Best Practice

The Implications of Unreported Tidal Fluctuations in Satellite Imagery

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Abstract: Remote sensing data and satellite imagery can be challenging to accurately produce, especially when tidal ranges affect the variation of land cover types daily, which are not represented in any Earth Map layer. Inconsistencies among maps create confusion and daily tidal fluctuations have effects on not only the land type and change over time, but many coastal species and their behavior like the American herring gull. Three grids were established on Fire Island, NY to understand if there had been a land change over time, if there is a difference among one forestry and three land cover Earth Map layers, their accuracy to ground cover photos collected through the Global Learning and Observations to Benefit the Environment (GLOBE) app, tidal height differences, and difference in activity of American herring gulls between high and low tide. This was done by utilizing the GLOBE Program to establish grids, collect ground cover photos using the GLOBE observer app, a ground count at 10-minute intervals for American herring gull data, Landsat time-series for land change over time, and Collect Earth Online for land cover type categorization. The results showed that the layers presented inconsistencies among one another and when compared to ground cover photos. There was also a significant difference in daily tidal fluctuations between high tide and low tide, a significant difference in American herring gull activity between high tide and low tide, and the land had changed over time from the year of 1984 to present. These findings suggest the value of daily tidal representations in satellite imagery, especially land cover layers like those presented in Earth Map, as well as the implementation of ground cover photos in the production of satellite imagery to produce the most accurate and usable maps possible.

Keywords: tides, satellite imagery, ground photos, land cover, American herring gull

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1. Introduction

Remote sensing is the acquisition of information from a distance and computing it into satellite imaging of various landcover types used for various purposes and research domains. It creates a map, pixel by pixel, of reflectance values by using sensors that capture electromagnetic energy emitted by the earth to make up raster grids arranged in columns and rows. Numerous sensors to capture this energy have been launched by either space-borne (orbiting around earth) or aerial imaging systems (attached to aircraft). Remote sensing is useful for solving problems and producing landcover maps which can be used within multiple disciplines (Stevens et al., 2012).

The Global Learning and Observations to Benefit the Environment (GLOBE) Program utilizes data collection and analysis from volunteers to improve the science of earth mapping (NASA, 2025). GLOBE Observer app users can collect data through photos, utilizing their personal cell phones, of various earth surface covers. These surface covers could include ocean, bare ground, developed land, etc. Participants can then upload their photos to the GLOBE open-source database utilizing the GLOBE Observer app, which is free of charge to anyone. The surface-based observations captured through photos are utilized to better our understanding of earth's various surfaces and challenge established-ideas about certain areas of the world. GLOBE can also be a tool for small to large research projects within a variety of scientific disciplines.

Earth Map (Morales et al., 2023) is a free web browser platform designed to present and analyze multi-temporal and climate datasets (Gorelick et al., 2017). It is a novel tool utilized for its climate assessment, advanced land monitoring, and fast performance. Earth Map has multiple different categories that umbrella various data sets. Within the Landcover umbrella there are several layers, or different data sets, to represent the various land cover types of the surface of the earth. Due to the nature of having several sources provide representations, there may be discrepancies among data sets and whether they agree with one another.

Collect Earth Online (CEO) is an open-source tool that can be used to classify and categorize various land cover types (Saah et al., 2019). CEO is useful for a more zoomed in approach to interpreting areas and can be applied over time to determine changes in an area. Information categorized in CEO can be stored and utilized in data analysis and compared to other satellite imagery.

The American herring gull is a large gull species living in various habitats across North America, typically near water. Their population numbers are abundant, and they can be found along coastlines, major rivers, and large lakes. It can be identified by its white head, pale eyes, grey wings with black tips, pink legs, and a yellow beak with a red spot (Weseloh et al., 2024; National Audubon Society, n.d.). Their great population numbers and notable identification make them a useful seabird species to monitor for activity changes per tide range.

Validating remote sensing data can be challenging, especially when attempting to identify tidal ranges and land cover change over time. Satellite imagery can also be inaccurate in appropriately identifying certain land cover types which can hinder research by providing false information on the landscape (Geyman & Maloof, 2020). Daily tidal changes and ranges occur in coastal areas around the world which temporarily and/or permanently alter the landscape and affect the activity of many seabird species like the American herring gull (Daunt et al., 2002). Many user-friendly and science-based satellite imaging datasets, utilized through Earth Map, do not account for daily fluctuations in landscape due to tidal ranges. This is important because understanding how the landscape affects seabird species within it helps us understand the ecological implications of these daily and/or long-term changes. Landsat time-series in Google Earth Engine (https://earthEngine.google.com) can help scientists understand long-term changes of coastal areas, but daily changes pose an important factor in ecological activity within any given area. Interpreting everyday fluctuations ultimately provides relevant information to long-term landscape change and many ecological factors.

There have been some studied and established techniques for monitoring and measuring tidal ranges like utilizing Landsat time-series to reconstruct tidal spatial structure (Geyman & Maloof, 2020), the waterline method (Kang et al., 2023), and utilizing satellite altimeters (Pan et al., 2025). However, benchmark studies are lacking on comparing the performance of these techniques and algorithms (Vos et al., 2023), not to mention the lack of connection between these techniques and their implications on accurately assessing ecological activity; like seabird species such as the American herring gull.

Strategies for addressing these gaps could include the implementation of ground cover photos and tidal gauges. Ground cover photos utilized through the GLOBE Observer app could be merged alongside satellite data to support the production of accurate mapping images. Collecting daily information from tidal gauges to create tidal lines and tide range representations could enhance land cover maps by providing another layer for researchers to use. Additionally, providing the opportunity for scientists to communicate with map developers to discuss maps and any procedures/techniques used, could allow researchers to guide projects and contribute to satellite map layers.

Analyzing the study area with Landsat time-series imagery reveals that its landscape has undergone changes in size and/or shape over time. The analysis of four different satellite imagery datasets, presented in Earth Map, will not represent daily tidal changes nor accurately present the various land cover types shown in ground level photos 100% of the time. The agreement among Earth Map layers will not all be 100%. Utilizing the NOAA tide gauge within the study area (NOAA, n.d.), there will be a significant difference in the tidal heights between high tide and low tide. Connecting the tidal differences to seabird species, there will be a significant difference of American herring gull activity between high tide and low tide.

This study will assess whether the landscape has changed over time using the Landsat time-series database. It will also use ground cover photos to evaluate four Earth Map datasets to determine if they accurately represent the tidal changes in the area, whether they all represent the various land cover types appropriately and agreeing in the same way. In addition, the significance of the difference between high tide and low tide will be checked. Lastly, an ecological connection will be made by testing the difference between American herring gull activity from high to low tide and its significance.

