Madurapperuma, Buddhika, Jess Barger, Melissa Collin, Christine Emerson, Sean Fleming, Brian Murphy. 2019. "A Geospatial Recipe for Identifying Social Values and Fragmentation Issues of the Friends of the Dunes Land Trust." *Humboldt Journal of Social Relations* 41: 6–19.

A Geospatial Recipe for Identifying Social Values and Fragmentation Issues of the Friends of the Dunes Land Trust

Buddhika Madurapperuma[a], Jess Barger[b], Melissa Collin[a], Christine Emerson[a], Sean Fleming[a], Brian Murphy[a]

Abstract

The beach and coastal sand dunes comprise a dynamic and fragile ecosystem that provides a bounty of ecological services. These lands provide protection from coastal erosion and sea level rise, and are home to a rich biodiversity of plant and animal species in addition to their recreational value. The Humboldt Coastal Nature Center and the surrounding coastal dunes (HCNC) are managed as a land trust by Friends of the Dunes (FOD). FOD prioritize the restoration of dune habitats and encourages public involvement through community supported education and stewardship programs, guided nature tours, and naturalist training programs. The faculty, students, and staff of Humboldt State University regularly collaborate with FOD for research and volunteer programs. For example, mapping of the coastal dune habitats was performed in 2016, 2017 and 2018 by students from the intermediate remote sensing class and produced results addressing research gaps on social trails, dune movement, sea level rise, and invasive species distribution. This paper examines the natural and anthropocentric changes to the dune habitat from a geospatial perspective and identifies the social values of visitors to the dunes using HCNC visitor records. A small Unmanned Aerial Vehicle (sUAV) was used to acquire high-resolution imagery and then an orthomosaic image with 14 cm spatial resolution was created using the Structure from Motion (SfM) technique within the software Agisoft PhotoScan. sUAV imagery and existing maps were used to digitize social trails and distinguish them from official trails. Coastline change and dune movement were determined using UAV imagery, NAIP satellite imagery, and lidar data. Visitor records of the HCNC were analysed using word clouds and line charts. The results showed that many of the social trails emerged from the neighborhoods southeast of the FOD land trust. As an observation, some directional signs for public access trails pointed out from the trail and may have caused confusion to visitors and misguided them into creating social trails. The social trails have disturbed nesting colonies of bees and led to trampling of dune mat habitats and rare plant communities. A word cloud created from visitor logs depicted that visitors had wonderful experiences at the coastal dunes and beach and highly support the conservation efforts underway. In conclusion, we believe these findings can be used as baseline information to help inform management techniques in order to better fit the region of interest and support the mission of the Friends of the Dunes land trust.

Keywords

Coastal sand dunes, sUAV imagery, social trails, dune movement, visitor records

The coastal dunes of Humboldt Bay are a dynamic and constantly changing environment that provide ecological benefits for living communities and act as a protective barrier from coastal inundation, bolstering our tsunami defenses. From information shared between land managers, we know that recreational trails are being created by human visitors, and that this is causing habitat fragmentation for other species (Bradford and McIntyre 2007). What we do not know is the degree of human-induced impacts on the ecosystem and the resulting effects on native plant and animal populations. Consequently, our research looks to address the potential impacts of habitat fragmentation created by recreational trails and their effects on animal and plant populations. The objective of this research is to create a lens through which to view threats to native plants and wildlife in relation to anthropocentric environmental change, with the focus of the case study being on which ways the dune habitats and its biotic communities may be affected by members of the public. Our research addresses a major gap in current scientific literature and will contribute theoretically, empirically, and analytically to the ongoing debates in the fields of natural resource science, environmental protection and management, environmental education and interpretation, and social relations.

History of the Friends of the Dunes Land Trust

Friends of the Dunes (FOD) manages approximately 130-acres of coastal dunes on Humboldt Bay's North Spit as a land trust (Fig. 1). As land owned by a non-profit, the Friends of the Dunes land trust (FOD land trust) is considered privately owned, and is managed to benefit wildlife as well as the public. Currently, the trail system and adjacent Humboldt Coastal Nature Center (HCNC) are regularly used by neighbors, community members, and tourists year round. Prior to the purchase made in 2007, the "Stamps Property" was owned by a retired couple that shared coastal access with the community of Manila, which allowed many social trails to be created. Through access from the Stamps' home and neighboring dune properties, a network of user-created routes (UCRs) have existed on the property for decades as seen through aerial photos (Rochefort and Swinney 2000; Madurapperuma et al. 2018). UCR's are simply trails that become established by the public when they deviate from designated trails set up by the landowner or public agency. There are many issues surrounding the user-created and unregulated trails, particularly the matters of public safety, habitat degradation, spreading of invasive species, and impacts to wildlife (Leung 2010; Moreno-Casasola 1986). As a novel approach, sUAV imagery provides better spatial and temporal resolution, which can be utilized to monitor disturbances such as social trails, distribution of invasive species, and habitat fragmentation (Lamping et al. 2018).

Due to a combination of visitors and locals that are determined to walk UCRs that they created and enjoy, FOD inherited a suite of issues and responsibilities when they purchased the property. UCRs cause a multitude of problems for landowners and the public; they spread invasive plant seeds, fragment wildlife habitat, and create more area that managers must monitor for safety concerns. Creation of a formal trails plan began in 2007 when the property was purchased, in order to begin to attempt mitigating the effects the UCR's had already created, such as loss of native bee habitat and invasive species spread. During the creation of this plan, the issues facing

[a]Humboldt State University
[b]Friends of the Dunes
Corresponding Author: Buddhika Madurapperuma
Department of Forestry & Wildland Resources and Environmental Science & Management
Humboldt State University, Arcata, CA 95521
Email: bdm280@humboldt.edu

