Recreational co-benefits associated with shoreline protection design

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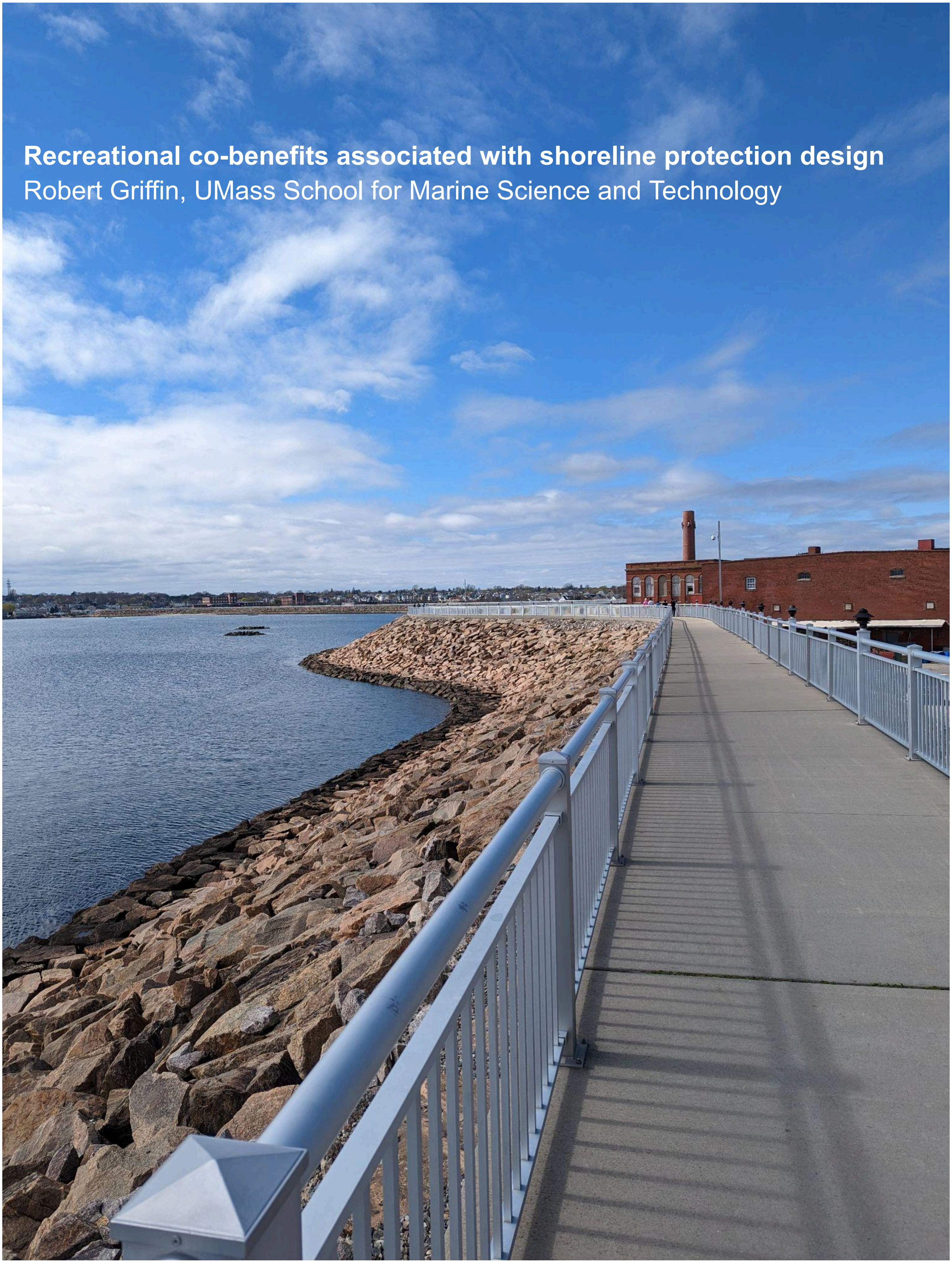