There is a gap in research comparing daily tidal ranges to land cover maps/datasets provided through Earth Map and their significance to ecological research. Utilizing the GLOBE Observer app (NASA, 2025) to analyze land cover types and conduct research on a coastal seabird species, such as the American herring gull, during different daily tidal stages has not been previously conducted nor has it been connected to the need for daily tidal range representation on land cover maps. Interpreting daily tidal changes regarding land cover and ecological factors allows ecological, geographic, and oceanography modes of research more knowledge into their designated study sites. Future research could include how to incorporate daily tidal gauge data and information from ground-cover photos into land cover maps utilized in Earth Map because it fluctuates the amount of land exposed; and it provides insight into previously mentioned scientific disciplines. Other areas of research could also aid in establishing a benchmark for tidal measurements to assess accuracy across multiple locations worldwide (Vos et al., 2023). In addition, many coastal species can be monitored to understand the importance of tides on their behavior. This may provide improved mapping data sets and a broader overview of land cover types that can support research across multiple scientific disciplines.

2. Study Area and Methods

2.1. Study Area

Fire Island (Figure 1) is a barrier island along the south end of Long Island, New York and extends to 50 km in length. While long, the island is narrow and varies in width from 200m to 1km (Pendleton et al., 2004). There are 26 miles on Fire Island that have been designated as a National Seashore to maintain its natural beauty. The western coastal region of Fire Island has a complex offshore geological framework and has been previously impacted by major storms such as the Hurricane in 1938, a nor'easter storm called the "Ash Wednesday" storm in 1962, another nor'easter in 1992 (Pendleton et al., 2004), and Hurricane Sandy in 2012. Barrier islands are crucial to ecosystems and coastal areas because their absorbance of wave energy protects the mainland from storm surge and flooding. Many factors cause barrier islands to disappear over time including erosion caused by human activities, damming and dredging projects, and climate change factors such as sea level rise and extreme weather events (NOAA, 2021).

The study area was on the western end of Fire Island, NY. The western end of the study area started at Democrat Point and spanned east to Fire Island National Seashore about 9km in length (East to West) and about 3km in width (North to South). Three grids were created by prioritizing the center point for each grid on land and assessing the number of accessible points to collect the most data.

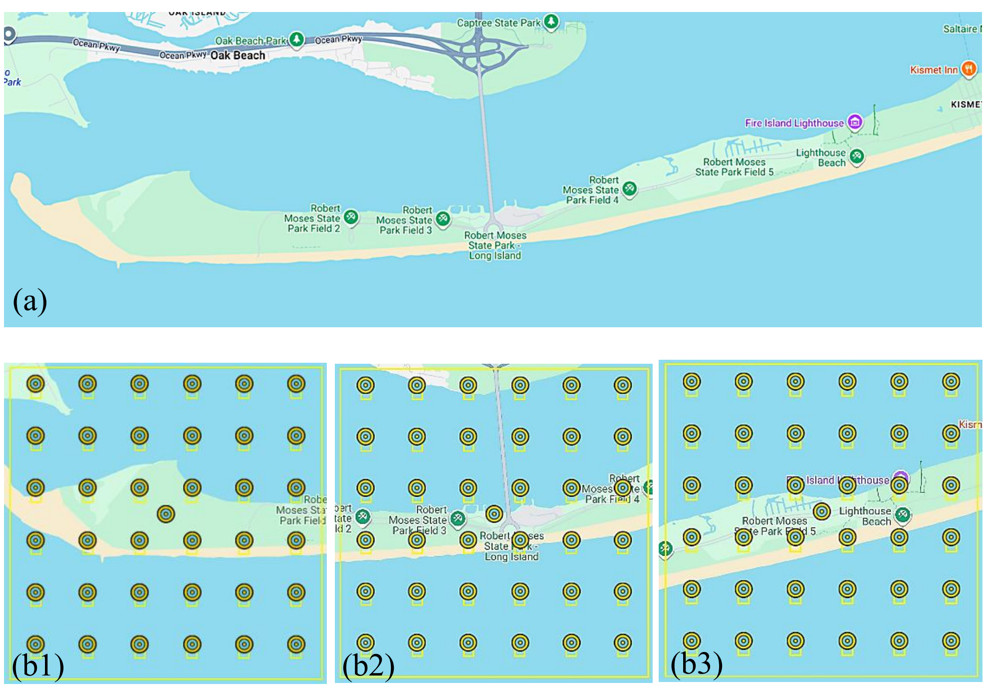

Figure 1. (a) Overview of the entire study area on Fire Island, New York without layers. (b1, b2 & b3) Grids 1, 2, and 3 from left to right of study area. (Background image courtesy of Google Earth Engine).

2.2. Data

Initial data collection came from Landsat time-series. Graphs of Normalized Burn Ratio of each primary sample unit (PSU) were collected and screenshots of each grid (3 total) within the entire sample area of each year starting from 1984 to most recent available year were also collected. Earth Map was also utilized to screenshot satellite imagery of each entire grid and each primary sample unit within the grids of four layers consisting of the land cover and forestry category in Earth Map. These layers included Global Forest Canopy Height- UMD GLAD (Tolan et al., 2024), Dynamic World (Brown et al., 2022), ESRI 2017/2024 Land Cover (Karra et al., 2021), and World Cover 10 m 2020/2021 (Zanaga et al., 2021). Tidal data was collected through NOAA Fire Island tidal gauge at Station ID: 8515186 to record peak tidal data, in feet, each time field observations were conducted (NOAA, n.d.).

Field data was collected from each accessible primary sample unit of ground photos through the GLOBE Observer app at high tide and low tide and 10-minute interval ground counts of American herring gulls, North and South, at high tide and low tide. Ground counts were categorized by either walking, walking and foraging, flying, and flying and foraging, where a bird could only be counted once among all the options.

Categorization of land cover types for each primary sample unit was collected through Collect Earth Online. This categorized 100 10-meter diameter point land cover types within each primary sample unit by selecting an identification among several choices for each. This ultimately determined land cover type percentages of each primary sample unit based on Collect Earth Online.

Visual assessment with a proportion calculation was used to produce agreements among each Earth Map layer to ground photos. This was performed by determining the primary land cover type among that Earth Map layer, such as water and no water, and using those parameters to conclude the primary land cover per PSU shown in the Earth Map layer and determining if the ground cover photos represented the same conclusion per primary sample unit. If ground cover photos could not be collected due to accessibility, then it was assumed the Earth Map layer agreed with the sample.

Further data was produced of agreements comparing each Earth Map layer to one another through a visual proportion calculation. This was done by determining how many layers, out of four, looked the same or represented the land the same way.

Conclusions on the significance of tidal differences and American herring gull activity differences per tide was done using R. A Shapiro-Wilk Normality test was done and since the data was not normally distributed for both parameters (tide heights and American herring gull activity), a Wilcoxon rank sum test with continuity correction was used for both determinations of significance. Graphic representations of these conclusions were also performed in R.

2.3. Methods

To create the sample area, three grids were produced using the GeoJSON software which was accessed through the Adopt-a-Pixel research framework (Nelson, 2024) within the GLOBE Program. Each grid produces 37 primary sample units, totaling 111 for this study, however 17 primary sample units were accessible for field data collection at high tide and low tide among the 3 grids, totaling 34 for the entire sample. At each primary sample unit, American herring gull data was collected facing North then facing South totaling 68 separate collections.

