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Is it safer at the beach? Spatial and temporal analyses of beachgoer behaviors during the COVID-19 pandemic

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\textbf{ABSTRACT}

Tourism localities worldwide continue to grapple with how best to sustain coastal visitation during the COVID-19 pandemic. Emerging epidemiological science illustrates the risk of disease transmission is lower outdoors than indoors, and exposure is likely lower in outdoor, coastal environments due to dispersion and dilution of respiratory droplets through regular air flow. That said, it remains unclear how beachgoer behavior affects the likelihood of disease transmission. During summer 2020, we analyzed publicly-available beachcam video data and collected unmanned aerial vehicle (UAV) imagery at the recreational beach oceanfront in Virginia Beach, U.S.A. Data were collected over 24 days, documenting tourists’ and recreationists’ behaviors related to the public health guidance from the U.S. Centers for Disease Control, Commonwealth of Virginia Department of Public Health and City of Virginia Beach. Specifically, using a sample test area of beach and adjoining boardwalk, we investigated diurnal patterns of beach and boardwalk use, the location and density of use, as well as the presence of face coverings (i.e., masks) on boardwalk users. Results from beachcam analyses indicate a curvilinear trend in beach use, peaking in the mid-afternoon, while boardwalk use remained consistent throughout the day. Beachcam observations were corroborated by UAV photography and spatial analysis, indicating concentrated use of the beach adjoining shoreline above high tide, with one-third of the landward adjacent upper beach vacant. Among boardwalk pedestrians, few (8.7\%) were observed wearing facial coverings. These findings point to both indirect and direct strategies coastal managers can implement to communicate when, where, and how to reduce the potential for transmission while accessing beach amenities during the COVID-19 pandemic.

1. Introduction

Since its discovery in December 2019 in the Wuhan province of China, the SARS-CoV-2 virus and resulting COVID-19 pandemic drastically impacted tourism industry and outdoor recreation behaviors worldwide. The global pandemic and economic fallout is estimated to contribute to a $320 billion loss in revenue between January and May 2020 for tourism operators (UNWTO, 2020). This loss in revenue stems largely from national, state/provincial travel bans, as well as restrictions on gathering sizes. In April 2020, 90\% of the world’s population experienced international travel restrictions (Gössling et al., 2020), and national travel restrictions continue to be used as a common strategy to prevent the spread of the virus (Rice et al., 2020). In the U.S., emerging reporting and research efforts indicate citizens respond to these restrictions by increasing visitation of coastal environments (Lewis, 2020), traveling shorter distances to access recreation and tourism resources, traveling shorter distances during their outdoor recreation activities, trying new areas, and recreating with smaller groups than before COVID-19 (Rice et al., 2020).

For these individuals who continue to access coastal tourism and

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\textsuperscript{1} COVID-19 disease transmission occurs primarily through human-to-human interaction (i.e., respired, airborne droplets from an infected person; Rothe et al., 2020). As of January 5, 2021, there were 86.2 million reported cases and 1.86 million deaths worldwide, with 20.9 million cases and 355,650 deaths in the United States (U.S.) (Johns Hopkins, 2020).

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recreation resources during the COVID-19 pandemic, as well as the communities where these activities occur, questions regarding the safety of coastal leisure opportunities remain. Emerging epidemiological science illustrates the risk of disease transmission is lower outdoors than indoors (e.g., Nishiura et al., 2020; Quain et al., 2020), and exposure is likely lower in outdoor, coastal environments due to dispersion and dilution of respiratory droplets through regular air flow. That said, it is unclear how individuals, specifically beachgoers, behaviorally respond to the possibility of outdoor disease transmission. Are beachgoers’ spatial and temporal behaviors similar to those that existed, globally, prior to the pandemic or do they now adopt protective measures (i.e., physical distancing, mask wearing) in their leisure activities to reduce exposure? Similarly, are the integrated management approaches that public safety, public health, municipal governance, tourism operators, destination marketing organizations (DMOs) and numerous other entities continue to institute having the desired impact or falling short of their mark?