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Stone Living Lab

Abstract

Little is currently known about how recreational activity varies with the design and form of shoreline hazard adaptation projects. Preliminary evidence suggests there is variation in visitation across existing projects, though this does not account for other factors that may simultaneously be driving visitation. Given the importance of recreation to the well-being and economies of coastlines, and the projected scale of change over the coming decades to adapt to flood and erosion hazards, a more systematic understanding of these relationships would be useful for decision making. Disaggregating this relationship across user groups would also be useful for understanding societal objectives like equity of access and distributional impacts of policy decisions. This document characterizes the opportunities and challenges associated with using geographic metadata from social media and mobile phones for disaggregating visitation and visitor preferences associated with the design of shoreline flood and erosion hazard adaptation strategies.

Introduction

By the end of the century, it is estimated that the current 100 year storm event in the U.S. Northeast will become close to an annual occurrence due to the compounded effects of sea level rise and changing tropical cyclone climatology (Marsooli et al., 2019). Shoreline protection will play a key role in responding to this threat, as it is forecast to represent nearly 60% of the roughly $500 billion in U.S. sea level rise adaptation costs by 2100 (Neumann et al., 2015). While traditional shoreline protection structures like seawalls and revetments will play a critical role in this, nature-based solutions (NBS) are increasingly being implemented and investigated as a viable part of a comprehensive adaptation portfolio.

While these efforts will have a direct impact on reducing flood and erosion risk, the sheer scale of this effort will drive significant impacts on other valued shoreline uses, like recreation. Recreational co-benefits have been shown to be an important part of the overall suite of benefits from NBS (Arkema et al., 2015; Reddy et al., 2016) as they functionally alter the landscape and the way people enjoy it. Little is currently known about how recreation varies with the design and form of shoreline hazard mitigation projects. There is a limited literature that has built a foundation for our understanding that variation in environmental and socioeconomic attributes and context drive variation in visitation, in general (Ghermandi and Nunes, 2013; van Zanten et al., 2016) and in the coastal zone (Coombes et al., 2011). As an example in the context of NBS, this might mean that NBS near population centers may be expected to have higher annual visitation by being proximate to more people and easier to access, all else equal.

Preliminary evidence in Massachusetts suggests there is variation in visitation across NBS categories (Figure 1, Table 1), though this does not account for other factors that may simultaneously be driving visitation. To date, there has been no systematic assessment of shoreline visitation and its relation to different NBS approaches. Nationally, coastal recreation supports more than 3 million jobs and $225 billion dollars in annual gross domestic product, and 160 thousand jobs and $11 billion dollars in New England (Kosaka and Steinback, 2018). Local coastal recreation is an important community resource that supports human well-being and enjoyment of the coast plays an important part of the cultural heritage of many coastal communities.