Each grid produces an individual GeoJSON file which was then uploaded to Earth Map to continue further assessments of the sample area. Earth Map was then used to record the coordinates of each primary sample unit produced by the GeoJSON file, which can be done by hovering the computer mouse over an individual primary sample unit; these coordinates were used for later field data. NOAA's Fire Island tidal gauge at Station ID: 8515186 was then used to record when high tide and low tide would occur and the peak height of the tide in feet each time field data was collected.

Using the previously recorded coordinates of the primary sample units, Google Maps provided directions to each accessible point to pursue field data collection. At each accessible point, field data collection started using the GLOBE Observer app to capture directional photos of Up, Down, North, East, South, and West. To prevent data loss, photos were also taken on our personal cell phone. Following that, we faced North 10 minutes then South 10 minutes to ground count American herring gull activity (Wetlands International, 2018). Visual parameters for counting faced in the appropriate direction spanned from east to west.

Once ground cover photo data and American herring gull activity was collected at each accessible point, Google Slides were used to organize ground cover photos from left to right with the coordinating Earth Map layers per primary sample unit. One Google Slide was produced per grid to maintain clarity. Raw American herring gull data was organized in Microsoft Excel, and each grid was organized separately within one sheet.

Landsat time-series was used to identify the land change over time for each grid by organizing photos of each year from 1984 to present in the appropriate Google Slide for assessment. Continuing with Landsat time-series, the coordinates of each primary sample unit were inserted into the Landsat URL to collect the Normalized Burn Ratio (NBR) graph and organize it into the appropriate Google Slide. NBR is an index derived from satellite data which measures the changes in soil and vegetation; it is often used to detect burned areas or major land cover change. High, or positive NBR values mean healthy or dense vegetation and low or negative NBR values mean bare soil, water, built areas, or recently burned areas.

Collect Earth Online aided in the categorization of land cover types within each primary sample unit and produced percentages of each land cover type per PSU. Additionally, it provided the primary sample units with a numerical identification where the primary sample units for grid 1 were labeled 100-136, grid 2 was 200-236, and grid 3 was 300-336. Categorization of land cover types was done by uploading the GeoJSON grids into Collect Earth Online and going through each PSU and categorizing 100 10-meter diameter points by choosing from the categories provided. Categorization was clear for PSU's where ground photos were previously collected, and non-accessible PSUs were inferred based on the most agreed land cover type among Earth Map data sets. Once every PSU had been entirely categorized by land cover types, photos of each one were organized into the appropriate Google Slide.

Photos of each Earth Map layer grid and individual primary sample unit per Earth Map Layer were also organized into the appropriate Google Slide to make comparisons and conclusions regarding agreement compared to one another. These were organized from left to right per PSU to conduct the visual comparison with the ground cover photos taken. An agreement assessment calculation was used when determining the agreement of each Earth Map layer to ground cover photos. Figure 2 shows an example of Earth Map layers in Grid 1.

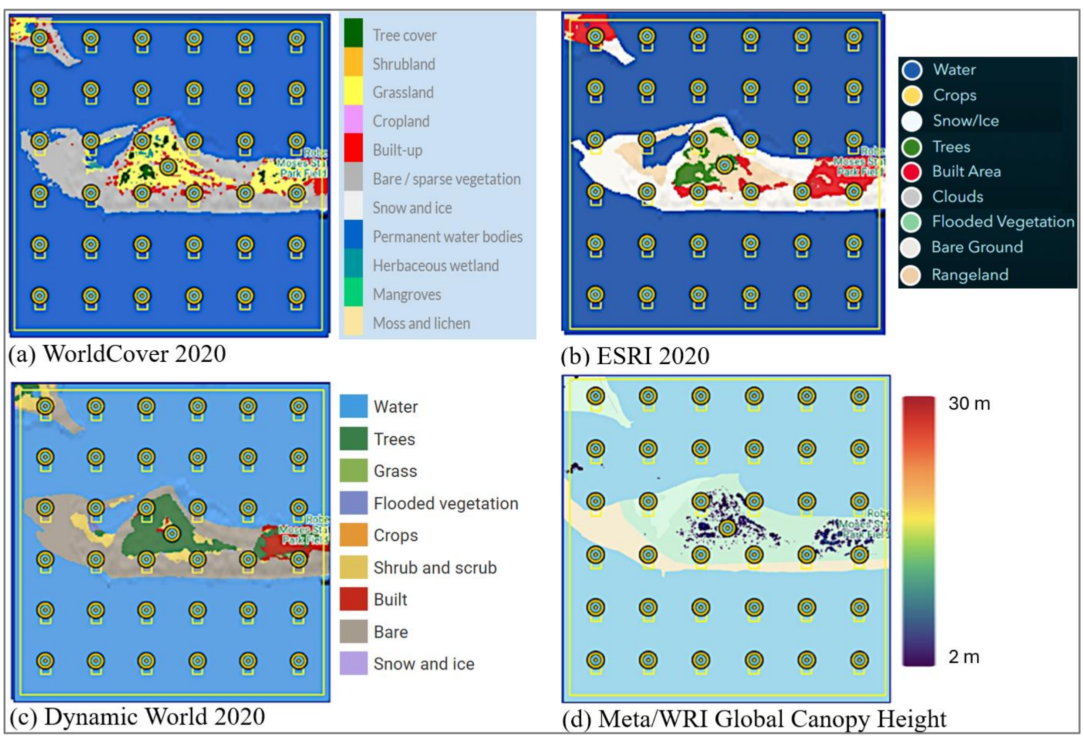

Figure 2. Land covers in Grid 1 identified by different sources with their corresponding legends.

Microsoft Excel was used to organize the raw field data of the American herring gull ground count and tidal data. All the American herring gull data was uploaded to R to conduct the two tests for high tide and low tide difference and two tests for difference in activity for American herring gulls per tide. R was also used to produce graphical representations of these results.

3. Results

When the land cover layers were compared to one another, they did not always agree, and agreement was especially inconsistent when the land became more diverse with different land cover types. Figure 3 shows an example of accuracy assessment for Grid 1, organized in a Google Slide. Assessment results are shown in the "Agree" column.