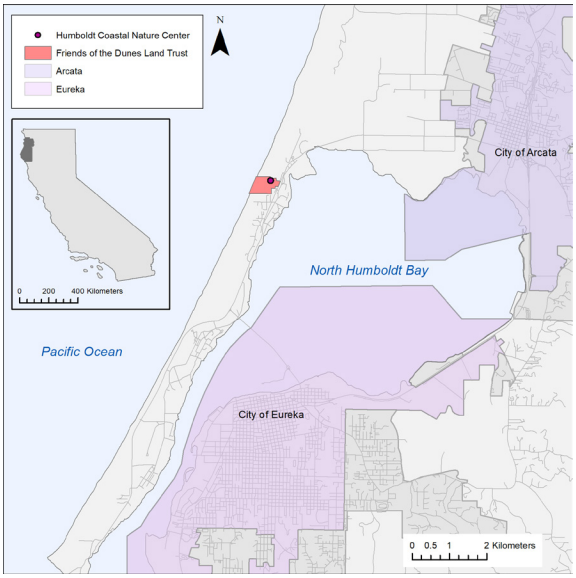

Figure 1. Locator map of the Friends of the Dune Land Trust and the Humboldt Coastal Nature Center in relation to the cities of Arcata and Eureka. Data from Humboldt County GIS data portal.

the dunes, as well as the needs of the community, were taken into consideration. Due to a high number of parallel and equivalent UCRs (i.e. trails that are relatively close together and provide similar access to the same area of the beach or dunes) that fragmented the unique ecosystem of coastal grasslands and dune-mat, closure of some UCRs was included into the plan. This induced controversy in the forms of public scrutiny and criticism. Many complaints stemmed from resistance to the idea of closing "historic trails" that the public previously accessed freely. Many local citizens had been using these areas for decades, considered the routes a part of the natural habitat, and were not willing to give up what many felt was their right to walk in the area that suited them most.

Due to the public outcry, many UCRs set for removal have remained untouched by FOD staff and volunteers for the past 12 years. Signs are placed at junctions of designated trails and UCRs to urge users to stay on the designated trails; however, these signs are ignored, removed, and frequently found broken by visitors. A great deal of time and effort goes into putting up these signs, as well as educating trail users about habitat fragmentation and the dune plant and animal species it affects. Friends of the Dunes organizes monthly walks on various dune properties in the area in the hopes that they can help to protect the dunes through education, as opposed to signs.

This is not an issue specific to FOD; balancing the needs of the environment with those of the public is a problem facing land managers everywhere (Coppes and Braunisch 2013; Korpilo et al. 2018; Walden-Schreiner et al. 2018). Locally, there is an ongoing debate between managers of coastal dunes and the public concerning the protection of these habitats and recreation needs. Members of the public are reluctant to see that UCRs are impacting the environment, and therefore take issue with FOD's desire to consolidate trails and provide more habitats, specifically for endangered coastal grasslands and dune-mat (Friends of the Dunes 2010). Part of this debate is a lack of quantifiable evidence that UCRs are degrading or taking away habitat, as most of the current evidence is based on logical deductions about the needs of endangered plant and sensitive animal species. If quantified impacts to the local environment could be determined, it would be a great tool for local land managers who have hit a wall with local government and citizens over the protection of the dunes.

Ecological and Social Values of the Dunes

Coastal dune ecosystems provide a wide ecological niche to house rich biodiversity unique to this ecosystem. For example, wild flora of the dune habitats support over 40 bee species as foraging and nesting grounds. Many of these species are ground-nesting, solitary bees that build

tunnels under the sand. This requires undisturbed areas where their offspring can spend the majority of the year developing safely (Friends of the Dunes 2019). The dune mat community provides micro-habitat conditions to grow rare and endangered plants, such as the Humboldt Bay wallflower (*Erysimum menziesii eurekensii*) and the Beach layia (*Layia carnosa*) (Friends of the Dunes 2015). These plants require open habitat where they can be exposed to low levels of sand movement. Due to their short and succulent nature and the lack of large animals in the dunes, many of the species do not survive if they experience any trampling (Friends of the Dunes 2017). The major threats for the endangered plants were reported as invasive species (i.e. European beach grass, rattlesnake grass, and yellow Bush) and trampling due to social trails (Friends of the Dunes 2015; Cortenbach et al. 2017; Julian 2012; Madurapperuma et al. 2018; Pickart and Patrick 2019).

Landowners with trail systems are responsible for designating, maintaining, and monitoring the impact that trails have on the environment, especially to listed species. Anecdotal evidence by FOD employees and volunteers show that endangered species are often found destroyed by human and domestic dog footprints. Additionally, UCR's provide access to remote areas which encourages illegal or potentially dangerous activities. It is not uncommon to find hypodermic needles, broken glass, and biologically dangerous items in remote areas of the dunes (J. Barger, personal communication, February 20, 2019). Due to limited resources, FOD is only able to monitor the designated trails on the property. The purpose of the FOD land trust is to provide places where members of the public can experience these unique habitats safely, but current conditions put the habitat at jeopardy, and potentially the visitors of the dunes as well (J. Barger, personal communication, February 20, 2019).

METHODS

This study outlines the mixed-methodology of using geospatial and social science qualitative methods (Rindfuss et al. 1998) to portray the land and ecological change in the FOD. Through the reconnaissance survey and panel discussion with the FOD staff, we located the majority of large-scale UCRs in the southern portion of the FOD. Using this information, two mission plans were developed and executed to take high resolution aerial imagery. Images were collected using a DJI Mavic Pro small Unmanned Aerial Vehicle (sUAV) for a 31 acre plot of the southern dunes at a height of about 80 meters (Madurapperuma et al. 2018).