To answer these questions, we used a quasi-experimental design to understand the behaviors of beachgoers (tourists and locals) in Virginia Beach, Virginia, U.S., during the peak beach tourism season between June and July 2020, specifically the spatial and temporal behaviors that may lessen or heighten the risk of exposure to COVID-19. Over 24 days, we collected publicly available beachcam data to observe the boardwalk and beach at 32nd Street, Virginia Beach. In addition, UAV drone imagery from a professional quadcopter was collected at opportunistic times to corroborate webcam data and document tourist’s individual and group distancing behaviors vis-a-vis the public health guidance from the U.S. Centers for Disease Control (2020) and Virginia Department of Public Health and City of Virginia Beach COVID-19 response plans. Following a review of common beach management practices and our selected methods, we present the findings from this innovative public health monitoring effort and transferable implications for coastal tourism and recreation managers worldwide, who seek to encourage safe access to these important resources during this unprecedented time.

1.1. Beach management

Prior to the COVID-19 pandemic, research in coastal environments indicated beachgoers’ habitual behavioral trends and perceptions surrounding acceptable conditions. Beachgoers often congregate around access points, especially ones located closer to parking facilities (Tatalos et al., 2013; da Silva, 2002), and within the first 20 m of the high waterline (da Silva, 2002; Serrano Giné et al., 2018). While the afternoon is commonly the most populated time in beach environments due, in part, to desired climatic attributes (Freitas et al., 2008), this fluctuates slightly based on holidays, as well as summer storms (Cumberbatch and Moses, 2011; Serrano Giné et al., 2018). In areas with multiple beaches, those popular with tourists predictably see a higher number of users. However, when asked about crowding at these locations (i.e., Barbados) (Cumberbatch and Moses, 2011), respondents regularly indicate that there are too many people on the beach and that 1–3 m is a desirable distance between groups.

To address issues, such as crowding, in both marine and terrestrial nature-based tourism and outdoor recreation environments, direct and indirect management are common strategies employed by managers. Direct management, also referred to as ‘hard enforcement,’ includes citations, regulations, access fees, and closures (Park et al., 2008; Manning, 2011), whereas indirect management, or ‘soft enforcement,’ includes signage, educational programming, and social media campaigns (Manning, 2011; Greer et al., 2017). Indirect management relies on what Heberlein (2012) refers to as the “cognitive fix,” wherein education and information is presumed to influence and impact the behavior of so-called ‘rational actors’ (see Dustin et al., 2019); whereas direct management relies on the “structural fix,” wherein management authorities reduce a certain amount of individual agency (freedom) in order to attain a result desired by the broader community. Direct management is more effective to solve problems in the short-term, such as lock-downs to stop the transmission of a highly contagious virus, however soft enforcement strategies are generally more desired by recreationists and tourists (Greer et al., 2017; Park et al., 2008).

1.2. Beach management during COVID-19

The focus of this study was the behavioral consequences from COVID-19-related management approaches at the Oceanfront of Virginia Beach, Virginia, USA. The Oceanfront is a mass tourism destination for Virginia Beach, comprising scores of hotels, restaurants, entertainment and retail businesses. In 2017, Virginia Beach hosted 19 million visitors who spent $2.45 billion during their visit (Sharp, 2018). The primary recreational focus of the Oceanfront is the beach itself, a wide and regularly-re-nourished, sandy beach with regularly stationed lifeguard stands, a large seawall, and multi-use boardwalk situated between the sand and hotels and streets. The boardwalk comprises a wide pedestrian path with scattered benches, overwalks for beach access at city street intersections, lighting, showers, and a parallel two-line bicycle path. Hence, the beach and boardwalk provided unique tourist and local recreationist flow, spacing, and potential for interactions yielding public health concerns.

In 2020, both direct and indirect management strategies were used at the Oceanfront to address the COVID-19 pandemic. Preceding and during the study period, in order to reduce the spread of the virus, sustain the tourism sector and provide for recreation and leisure opportunities for locals, Dr. Ralph Northam, the Governor of Virginia, issued a series of executive public health orders related to COVID-19 (Table 1). Relevant orders include the March 30, Executive Order 55, which closed all beaches with the exception of allowing fishing and exercise activities. Once Virginia moved into Phase 1 of reopening (May 8, 2020), which did not include opening of beaches in the Commonwealth, the Mayor of Virginia Beach presented a plan to reopen the Oceanfront and other beaches in the municipality. This plan included enforcing physical distancing and other public health measures, in part,
using signage (c.f., Fig. 1) and paid ‘beach ambassadors’ to verbally convey public health messaging at beach access points (Hall and Arevalo, 2020). This plan was approved by the Governor on May 28th.