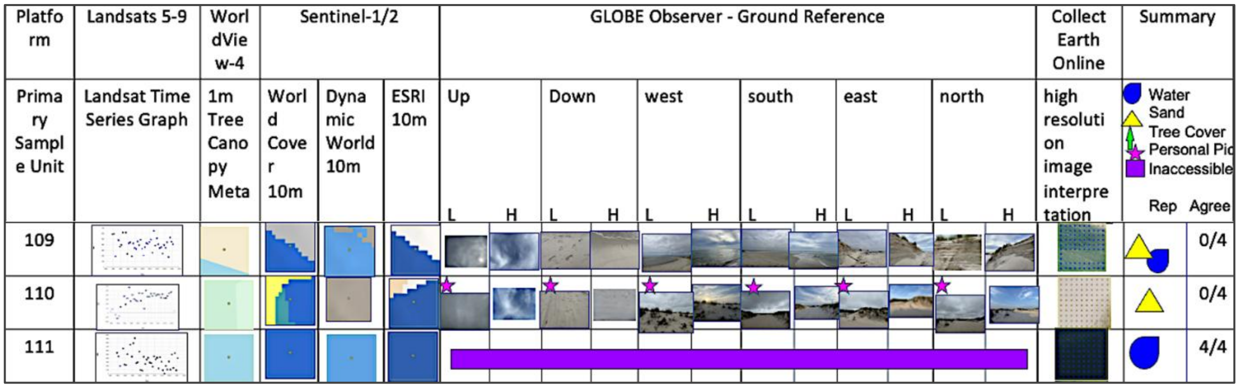

Figure 3. Example of Fire Island Grid 1 Google Slide, where the imagery data was organized and compared. "L": Low tide, "H": High tide, "Rep": Representation, "Agree": Agreement among Earth Map layers.

The table in Appendix 1 shows the land cover types labeled in Collect Earth Online and agreement percentages among the four Earth Map layers assessed. In the case of Primary Sample Unit 101, for example, visual assessment showed 100% water, Collect Earth Online also labeled 100% water, and all four Earth Map layers examined labeled 100% water, making 100% agreement percentage.

When we looked at the comparison between the maps and the ground photos of primary sample unit locations, we would expect disagreement because of the timing of daily tidal changes. Visually comparing the ground cover photos to the map layers, it was difficult to make a precise assumption about whether the Earth Map layer was more closely representing high tide or low tide. It appeared that some primary sample unit locations in Earth Map were more closely represented by high tide while others appeared more closely represented by low tide. These differences highlight the restrictions and overall inconsistencies within each Earth Map layer.

Again, it presented a trend where accuracy and agreement were especially inconsistent when the primary sample units became more diverse or showed more edge interference in land cover types. As shown in Figure 4, primary sample unit ground cover photos that were taken at low tide are organized in the L column and photos taken at high tide are shown in the H column. Results of the comparisons between the Earth Map layers and ground cover photos are shown in the row "Agreement" on each Google Slide where the imagery data was organized and compared.

The agreement assessment percentages represent a simplified way to understand if overall the Earth Map layer and ground photos represent the major land cover type. However, it does not assess individual pixels, nor does it account for exact layouts of the maps and the earth itself represented by the photos taken. Overall, the World Cover layer in Earth Map had the greatest average accuracy percentage with an average of 98% among all 111 PSUs across the three grids. However, some PSU classifications were estimated using informed classification assumptions for inaccessible locations.

The agreement assessment results across the three grids indicate that global land cover products (World Cover, Dynamic World, and ESRI) demonstrate exceptionally high user accuracy, particularly in identifying "Ocean" versus "Not Ocean" categories, with values consistently ranging between 95% and 100%. For instance, World Cover achieved a perfect 100% accuracy in Grid 1. In contrast, the 1 m Tree Canopy dataset shows a lower but consistent level of agreement, ranging from 84% to 86% across the study areas. While the 1 m Tree Canopy product avoided false positives by never mislabeling "Not Trees" as "Trees," it frequently missed actual trees; it misclassified 6 cases in Grid 1 and 5 cases in both Grids 2 and 3 as "Not Trees".

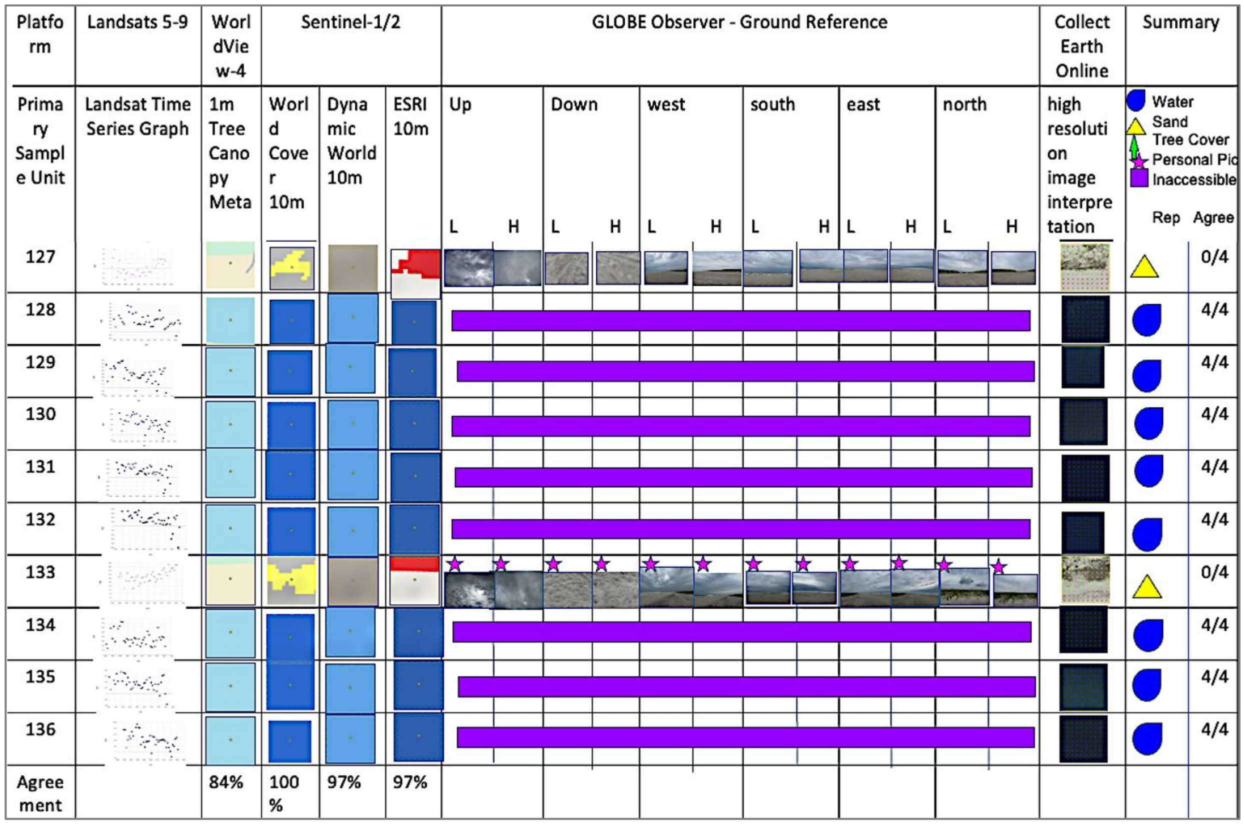

Figure 4. Example of Fire Island Grid 1 Google Slide where the imagery data was organized and compared. "L": Low tide, "H": High tide, "Rep": Representation, "Agree": Agreement among Earth Map layers, "Agreement": Comparison results between Earth Map layers and ground cover photos.