High-resolution data is useful in gathering fine scale characteristics, such as slope, aspect, and digital elevation models. NAIP imagery provides high resolution images within 1 meter spatial resolution throughout the United States every 3–5 years. Using the collected aerial images, an orthomosaic image was created using the Structure from Motion (SfM) technique in the Agisoft PhotoScan software. A digital elevation model (DEM) with a resolution of roughly 14 centimeters was also created in Agisoft with the aerial images using dense-point cloud data to show terrain characteristics and dune movements. Data available to the public for download from federally funded programs, such as NAIP imagery, between 2004 and 2014 from U.S. Department of Agriculture's (USDA) Geospatial Data Gateway and lidar imagery between 2010 and 2012 from National Oceanic and Atmospheric Administration's (NOAA) were used to detect coastline changes using screen digitizing (Kenas et al., 2016). UCRs and trails were digitized and categorized based manually, using trails maps from the FOD and

the orthomosaic for reference. The images were also utilized to identify changes in dune physical characteristics that could be linked to human activities during the peak visitor season.

The social data were gathered from the visitor log at the HCNC from 2011 to 2017. This included comments, where they were visiting from, and the date that they visited. In addition to HCNC visitor logs, clicker counts of the number of visitors to HCNC were documented. The data was analyzed using word clouds and line graphs.

The high resolution geospatial data was used to generate a visualization of the UCRs and to delineate invasive species habitats. The historical visitor records data were plotted to see the frequency of human activities throughout the year. Knowing when the peak time of visitor arrival occurs is useful in determining the best time to collect geospatial data again for better understanding on how human activities impact for fragmentation i.e. UCRs.

RESULTS

The results of this study fall within two broad themes: geospatial and social dimensions. Geospatial analysis was conducted by mapping the social trails and coastline changes in the dune ecosystem using high resolution images and lidar data. The social values of the dunes were graphically represented using the visitor records data. By coupling geospatial and social science data in this study, we determined useful finds regarding the relationships between anthropogenic disturbances and how visitor peak times are associated with ecological fragmentation.

Ecological and Social Values

It's estimated that for every meter of trail being monitored and maintained, there are almost two meters of undocumented, unmonitored trails. This means that the impact to the dune habitat through fragmentation and habitat loss is three times as what was anticipated in the FOD Trail Plan.

Remote sensing imagery is one of the newest and most cost-effective tools in a land manager's toolbox. The varying and ever-changing topography of the dunes causes challenges for mapping and maintaining an inventory of the social trails and presence of invasive species. During World War II, the United States Coast Guard patrolled the north spit coast of Humboldt Bay; however, recognition of these social trails from aerial imagery was unsuccessful (Friends of the Dunes 2010). Complicating this task further is the limitation of inadequate staffing and funding for monitoring projects. A multi-scale study on dune habitats was carried out by a group of undergraduate students at Humboldt State University, which identified social trails from sUAV imagery through the digitization social trails visible in the imagery (Cortenbach et al. 2017; Lamping et al. 2018). The total length of trails given in Fig. 2 was 911 m. Of the unmonitored trails, estimated length for minimal use was 317 m, moderate use was 159 m, and heavy use was 168 m. The invasive *Briza maxima*, with proximity to sea shore and the study area, was mapped using *in-situ* data collection.

During the peak visitor season in July and August, a large number of people visit the dunes from many regions. A noticeable amount of social trails have arisen due to off-trail use by visitors when accessing sites of interest and when attempting to take shortcuts. This leads to significant disturbance of endangered herbaceous communities and high risk of habitat loss from the increased fragmentation of natural areas. Habitat fragmentation caused by UCRs increases spatial isolation and could eventually lead to the spread of invasive species and reduction of native flora and fauna. These changes disrupt the