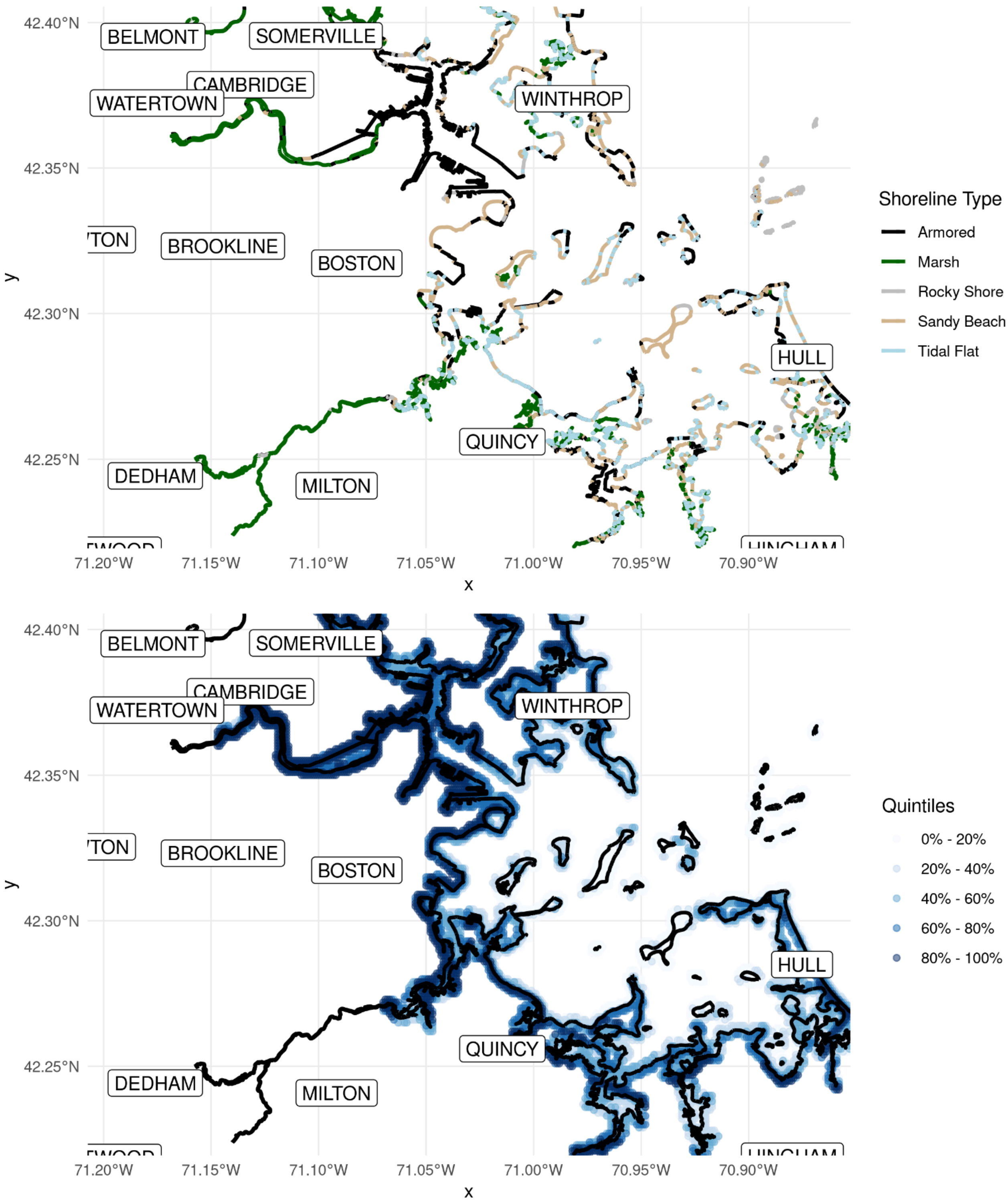

Figure 1. NOAA Environmental Sensitivity Index (top) binned by five shoreline types, and quintiles of annual average cellular device counts from 2019 AirSage aggregated cellular data (bottom).

Shoreline Class	% Shoreline Length	% Cell Device Counts
Armored	9.3%	38.1%
Marshes	50.4%	37.5%
Sandy Beach	16.1%	10.5%
Tidal Flat	21.8%	10.6%
Rocky Shore	2.3%	3.3%

Table 1. Proxies for visitation and their share of overall visitation and share of overall shoreline length, by shoreline class in coastal Massachusetts (sampling closest cell records).

Environmental justice and access to recreational opportunities are important considerations when studying the impacts of shoreline hazard adaptation projects on visitor behavior. Low-income and marginalized communities may have limited access to recreational opportunities (Hughey et al. 2015; Rigolon 2017; Tarrant and Cordell 2017; Rigolon et al., 2018; Suarez et al., 2020), and may be disproportionately impacted by shoreline adaptation projects if they displace access or reduce amenities. Disaggregating visitor data across user groups can provide insights into the equity of access and distributional impacts of policy decisions related to shoreline adaptation. Understanding how different visitor groups interact with these projects is critical in ensuring that policy decisions can incorporate equity considerations where this is a concern.

Given the scale and cost of anticipated shoreline change in the coming decades and the importance of shorelines to the well-being and economies of coastal communities, a better understanding of NBS recreational co-benefits would have far reaching implications. The aim here of this document is to summarize the potential advantages and obstacles related to utilizing geographical metadata obtained from social media and mobile devices to differentiate visitation patterns and visitor preferences across user groups.