Looking at the land cover types classified through Collect Earth Online, the overall area of interest (AOI) had a high percentage of water or rivers and streams (Figure 5), with the second most percentage of bare ground which can be otherwise known as sand. Knowing that water is the dominant land cover type within the AOI infers the importance of its influence. Especially having water adjacent to bare ground primarily, since those two land cover types are often found side by side, we recognize the area is the dynamic interface of the tide, but we don't initially know the tide levels on the maps.

This additional information also allows us to recognize the possible effects of edge interference between the water and bare ground. An example of the water and sand dynamic interface can be shown by primary sample unit number 109 in the west direction, as shown in Figure 6. At low tide there is an exceptional amount of sand exposed compared to high tide where the entire area is just about covered in water.

At primary sample unit number 109, each Earth Map layer is telling a different story about what you might expect to see at this location. The 1 m Tree Canopy Meta layer tells us that there will be plenty of sand exposure when standing in this PSU. World Cover 10 m and ESRI 10 m appear to be telling a similar story however World Cover classifies the exposed land as "Barren/Sparse Vegetation" while ESRI classifies the exposed land as "Snow/Ice". Dynamic World 10 m represents a location with very little bare ground exposure

A major part of this research is to explore the dynamic interface of the water and sand. The tides allow us to understand just how different a couple of hours can look in one spot. The results showed a significant difference between high tide and low tide among the primary sample units where ground photos were taken, where $p < 0.000$. This tells us the Area of Interest is overall a landscape that is exceptionally dynamic during each day.

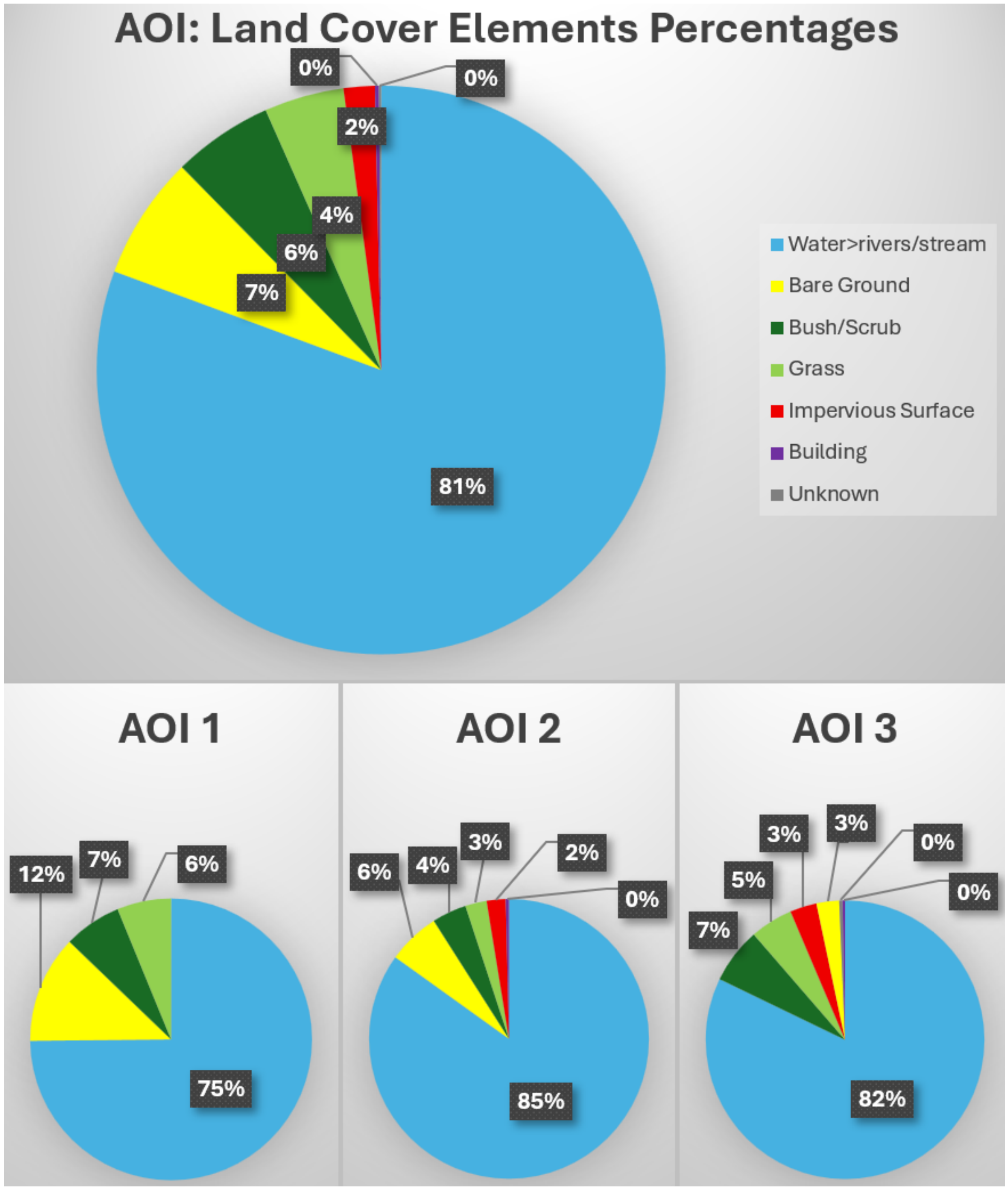

Figure 5. Pie chart of the overall Area of Interest (AOI) and pie charts of each individual AOI (grids), presenting the percentages of the land cover types categorized in Collect Earth Online.