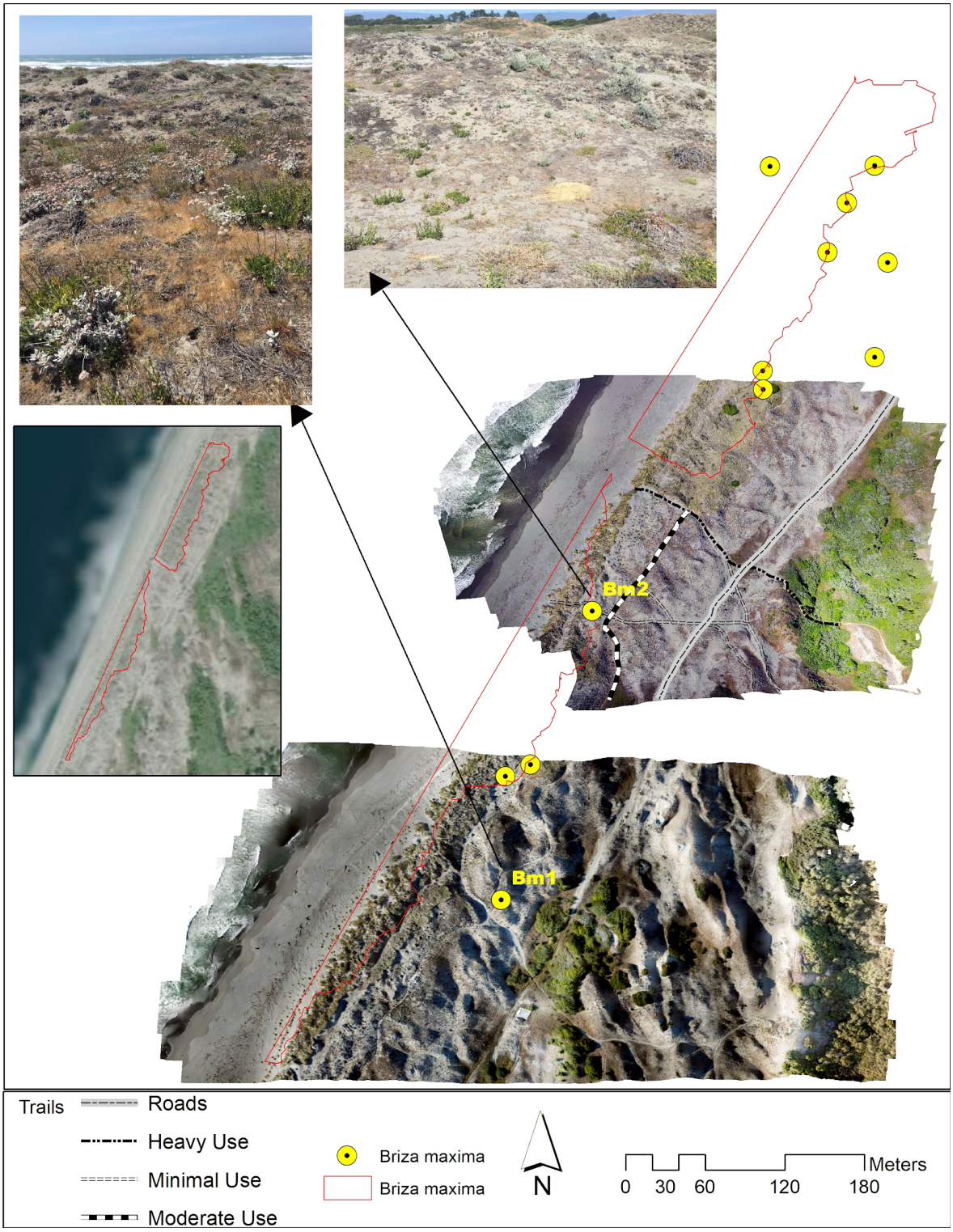

Figure 2. Social trails identified using sUAV imagery taken at the Friends of the Dunes (FOD) in 2017 (above image) and the southern FOD in 2018 showing dynamic sand dune habitats and prominent user-created rtoutes (below image). *Briza maxima*, annual invasive grass is shown by red polygon and dominant locations (yellow circle). The species occurrence at two sites (Bm1 and Bm 2) is displayed with photos.

essential spatial component necessary for genetic variation and could alter essential processes, ultimately leading to the risk of local extinction. Reduced genetic variation could also potentially hinder a species' ability to adapt to environmental changes (López-Pujol et al. 2003). For example, bee nests are highly sensitive to disturbance. Many of the bee species nests are just below the surface of the soil crust, making them extremely vulnerable to trampling. Other species, such as the silver bee nest in blown out areas, in open sand, or near the base of vegetated dunes. These kinds of nesting locations are often used as parts of UCRs because the sparse vegetation and gentler slopes make these areas easier for people to walk through.

Dune Movement

Coastal sand dunes are constantly shifting due to coastal erosion and the continual movement of the dunes by the wind (Mitasova 2005; Mull and Ruggiero 2014, Labuz 2015). The foredunes, which in our study site are the dunes west of the Waterline Trail, are dominated by dune mat vegetation or European beachgrass (Madurapperuma et al. 2018). These foredunes have only localized areas of sand movement. The dunes move slowly through small pockets or "tongues" of sand, especially during the summer months. Additionally, the large areas of sand that were shown to have significant movements are also expected to be that of a specific microhabitat—a moving sand sheet. Not only is dune movement is important for nutrient cycling, but it provides a niche for unique specialist species, and helps facilitate a diverse dynamic ecological community (Moreno-Casasola 1986). During the summer, the sand is dry and very susceptible to being moved by the wind (Rader et al. 2018, Pickart and Patrick 2019, Hapke et al. 2006, Hapke et al. 2009). The winds on this portion of the coast blow primarily from the northwest in the summertime. This wind pattern causes the formation of parabolic dunes, the type of dunes seen on the spits of Humboldt Bay (Moffat and Nichol 2013; Pickart and Patrick 2019; Hapke et al. 2006). Within the local dune ecosystem, very large unvegetated parabolic dunes, known as moving dunes, are slow to become colonized by plant species, and slowly move toward the southeast during the summer (Friends of the Dunes 2017).

Remote-sensing techniques are an important way to measure dune movement and/or expansion through the use of high resolution images. For example, SUAV imagery provides better sampling efficiency and data quality, which is useful in capturing the micro-topographical variation of dune ecosystems (Madurapperuma et al. 2018). According to the 2018 Lamping et al. study on dune movement, the largest amount of change can be seen on the northeastern facing slopes that are not directly exposed to wind from the ocean.

Kenas et al. (2016) used NAIP imagery and lidar data to measure dune movement at the Male'l Dunes and found slight dune movement and expansion towards the east between 2004 and 2014 (Fig. 3).

Social Values

Humboldt Bay beaches and dunes provide high amounts of social and recreational value as areas for hiking, walking, photography, and general recreation. The FOD land trust is frequently visited by not only locals, but tourists from all over the world (J. Barger, personal communication, February 20, 2019). Visitors' personal experiences, as well as their perceptions of the FOD land