Motivation

Employing nature to reduce the risk of flooding and erosion relies on a variety of different physical processes that depend on the interaction of water and the coastal environment, including trapping sediments, reducing wave height and energy, storing water, and physically impeding water movement (Ruckelshaus et al., 2016; Arkema et al., 2017). Recent advances in modeling have increased our understanding of the value of these risk reduction benefits. Storlazzi et al. (2019) estimate that coral reefs in the U.S. provide over $1.8 billion USD per year in flood risk reduction benefits, while Sun and Carson (2020) estimate that wetlands provide widely varying but significant protection value, with a median value of $91,000/km2/yr. The construction and maintenance costs of these Natural and Nature Based Feature (NBS) for shoreline protection are also increasingly well understood (Bayraktarov et al., 2015; Narayan et al., 2016), and this is fast-changing as more projects than ever are being implemented. Federal investment in coastal salt marsh restoration in the U.S. exceeded 50 thousand hectares between 2006 and 2015, with more than 600 hectares in RI and MA (Gittman et al., 2019).

Populated coastal areas are coupled human-natural systems, where spatial and temporal interactions between hydrodynamics and shoreline modification influence patterns of flooding, erosion, and resulting damage to communities (Hummel et al., 2021). Shoreline modification also influences a wide array of environmental benefits that are unrelated to protection, such as recreation, tourism, and aesthetic enjoyment, carbon storage and sequestration, and habitat for a diversity of ecologically and economically important species (Barbier, 2011). NBS protection projects, in particular, are thought to have an advantage in this regard, providing unique environmental services that traditionally engineered structures cannot. Unfortunately these goods and services are hard to value because many of them do not enter typical markets. While advances have been made to measure the value of these services (van Zanten et al., 2021), efforts to incorporate them into adaptation planning have suffered from inadequate baseline information of how people use the environment, a limited understanding of how usage changes as environmental conditions change, and challenges measuring these benefits in comparable and ways useful for decision processes (Guerry et al., 2022).

The most comprehensive large-scale implementation to date of including recreational co-benefits into shoreline hazard planning is that by FEMA's Hazard Mitigation Assistance program, which assigns a fixed recreation value per acre for land restoration/modification when assessing projects to reduce disaster losses. FEMA has updated guidance throughout the years to include more land use types, initially starting with two and expanding to nine different classes in their latest guidance (FEMA 2022). Values are estimated from a range of meta-analyses and prior valuation studies, with varying sample sizes for different land classes, and synthesized to a fixed value per acre to be included as part of a cost-benefit analysis for evaluating grants. The US Army Corps of Engineers also includes recreational benefits in their infrastructure projects and follows the National Economic Development protocol, which also employs cost-benefit analysis as a decision framework (Durden and Fredericks, 2009). As part of this protocol, a "unit day value" has been estimated and approved by the US Army Corps for calculating aggregate recreational impacts (USACE 2021). At its most basic, net recreational value impacts from a project would equal the change in area in each land class multiplied by the respective unit area value and summed for FEMA, or the change in visitor days multiplied by the unit day value for the US Army Corps.

Potential use cases for measuring coastal recreation value from nature based solutions

- Litigation over the recreational impacts of the Deepwater Horizon spill relied on estimates of over $600 million dollars in lost recreational value (English et al., 2018)
- Marine spatial planning and integrated coastal zone management needs to account for recreational activity and value in evaluating tradeoffs between uses (Papageorgiou, 2016) and estimating the potential for recreation itself to create environmental damage (Ban and Alder, 2008)
- Developing and evaluating funding mechanisms for coastal restoration, such as California's Measure AA, a regional parcel tax aimed at restoring and protecting coastlines, or Massachusetts' Coastal Resilience Grant Program
- Understanding tradeoffs between scenarios involving nature-based, hybrid, or traditionally engineered coastal flood and erosion protection. Recreational benefits are often cited as an important motivation for implementing nature-based coastal flood and erosion hazard adaptation strategies for public (Bridges et al., 2015) and private entities (Reddy et al., 2016).

Table 2. Example use cases for information on recreational value of coastal nature based solutions.