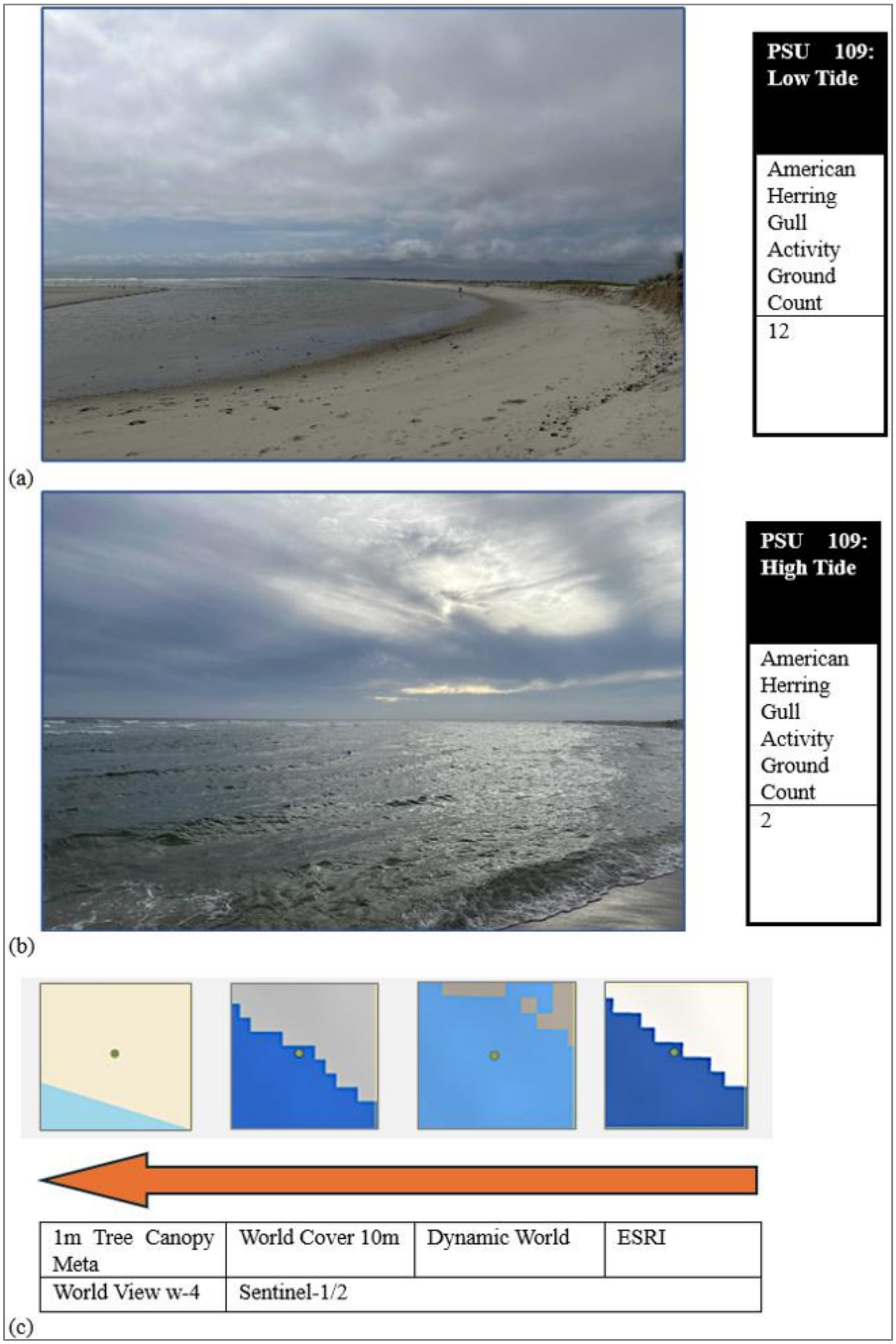

Figure 6. (a) Ground cover photo of primary sample unit number 109 in the West direction at low tide with American herring gull activity, (b) Ground cover photo of primary sample unit number 109 in the west direction at high tide with American herring gull activity, (c) Each Earth Map layer at primary sample unit 109 with its label following underneath the images. An orange arrow exemplifies the direction (west) the ground cover photos were taken.

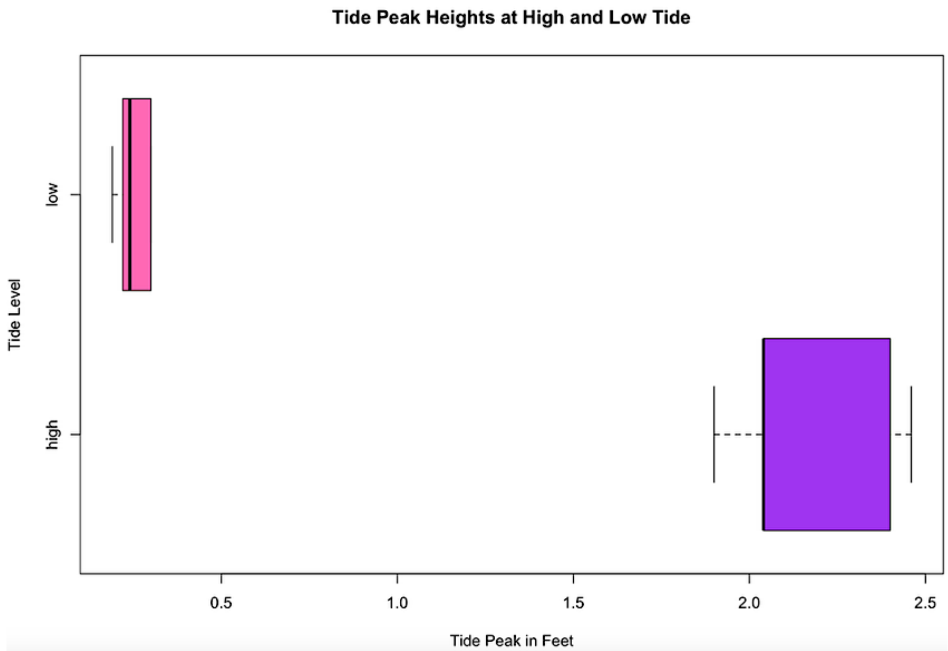

Figure 7. Box plot of the tide peak heights at high and low tide.

Understanding the difference in daily tidal fluctuations allows us to explore the dynamic interface between the water and sand, and utilizing the activity of American herring gulls helps us categorize these differences, along with the ground cover photos. Figure 7 shows the peak heights during low and high tides. The results in Figure 8 also showed a significant difference in American herring gull activity among the primary sample units where data was collected. There was more overall activity for low tide compared to high tide where $p<0.002$. These results tell us that the land is not only dynamic to itself, but it also affects wildlife behavior and the ecology of the area.

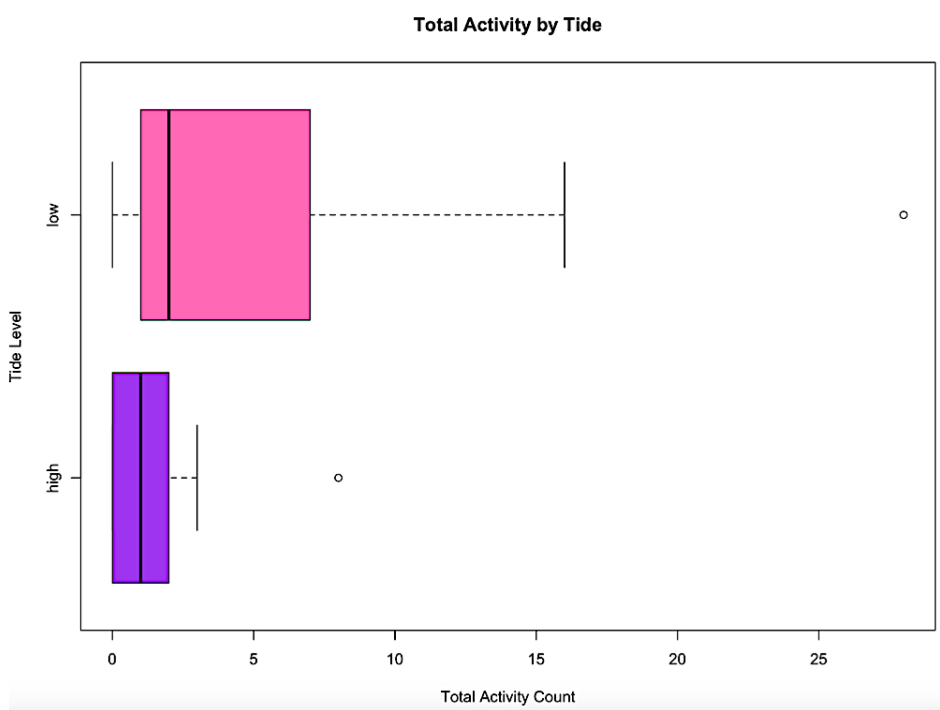

Figure 8. Box plot of total American herring gull activity at high tide and low tide.