The shift from direct (i.e., beach closures) to indirect management approaches (i.e., signage, beach ambassadors), provided the impetus for us to explore the behavior(s) of individual beachgoers and their compliance with messaging (i.e., 2 m of physical distance from other individuals) conveyed through visual prompts and verbal messaging from beach ambassadors. Additionally, we were curious if common beachgoer behavioral trends seen internationally prior to COVID-19 persisted or were altered due to the virus. Further, while Google began to capture and provide user activity data via mobility reports during this period as an aid to public health managers (c.f., Fig. 2; Google LLC, 2021), these reports were presented in aggregate across “parks” in Virginia Beach and lacked a specific focus on beachgoer behaviors. So, while mobility reports illustrate use rising and falling in tandem with direct management efforts across the City (c.f., City of Virginia Beach, 2020), more granular analyses were needed to fully understand beachgoer behaviors.

2. Materials and methods

To answer these questions, during May 2020, we conducted a pilot study to assess potential methods for physically-distanced beachgoer observation, design a sampling and measurement scheme, and prepare for spatial and statistical analyses. Following the pilot study, we employed two digital image capture instruments to document in situ beachgoer behaviors: a publicly accessible webcam video stream and UAV aerial photography.

2.1. Public webcam video stream

Webcams have been used in multiple studies to provide video and still images of specific populations (Timothy and Groves, 2001; Heerfordt et al., 2018). In this study, still images observing the sample area were retrieved from an open source webcam located at 32nd Street and boardwalk, Hampton Inn Oceanfront hotel, Virginia Beach. The webcam field of view provided a limited extent of the beach surface, approximately one block length or 100 m in the foreground. Fig. 3 presents key sub-areas within this intensive study area: zone (a) the boardwalk, (b) beach visible from the webcam and two areas of extent visible in the drone photography (c) a polygon bounding all individuals and (d) groups of individuals. This nested approach provided an unambiguous coverage of the boardwalk where individuals could be anonymously counted and recorded as fixed points. For the beach area, the overlapping webcam (b) and drone areas (c) and (d) provided the potential to corroborate and compare data.

Webcam images were captured using Python 3.8 script running for 24 days stratified across the months of June and July 2020. Stratified sampling was used to ensure equal representation of morning and afternoon beach and boardwalk user activity, as well as weekday and weekend activity. Each session of image capture consisted of 5 h, with images retrieved at the top of the hour (i.e., 9:00 a.m., 10:00 a.m., etc.). The open source counting software DotDotGoose (Ersts 2020) was then used to count and code beach and boardwalk users in each image. The resulting database captured all individuals as points (dots) in the images extracted from these hourly extracted video segments. A single investigator was responsible for all digitization, with a second, trained researcher reviewing and editing these points. Subsequent to this data review, all points were exported from the DotDotGoose software via ASCII files and imported in ArcGIS Pro (Esri ArcGIS Software) for analysis.

Within ArcGIS, points were geolocated on a map frame using pixel coordinates from the extracted webcam images. Each hourly dataset was next integrated in a single database and overlaid for spatial analysis, including the point mapping, proximity and visual density. Attempts to georeference the low-oblique webcam imagery (to allow overlay and measurement of points) were not successful owing to the extreme scale displacement of the geometry in the background. Nonetheless, the point- and image-relative accuracy was evaluated and deemed sufficient to allow point superposition and mapping the density of boardwalk users and beachgoer activity. In addition, SSPS statistical software was then used for descriptive analysis of temporal trends and presence of face coverings (masks) for boardwalk users.

2.2. Unmanned aerial vehicle imagery

UAVs, commonly known as drones, were employed to collect imagery of beachgoer physical distancing compliance. Provost et al. (2019) found that UAVs can be effectively used for quantifying beach use patterns at different time periods and for determining if beachgoer activity is influenced by environmental conditions. This concept can be naturally extended to examine changes in beachgoer behavior that may occur due to physical distancing recommendations or regulations that have been enacted as a result of the COVID-19 pandemic.