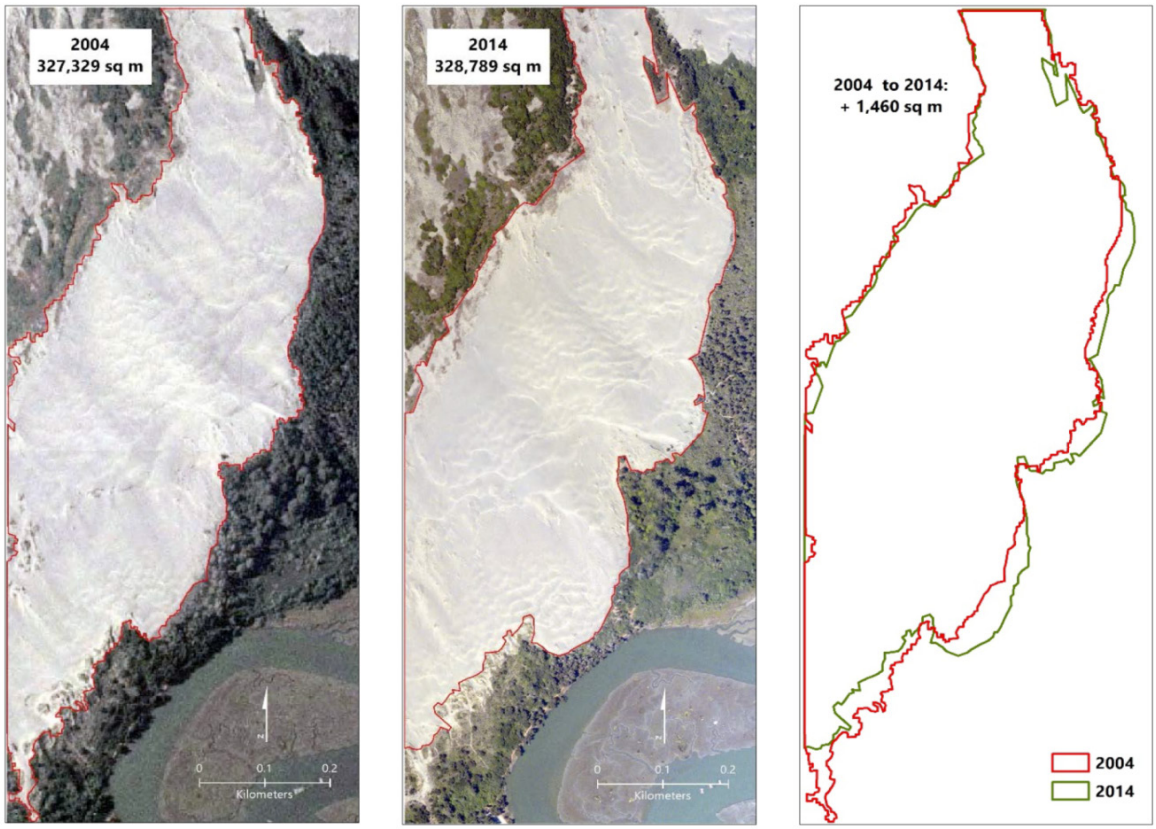

Figure 3. Coastal shoreline changes of Ma-le'l Dunes in Humboldt County between 2004 and 2014 (Left 2004 NAIP imagery and digitized shapefile, middle 2014 NAIP imagery and digitized shapefile, right comparison of 2004 and 2014 digitized shapefile) (Source: Kenas et al. 2016).

word cloud (Fig. 4). The frequency of words is represented by font size, with the most frequent words being the largest. The majority of visitors had great experiences at the FOD land trust based upon recreational value of the unique habitat, walking trails, and fun activities, such as restoration. The word cloud depicts visitor's satisfaction and their attraction to the FOD land trust. Visitors left reviews and comments with frequently used words such as love, cool, nice, great, beautiful, amazing, gorgeous, wonderful, awesome and fabulous etc.

The visitor records from HCNC were accumulated monthly and plotted from 2011 to 2016 (Fig. 5). The average monthly visitor records for the dunes was 125 over 6 years. 2015 had the largest number of HCNC visitors, with an average of 170 visitors per month. The visitor season is observed as July and August with an average of 214 and 178 visitors respectively.

Visitor records that were obtained from the clicker counts were plotted from 2012 to 2017 (Fig. 6). A few months of visitor records were missed in 2012. An average of 604 people per month visited the dunes from 2013 to 2017. The largest number of visitors (with average monthly

Figure 4. Word cloud of visitor comments from the FOD land trust visitor logs. Larger words indicate more frequent occurrence in the comment section of the visitor logs.

visitors) visited the HCNC in 2013, with peaks in April and October. Overall, a large number of visitors were observed in July and August (with an average of 861 and 747 respectively) at the dunes.

The visitor records from clicker counts indicate a large, consistent usage over five consecutive years of the HCNC with close to double the number of visitors during the summer seasons. Additional beach usage likely occurred, but was not documented, from those who visited outside of HCNC hours, visited using a different entrance, or were missed during the clicker count.

DISCUSSION

This study involved both a geospatial and social science lens in order to analyze the continuous human and natural impacts on the Humboldt Bay coastal dune ecosystem. The research conducted provides substantive information which could be used by decision makers for coastal habitat management.

High resolution aerial imagery is useful for delineating social trails and mapping invasive species habitats (Cortenbach et al. 2017; Madurapperuma et al. 2018; Lamping et al. 2018), which is crucial information for dune managers to implement the best management plans to conserve dune habitats. The ability to recognize trails from medium resolution images (i.e. Landsat) is not feasible; however, orthomosaic sUAV imagery overcome the limitation of recognizing social trails through open sand and sparse dune mat vegetation. Compared to Landsat imagery, sUAV imagery has more advantages: (i) high spatial resolution (~14 cm), (ii) high temporal resolution, and (iii) associate with elevation data which can create DEM.

Invasive species became dominant at Humboldt coastal dune areas, and we mapped *Briza maxima* colonization along the foredune of FOD (Fig. 2). Transgressive grasses and forbs, such as *Ammophila arenaria* and *Lupinus arboreus*, encroach towards dunefield due to wind blowout (Pickarta and Patrick 2019; Madurapperuma 2018). As Fig. 2 showed, the beach pine forest

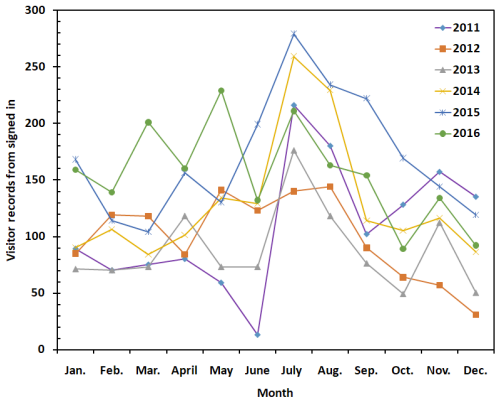

Figure 5. Visitor records at Friends of the Dunes from 2011 to 2016.