Visual assessment, as in Figure 9, shows a land change over time according to Landsat time-series from the years 1984 to 2025. There is more sand deposition on the Northwest area of Fire Island and sand mass fluctuations throughout the West end of the island. This further emphasizes how affected Fire Island is by the daily tidal fluctuations because it ultimately provides long term changes and impacts. Not only do daily tidal fluctuations create a dynamic landscape, but they can have long term impacts on not only the land itself but on the plant and animal life as well.

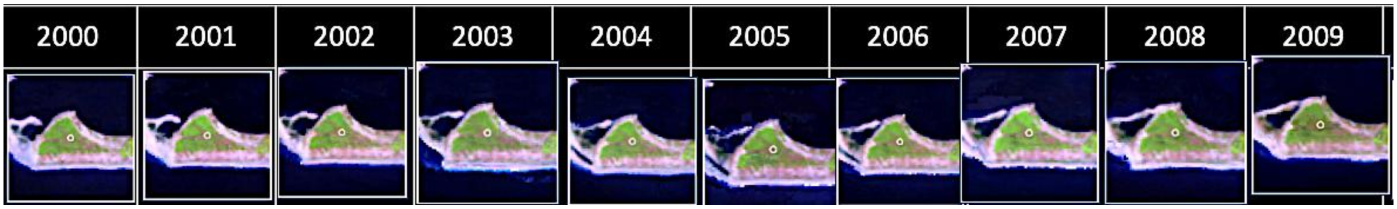

Figure 9. Example of Landsat time-series images of the Grid 1 Google Slide showing land cover change over time.

4. Discussion

The results showed that the land cover layers presented inconsistencies among one another and when compared to ground cover photos. Having 'water>rivers/stream' result in the most dominant land cover type, infers the importance of its significance, especially because water bodies influenced by tides is an ever-changing land cover type. There was also a significant difference in daily tidal fluctuations between high tide and low tide, further exemplifying its fluidity. With the inconsistencies of the satellite images, this may reduce confidence in how accurately land cover is represented. Especially if the information is not regularly updated and improved with its daily to long-term changes.

A significant difference in high tide and low tide in the study area present the result of a drastically changing landscape throughout one day. This is important to know prior to conducting field research on an area because a portion of land may or may not be exposed at certain points of the day. A dynamic landscape may affect many coastal species, and the movement of waves and tides may also influence species diversity and biomass (Brown & McLachlan, 2002). Ignoring tidal changes may overlook geological factors when mapping coastal study areas.

A significant difference in American herring gull activity between high tide and low tide suggests a relationship of American herring gulls with tidal fluctuations and how it affects their behavior. Without accounting for daily land cover changes driven by tides, ecological variation in coastal habitats can be missed.

The study area land had changed over time from the year of 1984 to present, where greater land cover, specifically bare ground, accumulated among the West and Northwest end of Fire Island due to possible longshore drift over the years of 1984-2025. Longshore drift is the transportation of sediment along the coastline and occurs from the movement of prevailing winds that cause an angled wave approach (Internet Geography, n.d.). Longshore drift affects not only the geographic layout but the location of flora and fauna as well, creating a cycle of cause and effect between living and non-living. This information may help support the making of past, present, and future inferences about species' behaviors and another key component to understanding the landscape.

These findings show differences among satellite mapping data sets and when compared with recent ground photos. Providing ground photos may support a more detailed and accurate map interpretation; in addition to providing as many photos and angles as possible. This aligns with the findings of Huang et al. (2023) because it practically implements the practice of putting together ground cover photos with satellite imaging where classification performance of land cover data sets improved as more photo views were added. Not only do the ground cover photos improve data sets for satellite imaging but our study extends from the study done by Geyman & Maloof (2020) where it is exemplified how remote sensing methods for water flux can be used to predict tides and their spatial structure. Bridging citizen science ground photos and tidal predictors may improve the accuracy and usability of data sets for satellite imaging.

There were a few limitations involved in the study. The study was limited in accessible primary sample units, creating a smaller sample size, therefore many undocumented points were deemed in agreement with the satellite imagery when it may not have been true. While American herring gulls were researched for background and identification purposes, there is a possibility of error in identification being that many gulls are similar in size and color, not to mention the possibility of a mixed species. To eliminate false identification, an American herring gull was only tallied if it was clear and apparent; sound identification was not used. Another limitation included the inability to upload some photos to the GLOBE Observer database through the GLOBE app due to cellular connectivity restrictions and the loss of data from the GLOBE Observer database. To prevent any loss of data entirely, photos were taken on our personal cell phones at each location as precisely as possible compared to the photos we were uploading to the GLOBE app. While the photos uploaded to the GLOBE Observer database are better used for the information collection needed for satellite imaging, collecting personal photos allowed the researchers to still make ground photo comparisons to satellite imagery from Earth Map if data was lost from GLOBE Observer. There is the opportunity to improve the GLOBE observer app by saving information to be uploaded later if connectivity is low.

Future research could include implementing GLOBE observer app ground photos into satellite imagery data sets and projects to maintain accuracy. Testing to see whether satellite imagery improves with the use of ground photos can allow more insight into the importance of citizen science and its role in GIS mapping. Additional future research can test how satellite imagery might be able to implement daily tidal fluctuations and the possible collaboration among organizations with tidal gauges and those with satellite data sets. Also, the creation of a tidal baseline in satellite mapping may be useful to consider to help account for accuracy if other data sets produce maps with tidal representations. Furthermore, another research project like this one can be replicated in the same area after a few years to observe land cover changes, tidal patterns, and species activity. Providing a well-rounded map to citizens and scientists allows for a more comprehensive tool in research and the allowance for multiples disciplines to utilize it.

This project further highlighted how satellite imagery may be influenced by ecological conditions and how it may be improved using citizen science and daily tidal data. The Adopt-a-Pixel Research Framework was also useful as an ecological monitoring tool within this study. Overall, multiple environmental factors may contribute to how satellite imagery data are represented and interpreted. This supports the need for continued refinement and future research in improving satellite imagery interpretation.