UAV image acquisition required careful planning and compliance with a set of explicit regulations for U.S. Federal Aviation Administration (FAA) airspace, operator, and platform registration. Our location was within a restricted, Class D airspace controlled by the U.S. Department of Defense Naval Air Station Oceana. Thus, a Certificate of Waiver or Authorization (COA) issued by the U.S. Federal Aviation Administration (FAA) was necessary to conduct UAV operations and our drone flight could not exceed 30.5 m ceiling above ground level. Additionally, the area location and broader FAA regulations also prohibited flying over groups of people, necessitating reliance upon images non-nadir to individuals and groups and also prompting our selected mapping via high-oblique viewing from over the water.

A DJI Mavic 2 Pro quadcopter with a 20-megapixel camera was the UAV used for data capture. An initial aerial survey of the Oceanfront site was performed in the early morning of June 27, 2020, to test and identify the best camera gimbal angle to be used for future beachgoer observation flights and to collect an inventory of 526 images without beachgoers present. The Oceanfront site was revisited near mid-day on July 4, 2020 (Independence Day, a U.S. national holiday), and the drone recorded 13 high resolution images of the crowded beach.

Following flights, images were post-processed using the Pix4D photogrammetric engine (https://www.pix4d.com/) to create a 2-dimensional georeferenced orthomosaic and a 3-dimensional digital surface model (DSM) for the study area. Creating a mosaicked 2D seamless image would provide for subsequent digitizing of individuals and groups within the mapped area. Fig. 3 shows the drone imagery mosaic that was imported into ArcGIS Pro for mapping. A GIS database...
was designed to record the location and attributes of individual beachgoers (as points) and groups (points) of clustered beachgoers. These features were manually interpreted and digitized by one observer and evaluated for accuracy by a second researcher. Next, in order to measure the spatial density of beachgoers and groups per unit area, we created two polygonal zones that captured the observed extent of each. One zone captures the maximum bounding polygon of individuals (Fig. 3c) and a second the maximum extent of observed groups (Fig. 3d). Separate areal extents allowed for the independent assessment of individual versus group spatial distancing.

Fig. 2. Google Mobility Report for Virginia Beach parks preceding and through the study period, 15 February to July 31, 2020. Note: The exploration of this report provided the impetus for our study. Trends showed a clear depression of recreational activity during mid-March, as direct management (i.e., pandemic lockdowns and restrictions) were implemented. Trends also correlate with inclement weather events.

Fig. 3. Study area location Virginia Beach, Virginia, USA, showing oceanfront hotel strip and mapping zones. The map at right shows delineated areas for the boardwalk zones a) boardwalk b) beachcam visible recreational beach and the UAV imagery as c) vertical aerial view of individuals bounding polygon and d) drone aerial view groups bounding polygon.
For coding, individuals were identified and mapped as points if the person could be physically seen (e.g., sitting in a beach chair, lounging on a towel, in the sand, walking on the beach, or in the shoreline part of the beach). Thus, persons obscured by beach umbrellas, swimming, walking outside of the aerial imagery zone, or under the water were unable to be observed and counted. For group locations, we implemented a rule that sought to locate points, such as clusters of beach towels or chairs, umbrellas, or towels. Individuals alone at the beach (i.e., one chair or towel) were included and counted as a single group. The result of these mapping procedures would provide a first-order estimate of the location of individuals and groups, their distances and density for a representative observation period, including mapping point patterns of individuals and groups and measuring their abundance relative to the shoreline, boardwalk, and open beach area.

3. Results

3.1. Webcam video analyses

Descriptive analysis of the webcam images illustrated a curvilinear trend with beach usage increasing until peaking at 3:00pm (M = 30.42, SD = 16.05), after which use slowly decreased (Fig. 4). Boardwalk usage fluctuated throughout the course of the day but generally increased, peaking at 6:00pm (M = 5.96, SD = 4.74). An independent samples t-test found a significant difference in the average number of beach visitors in the morning and afternoon (t = -5.235, p < .001). Average afternoon use was 9 individuals higher than morning use. A second independent samples t-test found a significant difference in the average number of visitors on the beach and boardwalk (t = 18.253, p < .001). The average hourly beach visitor count was 25 individuals higher than average boardwalk users. This is likely due to static image capture of largely-stationary leisure behavior on the beach at hourly increments, as opposed to active leisure behaviors on the boardwalk that suppress overall volume over the full hourly. Finally, masks or face coverings were not identifiable during beach counts, but North-bound boardwalk users could be identified as mask wearing (8.7%) or not (91.3%).