Other entities conduct conservation and restoration activities, including non-profits like conservation organizations and land trusts, municipalities, states, private companies and individuals (Table 2). Cost-benefit analysis is a common decision framing across these as well, though other priorities may be reflected in decisions, such as employment impacts, distributional consequences, ecological/physical targets, and more, all of which may feature tradeoffs with each other and may have overlapping information requirements to assess. The nascent state of the science and the tools to incorporate recreational benefits from NBS projects into project assessment mean that many of these other entities are challenged to regularly estimate these values. Even FEMA's and the US Army Corps methods and tools are challenged in this regard. The US Army Corps approach is sensitive to contextual recreational demand (number of user days), but does not provide any approach for measuring the change in the number of user days in relation to project attributes. The FEMA approach assigns a fixed value per land class regardless of location and other contextually relevant factors, resulting in similar recreation value estimates for beach renourishment near a busy metropolis or at rural beach per area, for example, despite many more users potentially enjoying the first. Figure 2 demonstrates wide variation in annual mean cellular device counts across Massachusetts shoreline classified as Sandy Beach, suggesting other factors are also relevant for visitation.

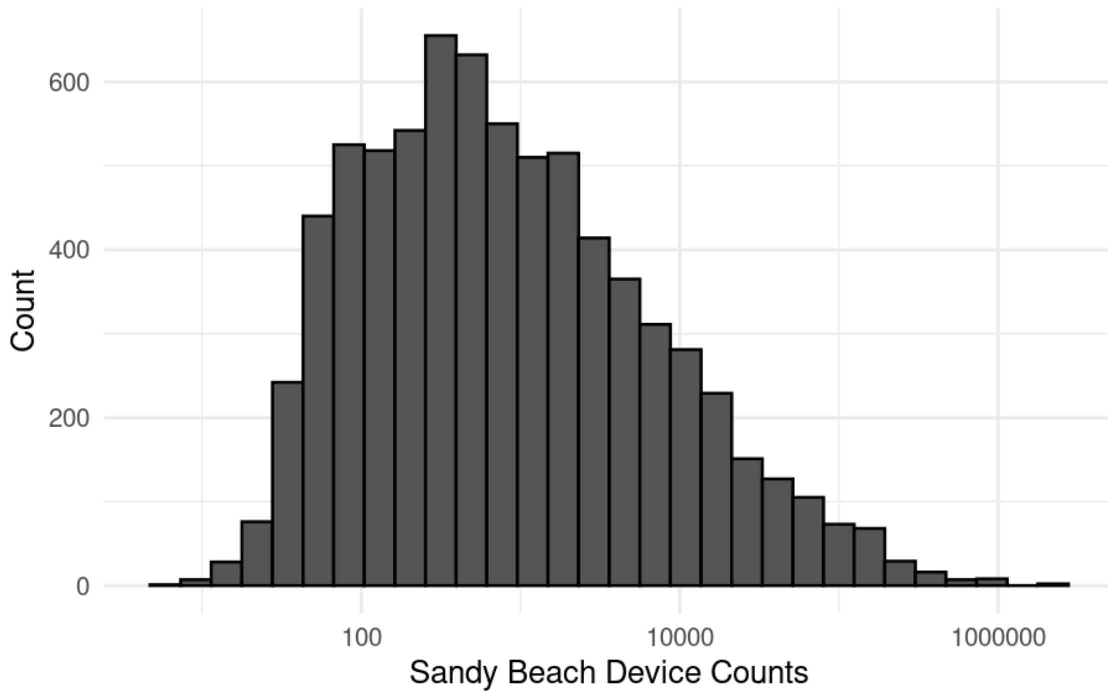

Figure 2. Histogram of device counts for coastal shoreline in Massachusetts classified as Sandy Beach.