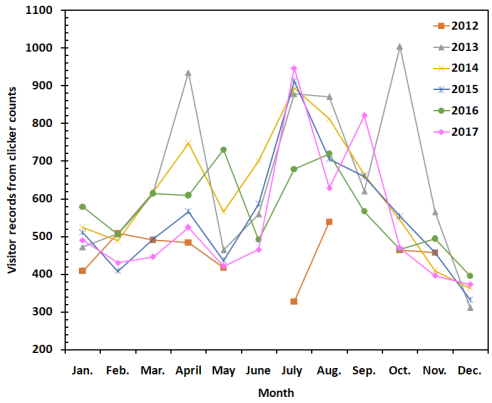

Figure 6. Visitor records at Friends of the Dunes from clicker counts from 2012 to 2017.

was scattered around central and far-east dune which permits less barrier for wind blowout. Lamping et al. (2018) and Madurapperuma et al. (2018) mapped invasive species distribution in these areas using SUAV imagery and supervised classification techniques. The dune habitat restoration was employed on the North Spit of Humboldt Bay by manual removal of exotic species (i.e. *Lupinus arboreus*, *Vulpia bromoides*, and *Holcus lanatus*) through volunteer programs resulting in re-colonization by native species (Pickart et al. 1998).

According to Kenas et al. (2016), findings on dune movement in the Malel'l dunes between 2010 to 2012 reported to be 0.5 m to 1.0 m with an elevation gain of six to seven centimeters. Similarly, Hapke et al., (2009) reported 0.3 m–0.5 m shoreline change in Northern California. In particular, Eureka attributed long-term shoreline change patterns due to variations in waves and currents (Hapke et al. 2006; 2009). The geomorphology of the Northern California coastline has contributed such coast line changes via cliff formation, crenulated headlands and embayments (Hapke et al. 2009).

A participatory GIS (PGIS) approach would be an ideal scenario to collaborate with the local neighboring community for restoration programs to control invasive species, and to make an awareness program on UCRs and their impact on native and invasive flora. Participatory GIS has the ability to inform land managers, environmental educators, and environmental interpreters on aspects of the ecosystem being studied in ways that are otherwise impossible. By incorporating the community into the process of conservation, they receive power over how the land they interact with is represented into data which will, in turn, be applied to how it is managed (Tsai 2013). Public PGIS can redistribute power to the visitors because they can depict their subjective view of the dunes, and how management affects their experiences (Tsai 2013). However, while PGIS can greatly increase the amount of data, representation is still limited by technological and social obstacles (Elwood 2008).

Many non-profit organizations, such as FOD, have limited staff and funding, making cost and time-effective techniques invaluable. From a land manager and dune ecology perspective, aerial imagery is an incredible time-saving resource that can allow managers to visually evaluate an environment that has topographical barriers, such as high dunes, some of which are forested. Additionally, it allows managers to capture changes in sand movement that can otherwise

only be measured using expensive lidar experiments that require replicable surveys, and are not always possible in the ever-changing terrain, such as a moving sand sheet.

When the cause of the sand movement is UCRs, the implications of PGIS are not only ecological, but social. Many members of the public need some sort of tangible effect of their fragmentation to understand their impact, and cause a change in their behavior. The results of this research can be used to demonstrate to the public how many acres a UCR fragments, and how many square feet of dune mat vegetation are lost, etc., which can be used in environmental education and interpretation programs. This data could be incorporated into a web page, facilitating the public with the data that PGIS collects (Tang 2016). A mobile app could also increase the amount of educational material the FOD visitors could receive without building new infrastructure, such as signs (Lorenzi 2014). Using PGIS in the form of a mobile app could allow visitors to generate data that has been spatially located and time stamped.

As visitor records portray (Figs. 5 and 6), during the summer or tourist season, there is a possibility that UCRs would be reinforced or widened by unfamiliar tourists. The sUAV imagery can monitor, during visitors peak times, social trails, and can be coupled with recruiting more volunteers for patrolling and conducting awareness programs to mitigate the human impact on dune habitats. In addition, waypoints could be incorporated into an app in order to ease visitors into reorienting themselves if they get lost. Waypoint systems can function without the use of network access, making them a valuable tool for hikers who experience loss of cell signal or GPS failure (Lorenzi 2014). This assisted navigation applied at the FOD land trust could redirect visitors off of UCRs and to the designated trails. Alternatively, during non-tourist season, it could be predicted that new social trails would be created by locals that have a higher level of ownership for the area, and are more likely to "explore" in off-trail areas, creating UCRs in the process.

This research opens the door into studying human behavior in the context of natural resource ownership by evaluating the effect of different kinds of use on a habitat. Dunes are a particularly responsive habitat; it only takes a few visitors to walk in the same path to establish a path through the vegetation. Future applications of this research could help determine in which months to focus education about trails, and to quickly determine which UCRs are becoming most established or most detrimental.

While land managers will likely continue to face challenges surrounding public access and trail maintenance, the increased integrated use of GIS technology and land trust organizations can aid in developing more efficient and effective education and stewardship strategies for combating habitat fragmentation and degradation created by UCRs.

CONCLUSIONS

This study presents an overview and methodology on the use of geospatial technology, such as sUAVs, to monitor changes in a coastal dune environment. Because this type of analysis can be used to inform management and policy decisions, it has implications in the fields of natural resources, ecological restoration, environmental education, and environmental interpretation. Geospatial analysis and the use of remote sensing allow for improved information gathering because of the high spatial and temporal

resolution that sUAV data provides. As shown in this study, sUAVs are extremely useful in generating valuable geospatial data, such as social trail identification, with high accuracy and relatively low cost. This valuable data can be used to monitor the most current state of the dunes and make models and predictions of future land use/cover changes. Future use of PGIS could also play an integral role in collecting data and incorporating the visitors into the conservation process. Understanding where social trails are emerging and being able to map the extent of invasive species is crucial for the FOD land trust in order to implement best land management practices and meet their goals of ecological restoration of native plant habitats, controlling invasive plant populations, and conservation and preservation of coastal land. Meeting these goals is important because of the high value the public has assigned to these areas, as evidenced by the visitor records charts and word cloud presented in this study.