Results of the spatial analysis of webcam point data are depicted in Fig. 5, highlighting (a) the initial point locations of all observed individuals for each zone (magenta points for beach and green points for the boardwalk) and (b) patterns of density concentration and dispersion of persons in each zone as measured by kernel density analysis. Inferences of the point patterns alone show a concentration of beach users along the shoreline-adjacent recreational beach (Fig. 5a) with boardwalk users showing a more uniform distribution with subtle clustering in groups. The kernel density analysis results in Fig. 5b.

3.2. UAV mapping results

On July 4th, patterns of beachgoer clustering behavior were recorded with the aid of oblique UAV-acquired aerial imagery (Fig. 5). We observed that beachgoers were highly clustered within a 60 m wide zone adjacent and parallel to the waterline. This zone represents approximately 43% of the 145 m wide sandy beach found between the boardwalk and the waterline. Clustering zone width throughout the study area appeared to be relatively uniform, likely owing to the abundance and even distribution of beach access points. The remaining 57% comprises the 25 m-wide shoreline section of beach (swash zone) with a steep beach face and a 55 m landward swath of beach immediately adjacent and parallel to the boardwalk. The landward beach zone represents just over 1/3 of the total beach area and was largely vacant except for beachgoers in transit to/from the shore and boardwalk.

Additional spatial analysis of imagery was performed to develop individual point data, detect and delineate groups/clusters, and analyze point density. Point data representing 288 individuals were digitized through identification of persons, chairs, umbrellas, tents, and towels visible in the imagery. Point data representing 145 groups were identified as collections of individuals separated by no more than 2 m to the nearest group member and digitized accordingly. Digitized point data were used to calculate a convex hull (minimum bounding polygon) for each set, groups and individuals. The individual persons bounding area was calculated at 10,695 m², resulting in a person density of 0.027 persons/m², approximately 269 persons per hectare. The groups bounding area was calculated at 8355 m², resulting in a group density of 0.017 groups/m², approximately 174 groups per hectare.

Spatial patterns of individuals and groups are also presented in results from the UAV vertical orthophoto mosaic and oblique images in Fig. 6. This map depicts the location of individuals and groups mapped and reported above. In addition, the map shows 5-m buffers from the shoreline toward the boardwalk that provided zonal measures for calculating distance from the shoreline. Both individuals and groups are concentrated in a relatively-narrow zone of the recreational beach just above the swash zone (Fig. 7).

4. Discussion and management implications

In Summer 2020, we collected and analyzed webcam and UAV
imagery to understand beachgoer and boardwalk user behaviors that impact potential exposure to COVID-19 at the Oceanfront in Virginia Beach. Our aerial imagery findings indicate a concentration of beach use in the afternoon, within 60 m-wide zone proximate to the shoreline, swash zone. Accordingly, beach use is concentrated in approximately 43% of the total beach surface area, leaving approximately 1/3 of landward beach surface vacant. These findings are corroborated by low-oblique webcam imagery depicting beach use. Static webcam images of the boardwalk also indicated relatively-consistent use throughout the day, a concentration of use at beach access points and points of interest (i.e., King Neptune statue), and low use of face coverings for observed northbound boardwalk users (8.7%). These results provide numerous points of discussion related to the management of tourism and recreational opportunities during the COVID-19 pandemic at Virginia Beach and in beach tourism settings throughout the world. We illustrate these suggestions below.