In these decision contexts, the challenge for incorporating recreational value into decisions originates from: 1) inadequate baseline information of where people visit; 2) a limited understanding of how visitation is impacted by shoreline attributes; 3) limited capacity to assess people's preferences and values for shoreline recreation; 4) unknown distributional consequences of actions. Issues 1 and 2 relate to visitation and issues 3 and 4 are what allows social scientists and economists to translate visitation and project attributes into an estimation of recreational value. These could be addressed by surveying relevant populations and evaluating their existing use patterns and preferences for different design choices. Travel cost models and contingent valuation surveys are widely used to value scientifically novel recreational valuation questions and are approved practices under the US Army Corps guidance for National Economic Development. In practice, these are rarely done as designing, conducting, and analyzing surveys is effort-intensive and costly for one-off shoreline protection projects, and surveys also have a range of issues including recall bias, salience, protest responses, and more (Lupi et al., 2020).

Filling the gaps

To address the shortcomings of survey-based practices for measuring recreational visits and values, a promising field of inquiry has developed that leverages different forms of user-generated content, including cell phone and social media data. These newer forms of data hold promise for estimating recreational benefits as they can reflect human movement patterns over time and space and reveal recreational preferences through visitation choices derived from metadata (Keeler et al., 2015, Fisher et al., 2019) and from text and image content (Lin et al., 2022; Winder et al., 2022). They are also widely available and are latently collected, reducing the need for costly surveying (Wood et al., 2013). In the last decade the use of this data has expanded rapidly for characterizing recreation, coastal hazards, cultural ecosystem services, and a whole host of other social phenomena (see Ghermandi et al., 2023 for a recent review).

As a means of gapfilling for traditional survey methods to understand recreation, this data has typically been leveraged to estimate visitation numbers geospatially. While these types of data are not necessarily representative of visitation, as not everyone has a cellphone or a social media account, these relative measures can be calibrated to nominal values using existing or purpose-built sampling approaches with intercept surveys, gate records, passive monitoring with sensors, or other approaches (Merrill et al., 2020). The relationship between total visitation and proxies derived from these sources varies (Tenkanen et al., 2017); for example, cell phone data may be more strongly correlated with cell network availability than Flickr or Instagram, where visitation is proxied by geotagged photographs.

In addition to visitation estimates, recreational preferences can be derived from this data in a variety of ways. To understand how visitation varies with changes in landscape attributes, many studies have conducted multiple regression statistical analysis to associate visitation with a range of key landscape predictors, often controlling for key contextual information like adjacent population size, site amenities, and access to isolate on impacts of landscape ecological attributes for restoration or conservation decisions (van Zanten et al., 2016; Furey et al., 2022; Nelson et al., 2023). These types of analyses can be expanded to understand preferences for landscape attributes through travel cost models that assess how people balance tradeoffs between visitation choice and costs incurred to visit. While these have principally been employed using survey data, with information on home location user-generated mobility data can be leveraged for this as well (Sinclair et al., 2020).

Limitations and biases

Research in this space has demonstrated the potential for filling gaps to understand visitation continuously across space and time, the value visitors attach to the site attributes and amenities, and a whole host of qualitative/quantitative cultural benefit relevant indicators through semantic and image analysis. The potential for expanding our knowledge in this space is also driven by reduced costs associated with less need for surveying. Despite these strengths, the reliability of these data for measuring visitation and recreation value is a burgeoning new field (Ghermandi and Sinclair, 2019) and there are considerable challenges remaining to fully realize their potential.

An essential subcomponent of deriving value estimates through travel cost modeling is determining visitor origins. The home location of visitors is used to calculate travel cost to shoreline locations in individuals' choice set. All else equal, we would expect increased travel cost to reduce the number of visitors and thus this is an important predictor of visitation. Unlike traditional surveys where visitors can be asked directly, this needs to be inferred from attributes of cellular and social media data. Home location can also be an important part of understanding who is recreating and disentangling the joint issue of whether populations have access to recreational activity and heterogeneous preferences for recreation.

