculate other traditional thermal comfort indices, and 3) NetLogo was used to simulate RB. These tools may assist recreation management agencies in conducting research that is timely and cost effective.

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