4.1. Spread out to stop the spread

Both drone and webcam imagery indicated that roughly one-third of the landward beach surface was vacant during monitoring periods, as beachgoers predictably preferred close access to the shoreline. This finding is consistent with previous research indicating beachgoers congregate within the first 20 m from the waterline (da Silva, 2002; Cumberbatch and Moses, 2011; Serrano Giné et al., 2018). During the

![Fig. 5. Results of cumulative beach and boardwalk observations digitized and georeferenced relative to webcam field of view, showing a) distribution of individual person points for each zone and b) kernel density analysis of points highlighting relative concentration and dispersion of individuals in each zone. Beach density was ≤0.05 with pockets of ≤0.058. Density on the boardwalk was ≤0.018.](image)

![Fig. 6. Points data derived from UAV-acquired imagery representing individuals and groups in relation to 5-m buffer lines parallel and relative to the shoreline.](image)
COVID-19 pandemic, these findings indicate the potential to leverage underutilized beach surface area for additional capacity, as well as the potential to incentivize and manage for appropriate physical distancing through a variety of approaches. Indirect management involving signage and verbal messaging from beach ambassadors (Hill, 2020), as well as online messaging or incentive systems (Crompton, 2016) may help to coax visitors to underutilized resources. Direct management approaches to maximize the use of beach surface and minimize exposure potential including demarcating quadrants for use (Naftulin, 2020), coupled with time ticketing by section or access point. Depending on the local, state, or national regulations, as well as the mandate of the managing agency, coastal managers can select amongst these strategies to align with their context-specific needs.

4.2. Interpret at access points

Previous beach management research has indicated the visitors congregate around access points (Tratalos et al., 2013; da Silva, 2002), and we found similar patterns in both webcam and drone image analysis. This is, of course, problematic during the COVID-19 pandemic. As a result, we suggest interpretation, such as Virginia Beach’s ambassador program, at high-volume access points is critical to assure messaging reaches the maximum number of beachgoers and reduces the potential for exposure. Activating normative, protective behaviors at these points through appropriate signage, mask-wearing volunteers or management agency staff may establish or reinforce social norms surrounding protective measures to reduce exposure to COVID-19.

4.3. Arrive early

Our findings mirror previous beach research (Cumberbatch and Moses, 2011; Serrano Gine et al., 2018), in that peak use occurred in the afternoon hours for both the beach and boardwalk. Though early times of day may not align with tourists’ and recreationists’ desired climate features (i.e., ambient temperature), temporal substitution (see Manning, 2011) can disperse use to lower-use morning hours. Substitution behaviors can be encouraged through indirect and direct management approaches. In trail environments, time ticketing allows for increased spacing and access to resources which provide a more enjoyable experience. Early beach arrival is a coping method to avoid crowding and conflict among surfers (Usher and Gómez, 2017) and no doubt can be extended to protective behaviors related to COVID-19 exposure.

4.4. Monitor at height

The high spatial and temporal resolution of UAV image sensor data, coupled with the ability to acquire human subjects’ data remotely, makes the use of drones an extremely attractive data collection mechanism for socially-distanced field work in the age of COVID-19. Numerous recent studies have shown promise in the use of drones and drone sensor-derived products for the monitoring of human movement, spatial dispersion, and site-specific impacts (e.g., Provost et al., 2019). Measurements derived from drone-acquired imagery processed with photogrammetric tools have been found to provide accurate and reliable estimates of human movement and related environmental impacts (Ancin-Murguzur et al., 2019) and of density of crowd gatherings (Almagbile, 2019). Our findings suggest that these methods can be extended to assist coastal managers in monitoring compliance with COVID-19 related policies and assisting with data driven management.

4.5. Integrated management

The COVID-19 pandemic illustrates the necessity for integrated management across public safety, public health, municipal governance, tourism entities (i.e., accommodations, restaurants), destination marketing organizations (DMOs) and numerous other entities. This research illustrates the de facto behavioral response of recreationists and tourists to all parties’ coordinated (or uncoordinated) efforts in the midst of a
global pandemic. COVID-19 has impacted the tourism industry worse than any other event in modern history (Higgins-Desbiolles, 2020). However, the community in our study has demonstrated the ability to engage in tourist and local recreationists behaviors, such as beach use, in a relatively-safe manner. Though the above implications for beachgoers, recreationists, and coastal managers at Virginia Beach and elsewhere provide further actionable steps to reduce the potential for exposure to COVID-19, existing efforts (i.e., beach ambassadors, signage) point to the importance of coordination and communication across these various entities to address this public health crisis.