Alongside tables and maps of device counts, cellular data providers often provide estimated home locations at the census block level based on clustering or other heuristic algorithms of location coordinates, such as presence at night (Sinclair et al., 2020). These approaches can also be applied to geotagged social media data like twitter and flickr. Home location can also be extracted from user profiles, when available (Sessions et al., 2016; Hamsted et al., 2018). While these data generally fall short of providing a means of understanding demographic information aside from home location, researchers often append other demographic information from home census units to understand recreational access issues (Abercrombie et al., 2008; Montgomery et al., 2015; Kim et al., 2019; Twichell et al., 2021). Higher resolution home location and more demographic data may be achievable depending on the type of data and means for estimating home location. For example, the

New York Times published a series detailing how they were readily able to identify individuals from anonymized cellular data based on their home and work locations, and combine this with other data to essentially track individuals through space and time. The privacy implications of this pose a significant challenge, especially when cellular tracking is done without users opting in.

There are a wide array of considerations with bias using this data. Wilkins et al. (2021) detail several of these in a literature synthesis. Users only share select content on social media, which may not accurately reflect their experiences and activities. Social media use varies by country or year, and users share different content on different platforms depending on social norms and platform capacities. Incomplete understanding of demographics makes it challenging to understand how a sample of users compares to the population. Some areas may have a low amount of social media use, and certain things may be hard to photograph, leading to incomplete data. Access to platforms may introduce bias, including personal issues with access, or imposed restrictions like governments restricting access. Many of these issues may be exacerbated if content analysis is performed and not simple metadata collection. Despite how extensively these datasets are used, user bias has not been investigated extensively (Ghermandi et al., 2023).

Ways forward to address distributional considerations

While the promise of user-generated mobility data is high to help us understand key policy gaps, it should be emphasized that it is still early days for understanding the scientific reliability of estimates. At this early juncture, we still have little idea how much recreation is going to change across different NBS approaches to protect from coastal hazards even at an aggregate level, let alone as distributed across different populations. This holds for estimates from any data source, not just for user-generated mobility data. Aggregate estimates seem like a natural place to begin investigating, as demographic information for visitors is a key challenge and will likely remain so to protect the privacy of users. Nonetheless, anticipating and overcoming methodological challenges with distributional consequences of NBS implementation is a priority, especially given initiatives like President Biden's recent executive order, *Revitalizing Our Nation's Commitment to Environmental Justice for All*.

Anonymization has had a role in early efforts to protect privacy while still providing essential information for distributional analysis. There has historically been a tradeoff here, as higher spatial and temporal resolution needed for accuracy tend to erode the anonymity of the sample. There have been research advances to introduce *differential privacy* techniques into research databases where anonymity is a priority. For example, the 2020 U.S. census used differential privacy to introduce small errors into the data at the household respondent level so that aggregated data couldn't be mined to recreate household level information. The idea is to balance tradeoffs between privacy and usability with these methods, and research has found that at least for some questions that cover a large geographic area that they do not materially affect a decision's outcome, like for redistricting (Cohen et al. 2022). Other researchers contend that these methods pose significant challenges for analysis across a range of contexts and are disproportionately costly compared to their privacy benefits (Ruggles et al., 2019).

Expanding the use of *mixed methods* may prove to be useful in this space, such as combining surveys with user-generated data. While each has their limitations as described earlier, in combination they can cross-validate each other, or at least provide complementary information and gap filling for missing data. Some examples of this include Sinclair et al. (2020) who use traditional surveys and social media data to separately estimate consumer surplus per visitor day, finding close mean estimates with the two methods (<10%). A single survey could be paired with multiple social media studies, such as the case of an effort to derive *calibration tools* to correct demographic profiles for social media users in different areas or on different sites with population-level demographics (Ribiero et al., 2021). Depietri et al. (2021) use image analysis of social media data to characterize the relative importance of different recreational locations and site amenities that can be identified in photographs, and then uses public participatory GIS to gather comprehensive details about the landscape features of interest and the specific activities that visitors engage in at each site.

Conclusion

While there are many benefits to NBS, it is important to understand the potential trade-offs and challenges associated with their implementation, including recreational benefits. Some of these challenges include addressing issues of equity and distributional impacts, as well as the need for reliable and accurate data to understand the effectiveness of these solutions. In order to address these challenges, emerging data sources such as user-generated mobility data and social media data are going to play a significant role. In this context, the use of anonymization and multiple methods techniques can help balance the need for accurate data with the need to protect individual privacy.