ACKNOWLEDGEMENTS

James Lamping, an FAA Certified Remote Pilot, flew the UAV under FAA regulations, and with permission from HSU Unmanned Aircraft System (UAS) Review Committee and Friends of the Dunes. The authors gratefully acknowledge 2016, 2017, and 2018 students from the intermediate remote sensing class, who collected the geospatial data for this study.

REFERENCES

Bradford, L.E. and McIntyre, N. 2007. "Off the Beaten Track: Messages As A Means Of Reducing Social Trail Use At St. Lawrence Islands National Park." *Journal of Park and Recreation Administration* 25(1).

Coppes, J. & Braunisch, V. 2013. "Managing visitors in nature areas: where do they leave the trails? A spatial model." *Wildlife Biology* 19(1) DOI: 10.2981/12–054

Cortenbach, J.W., Arthur, T., Johnson, G., Trockey, E., Borrowdale, C., Close, P., Fleming, S., Collin, M., Luckens, E., Thuresson, K., Kelley, A., Saint, R., Osipowitsch, I., Rodriguez, K., Settelmayer, M., Douglass, N., Lanz, C., Le Donne, T., Bogner,S., Castro, S., Mayfield, N., Williams, R., Dellysse, J., Lamping, J. and Madurapperuma, B.D. 2017. "Mapping Ma-le'l Dune Coastal Ecosystem: A Multiscale Approach Using UAV Images." INRSEP/CNRS UG Scientific Research Symposium, October 2nd, Humboldt State University Library, Volume: 2.

Elwood, S. 2008. "Volunteered Geographic Information: Future Research Directions Motivated by Critical, Participatory, and Feminist GIS." *GeoJournal* 72(3&4):173–183. doi:10.1007/s10708-008-9186-0.

Friends of the Dunes. 2019. "Solitary Bees." FOD website. Retrieved February 25, 2018. (https://www.friendsofthedunes.org/science-nature)

Friends of the Dunes, 2017. "Coastal Naturalist Manual: A guide to understanding the natural history of the Humboldt Bay region and sharing it with others. Eureka, CA: Times Printing."

Friends of the Dunes. 2015. "Coastal Development Permit Application Notice." Retrieved October 25, 2018 (http://www.friendsofthedunes.org/nature-center/FOD_CDP_Application_5_19_15%20WEB.pdf)

Friends of the Dunes. 2010. "Public Access Trail Plan for the Friends of the Dunes." Humboldt Coastal Nature Center, Friends of the dune. (Unpublished).

Hapke, C.J., Reid, D. and Richmond, B. 2009. "Rates and Trends of Coastal Change in California and the Regional Behavior of the Beach and Cliff System." Journal of Coastal Research 603–615.

Hapke, C.J., Reid, D., Richmond, B.M., Ruggiero, P., and List, J. 2006. "National Assessment of Shoreline Change: Part 3: Historical Shoreline Change and Associated Coastal Land Loss Along Sandy Shorelines of the California Coast: U.S. Geological Survey Open-file Report 2006: 1219" (http://pubs.usgs.gov/of/2006/1219)

Julian, L.S. 2012. "A Comparison of Bee Fauna in Two Northern California Coastal Dune Systems." Master Thesis, Humboldt State University. Retrieved October 20, 2018 (http://hdl.handle.net/2148/1250)

Kenas, E., Barry, T. and Bauss, C. 2016. "Measuring Dune Movement Using Lidar and NAIP Imagery." A project report completed for the partial fulfillment of intermediate remote sensing class, 1–15pp. (Unpublished).

Korpilo, S., Virtanen T., Saukkonen T., Lehvävirta S. 2018. "More than A to B: Understanding and managing visitor spatial behaviour in urban forests using public participation GIS." *Journal of Environmental Management* 207. doi.org/10.1016/j.jenvman.2017.11.020

Łabuz, T.A., 2015. "Coastal dunes: Changes of Their Perception and Environmental Management". In Environmental Management and Governance. Springer, Cham. 323–410.

Lamping, J., Murphy, B., McFarland J., Porteous Z., Smith C., Monroe S., Kennedy, J., MacAdam S., Bueche, S., Becker, R., Massey, T., Sandhu C., DeYoung, K., Wood, S., Corro, L., Mcdermott, M., Emerson, C., Christiansen, A., Stevenson, M., Magstadt, S., Thompson C., Thomas, C., Stairs, G., Soliz, J., Madurapperuma, B., Dellysse, J., Collin, M. and Fleming, S. 2018. "UAV Photogrammetry for Surveying Dune Habitats: A Review of Research Needs of the Friends of the Dunes Land Trust." INRSEP/CNRS UG Scientific Research Symposium, September 28th, Humboldt State University, Library, 2.

Leung, Y., Newburger, T., Jones, M., Kuhn, B., and Woiderski, B. 2010. "Developing a Monitoring Protocol for Visitor-Created Informal Trails in Yosemite National Park, USA." *Environmental Management* 47(1): 93–106. doi:10.1007/s00267-010-9581-4

López-Pujol, J., Orellana, M.R., Bosch, M., Simon, J. and Blanché, C. 2003. "Effects of Habitat Fragmentation on Allozyme Diversity and Conservation Status of the Coastal Sand Dune Plant *Stachys maritima* (Lamiaceae) in the Iberian Peninsula." *Plant Biology* 5(5): 504–512.