5. Conclusion

As with any research effort, our study is not without limitations which point to future directions for coastal research and management. First, we employed a quasi-experimental design, where no specific control (i.e., pre-pandemic data from Summer 2019) was accessible for analysis of behavior change at the site. Accordingly, we compared Oceanfront beachgoer behaviors to well-documented, international beachgoer behaviors evidenced within the coastal management, outdoor recreation, and tourism literatures (e.g., da Silva, 2002; Cumberbatch and Moses, 2011; Serrano Gine et al., 2018; Tratalos et al., 2013) evidencing that behaviors during the pandemic mirrored those documented in other settings prior to the pandemic. This lack of behavior change (i.e., low mask usage on the boardwalk), reinforces the need for indirect and direct management approaches we suggest above.

Second, with regards to our instrumentation, approximately a dozen webcams are in nearly-continuous operation along the coastal zones of Virginia Beach and accessible in publicly accessible web pages (e.g., VBBound.com, SurfChex.com, or Livebeaches.com) or through subscription-based services (e.g., SurfLine.com). Further study could evaluate the effectiveness of alternative webcams to the 32nd street webcam used in this study, including analyses for location, field of view, and temporal data collection. Our approach used data analytics and a web application to capture and catalog systematically, with resulting static JPG graphics subsequently analyzed in a non-georeferenced, planar raster view. Setting up a webcam from a higher vantage point with a high-oblique view would provide for spatial georeferencing, allowing integration of the videography with UAV imagery and other GIS datasets.

Limitations of our approach using UAV imagery are several, but point to strong potential to overcome with future study designs, as well as regulatory cooperation and approval. For instance, FAA and local airspace control prohibited us flying at a higher altitude, which could have provided a larger extent of study of the imagery to capture other patterns of use and density (e.g., effects of lifeguard stands, differences in the beach slope, influence of the proximity of multiple beach overwalks, etc.). Even though nearby high-rise hotels are in excess of 60 m height, our COA and flight plan was only approved for ~30 m maximum above ground level. The FAA-wide regulation prohibiting flying over people or gatherings further constrains the approach. However, a higher flight along or just offshore the shoreline could provide a high-oblique perspective with minimal degradation of the spatial accuracy. Additionally, utilization of UAVs equipped with automated self-deploying parachutes would increase the likelihood of obtaining a waiver of FAA rule §107.39 and therefore permission to conduct operations over people. With such approval, more flights could be done, image pattern recognition could be trained to detect and classify objects with a machine-learning algorithm, and UAV videography could be applied to capture group spacing interactions, distance and dwell times to quantify potential disease transmission with more confidence.

Importantly, our focus on the recreational beach did not address potential beachgoer tourists and recreationists’ behaviors off the beach including streets, sidewalks other than the boardwalk, and of course restaurants, bars, shops, or other mass tourism amenities. Nonetheless, such areas and activities could be evaluated if streetcams or other source of pedestrian traffic are analyzed, including passive Smartphone geolocation-enabled tracking, geofencing social media postings and geotagged photographs within study area, installing wildlife cameras in public spaces, or designing a volunteer-based citizen science mapping campaign. Additionally, our study did not collect self-reported data from beachgoers themselves. Collection of demographic data from beachgoers could help managers and researchers understand the proportion of locals or tourists, as well as what specific management strategies individuals might be willing to accept to increase beachgoer safety.

Despite these potential limitations, our results point to an innovative application of webcam and drone imagery for public health monitoring in coastal environments. Coastal tourism localities continue to grapple with effective management strategies to reduce the spread of COVID-19, while simultaneously mitigating the economic fallout of the global pandemic. The results of this study illustrate implications for data collection to assist in management decision-making surrounding recreational beach amenities during these twin public health and economic crises. Strategies such as spatially and temporally distributing beach use, interpreting at access points, monitoring at height, and leveraging integrated management efforts will aid coastal managers who continue to craft indirect and direct management strategies. And, though the necessity of these efforts will hopefully abate in tandem with global pandemic, the methodological advances buoyed by COVID-19 will enable coastal researchers and managers to tackle new and pressing questions for years to come.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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