5. Conclusions

The aim of this study was to determine land change over time, satellite mapping accuracy, the influence of tidal changes on land cover, and its ecological connection to the American herring gull. Understanding daily land cover changes and tidal fluctuations may provide a more complete interpretation of a study area and how the landscape has changed over time. This may help researchers better anticipate site conditions prior to fieldwork and improve interpretation when field observations are limited. It may also help strengthen the connection between GIS mapping and ecological research.

This study supports the connection between GIS-based satellite mapping systems and ecology-focused research. Land change occurred over time, and both tidal height and American herring gull data showed significance and were accompanied by inconsistencies among satellite imaging. These findings suggest that incorporating tidal markers and ground cover photos may improve the interpretation of satellite imagery for coastal research applications. This approach may provide a more useful tool for interdisciplinary research requiring accurate coastal land cover interpretation.

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Appendix 1. Land cover types labeled in Collect Earth Online and agreement percentages among the four Earth Map layers assessed. An asterisk (*) is marked for the primary sample units with field data collection.

Primary Sample Unit	Land Cover Type Percentages (%)	Land Cover Labels (Collect Earth Online)	Agreement Percentage (%) Among Earth Map Layers
100	100	Bush/Scrub	0
101	100	Water>rivers/stream	100
102	100	Water>rivers/stream	100
103	100	Water>rivers/stream	100
104	8, 92	Bush/Scrub, Bare Ground	50
105	100	Water>rivers/stream	100
106	25, 29, 46	Bush/Scrub, Water>rivers/stream, Bare Ground	0
107	100	Water>rivers/stream	100
108	100	Water>rivers/stream	100
109*	21, 79	Bare Ground, Water>rivers/stream	0
110*	100	Bare Ground	0
111	100	Water>rivers/stream	100
112	100	Water>rivers/stream	100
113	100	Water>rivers/stream	100
114	100	Water>rivers/stream	100
115*	5, 45, 50	Grass, Bare Ground, Bush/Scrub	0
116	100	Bush/Scrub	50
117	100	Water>rivers/stream	100
118	100	Water>rivers/stream	100
119	100	Water>rivers/stream	100
120	100	Water>rivers/stream	100
121*	6, 37, 57	Bush/Scrub, Bare Ground, Grass	0
122	39, 61	Bare Ground, Water>rivers/stream	0
123	100	Water>rivers/stream	100
124	100	Water>rivers/stream	100
125	100	Water>rivers/stream	100
126	100	Water>rivers/stream	100
127*	43, 57	Bare Ground, Grass	0
128	100	Water>rivers/stream	100
129	100	Water>rivers/stream	100
130	100	Water>rivers/stream	100
131	100	Water>rivers/stream	100
132	100	Water>rivers/stream	100
133*	1, 29, 70	Bush/Scrub, Bare Ground, Grass	0
134	100	Water>rivers/stream	100
135	100	Water>rivers/stream	100
136	100	Water>rivers/stream	100
200*	1,6, 15, 17, 61	Bare Ground, Building, Impervious Surface, Grass, Bush/Scrub	0
201	100	Water>rivers/stream	100
202	100	Water>rivers/stream	75
203*	3,8,14, 27, 48	Bush/Scrub, Building, Grass, Bare Ground, Impervious Surface	0
204	100	Water>rivers/stream	100
205	100	Water>rivers/stream	100
206	100	Water>rivers/stream	100
207	100	Water>rivers/stream	100
208	100	Water>rivers/stream	100
209*	33, 67	Grass, Bare Ground	50

Primary Sample Unit	Land Cover Type Percentages (%)	Land Cover Labels (Collect Earth Online)	Agreement Percentage (%) Among Earth Map Layers
210	100	Water>rivers/stream	100
211	100	Water>rivers/stream	100
212	100	Water>rivers/stream	100
213	100	Water>rivers/stream	100
214	100	Water>rivers/stream	100
215*	3, 10, 87	Grass, Water>rivers/stream, Bare Ground	75
216	100	Water>rivers/stream	100
217	100	Water>rivers/stream	100
218	6, 24, 70	Bare Ground, Bush/Scrub, Water>rivers/stream	0
219	100	Water>rivers/stream	100
220	100	Water>rivers/stream	100
221*	36, 64	Bare Ground, Water>rivers/stream	75
222	2, 98	Impervious Surface, Water>rivers/stream	75
223	100	Water>rivers/stream	100
224	100	Water>rivers/stream	100
225	100	Water>rivers/stream	100
226	100	Water>rivers/stream	100
227*	100	Water>rivers/stream	100
228	100	Water>rivers/stream	100
229	100	Water>rivers/stream	100
230	100	Water>rivers/stream	100
231	100	Water>rivers/stream	100
232	100	Water>rivers/stream	100
233	100	Water>rivers/stream	100
234	16, 24, 60	Impervious Surface, Grass, Bush/Scrub	0
235	100	Water>rivers/stream	100
236	100	Water>rivers/stream	100
300	14, 28, 58	Impervious Surface, Grass, Bush/Scrub	0
301	100	Water>rivers/stream	100
302	100	Water>rivers/stream	100
303	1, 22, 36, 41	Building, Impervious Surface, Grass, Bush/Scrub	0
304	100	Water>rivers/stream	100
305	100	Water>rivers/stream	100
306	100	Water>rivers/stream	100
307	100	Water>rivers/stream	100
308	100	Water>rivers/stream	100
309*	5, 12, 25, 58	Bare Ground, Bush/Scrub, Grass, Impervious Surface	0
310	100	Water>rivers/stream	100
311	100	Water>rivers/stream	100
312	100	Water>rivers/stream	100
313	100	Water>rivers/stream	100
314	100	Water>rivers/stream	100
315*	1, 5, 37, 57	Impervious Surface, Unknown, Grass, Bare Ground	100
316	2, 18, 80	Bare Ground, Bush/Scrub, Water>rivers/stream	75
317	100	Water>rivers/stream	100
318	100	Water>rivers/stream	100
319	100	Water>rivers/stream	100
320	100	Water>rivers/stream	100

Primary Sample Unit	Land Cover Type Percentages (%)	Land Cover Labels (Collect Earth Online)	Agreement Percentage (%) Among Earth Map Layers
321*	13, 87	Bare Ground, Water>rivers/stream	100
322	1, 7, 19, 73	Grass, Bare Ground, Bush/Scrub, Water>river/stream	0
323	100	Water>rivers/stream	100
324	100	Water>rivers/stream	100
325	100	Water>rivers/stream	100
326	100	Water>rivers/stream	100
327	100	Water>rivers/stream	100
328*	2, 10, 12, 20, 56	Grass, Building, Bare Ground, Impervious Surface, Bush/Scrub	0
329	100	Water>rivers/stream	100
330	100	Water>rivers/stream	100
331	100	Water>rivers/stream	100
332	100	Water>rivers/stream	100
333	100	Water>rivers/stream	100
334*	1, 9, 36, 54	Bare Ground, Unknown, Bush/Scrub, Grass	0
335	100	Water>rivers/stream	100
336	100	Water>rivers/stream	100