Lorenzi, D., Vaidya, J., Chun, S., Shafiq, B. and Atluri, V. 2014. "Enhancing the Government Service Experience Through QR Codes on Mobile Platforms." *Government Information Quarterly*, 31(1): 6–16. doi:10.1016/j.giq.2013.05.025

Madurapperuma, B., Close, P., Fleming, S., Collin, M., Thuresson, K., Lamping, J., Dellysse, J. and Cortenbach, J. 2018. "Habitat Mapping of Ma-le'l Dunes Coupling with UAV and NAIP Imagery." *Multidisciplinary Digital Publishing Institute Proceedings* 2(7):368. doi:10.3390/ecrs-2-05182

Mitasova, H., Overton, M., and Harmon, R.S. 2005. "Geospatial Analysis of a Coastal Sand Dune Field Evolution: Jockeys Ridge, North Carolina." *Geomorphology* 72(1&4): 204–221. doi:10.1016/j.geomorph.2005.06.001

Moreno-Casasola, P. 1986. "Sand Movement as a Factor in the Distribution of Plant Communities in a Coastal Dune System." *Vegetation* 65(2): 67–76. doi:10.1007/bf00044876

Mull, J. and P. Ruggiero. 2014. "Estimating Storm-Induced Dune Erosion and Overtopping along U.S. West Coast Beaches." *Journal of Coastal Research* 30(6):1173–1187. doi: 10.2112/JCOASTRES-D-13-00178

Moffat and Nichol. 2013. "Coastal Regional Sediment Management Plan: Eureka Littoral Cell, California." U.S. Army Corps of Engineers, Los Angeles District. M&N File No. 6731–06.

Pickart, A.J., and Patrick A.H. 2019. "Spatio-temporal geomorphological and ecological evolution of a transgressive dunefield system, Northern California, USA." *Global and planetary change* 172 : 88–103.

Pickart, A.J., Miller, L.M. and Duebendorfer, T.E. 1998. "Yellow bush lupine invasion in northern California coastal dunes I. Ecological impacts and manual restoration techniques." *Restoration Ecology* 6(1): 59–68.

Rader, A.M., Pickart, A.J., Walker, I.J., Hesp, P.A. and Bauer, B.O. 2018. "Foredune Morphodynamics and Sediment Budgets at Seasonal to Decadal Scales: Humboldt Bay National Wildlife Refuge, California, USA." *Geomorphology* 318: 69–87.

Rochefort, R.M. and Swinney, D.D., 2000. "Human Impact Surveys in Mount Rainier National Park: Past, Present, and Future." I Cole, DN; McCool, SF; Borrie, WT; O'Loughlin, J., comps. *Wilderness science in a time of change conference* (5):165–171)

Rindfuss, R.R., Stern, P.C., Liverman, D. and Moran, E.F., 1998. "People and Pixels: Linking Remote Sensing and Social Science." *People and Pixels: linking remote sensing and social science*.

Tang, Z., Zhou, Y., Yu, H., Gu, Y., and Liu, T. 2016. "Developing an Interactive Mobile Volunteered Geographic Information Platform to Integrate Environmental Big Data and Citizen Science in Urban Management." *Seeing Cities Through Big Data*. Springer, Cham. doi:10.1007/978-3-319-40902-3_4.

Tsai, B., Lu, D., Chung, M., and Lien, M. 2013. "Evaluation of PPGIS Empowerment — A Case Study of Meinong Yellow Butterfly Valley in Taiwan." *Journal of Environmental Management* 116: 204–212. doi:10.1016/j.jenvman.2012.12.005

Walden-Schreiner C., Dario Rossi S., Barros A., Pickering C., Leung, F. 2018. "Using crowd-sourced photos to assess seasonal patterns of visitor use in mountain-protected areas." *Ambio* 47:781–793 doi.org/10.1007/s13280-018-1020-4

ABOUT THE AUTHORS

Buddhika Madurapperuma, Ph.D., is a Lecturer/Research Associate in the Department of Forestry and Wildland Resources and the Department of Environmental Science and Management. Madurapperuma teaches geospatial classes including GIS and Remote Sensing, and Forest Ecology. He conducts multidisciplinary research on coastal habitat mapping, invasive species, wildfire severity mapping, and post-fire seed germination/recruitment. Madurapperuma is keen on engaging student's research projects and also collaborating with students and faculty for his research projects.

Jess Barger earned her B.S. in Wildlife Management and Conservation from Humboldt State in 2015 before working in environmental education and habitat restoration. She is currently pursuing a Master's Degree in Natural Resources, researching the impact of environmental art on community and individual values.

Melissa Collin is currently an undergraduate at Humboldt State University majoring in Environmental Science and Management, with a concentration in Geospatial Science and minoring in Ecological Restoration. This coming fall she will begin her studies with HSU's graduate program, working towards a master in Natural Resources. She is currently working as a GIS Specialist for an environmental consulting company, and was previously an Instructional Student Assistant for the geospatial curriculum. Melissa's research interests and experience include web development, watershed modeling, land cover analysis, cartography, and coastal habitat mapping.

Christine Emerson is an undergraduate student majoring in Environmental Science and Management with a focus in Geospatial Science. She is currently in her last year at Humboldt State University and during her time there has worked on research topics such as site suitability for hydroelectric turbines, the effects of slash piles on timber forests, and the changing range of wolverines in North America.

Sean Fleming is an undergraduate student majoring in Environmental Science with a focus in Geospatial Science and minoring in Geography. He is the former Instructional Student Assistant for the geospatial curriculum. Sean has done a majority of his research on watershed and riparian habitat modeling, fire emission modeling, alpine and arctic remote sensing, and political mapping.

Brian Murphy is an undergraduate student majoring in Environmental Science with a focus in Geospatial Science and minoring in Geography. He is a current Instructional Student Assistant for the geospatial curriculum. Brian specializes in cartography, and uses design and graphics as a bridge between the scientific community and the general public.