Evaluation of Remote Sensing Imagery for Use in Monitoring of Bull Kelp, (*Nereocystis luetkeana*) off the Northern Coast of the Quimper Peninsula

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1. Abstract

The Jefferson Marine Resources Committee (JMRC) is interested in investigating additional tools that can contribute to the understanding of floating kelp along the full extent of the northern Quimper Peninsula in addition to the site-specific study at the North Beach kelp bed by kayak. The goal of this project is to test the quality and potential use of satellite imagery as a qualitative method to detect large shifts in floating kelp extent along the Quimper Peninsula as a tool to flag regions of the shoreline where more in depth studies could be used to better understand trends, density, and potentially causes of changes in kelp distribution. Bull kelp monitoring and conservation is a priority of the JMRC. The JMRC monitors the North Beach kelp bed via kayak-based surveys, but has an interest in better understanding bull kelp presence and trends along the full Quimper Peninsula. This study will provide the JMRC with an understanding of additional tools that can be used to qualitatively track trends in bull kelp along a larger stretch of shoreline and potentially identify other areas of interest that could warrant more in depth studies. The JMRC procured multiple sources of satellite imagery and qualitatively assessed its applicability to detect large shifts in kelp distribution. Results included finding an area with a significant decline in kelp that was detectable under a variety of tidal and current conditions. JRMC concludes that satellite imagery could provide a qualitative method to detect large changes in kelp distribution and highlight opportunities for further study.

2. Project Goals

The Washington Department of Natural Resources (DNR) has been using aerial imagery to monitor bull kelp beds in each of the 7 counties along Puget Sound since 1989. Annual polygons have been drawn around these beds from those images, which recently have included a Near Infrared (NIR) band in addition to the RGB bands. In Jefferson County, DNR bull kelp polygons extend along the 6 km long northern coast of the Quimper Peninsula, from McCurdy Pt to Point Wilson, where most of the county’s kelp is located. The Jefferson County Marine Resources Committee (JMRC) joined the state’s effort to monitor bull kelp in 2015. This project involves the use of kayak surveys to define the perimeter of a small bed that extends approximately 0.5 km along North Beach Park (Fig. 1). The surveys are carried out several times each year during the peak bull kelp season of July through September. Safety and manpower constraints have restricted these surveys to this small bed, which is less than 10% of the bull kelp resources along this coastline. JMRC is interested in investigating additional tools that can contribute to the understanding of floating kelp along the full extent of the northern Quimper Peninsula in addition to the site-specific study at the North Beach kelp bed by kayak.

- The goal of this project is to test the quality and potential use of satellite imagery as a qualitative method to detect large shifts in floating kelp extent along the Quimper Peninsula as a tool to flag regions of the shoreline where more in depth studies (using a variety of monitoring methods such as underwater surveys, kayak-based surveys, drones, aerial surveys, etc.) could be used to better understand trends, density, and potentially causes of changes in kelp distribution.

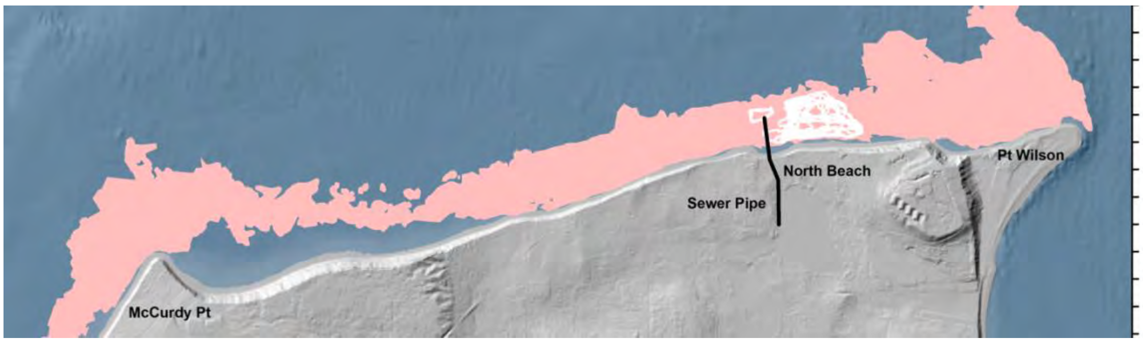


Figure 1: Perimeter lines from kayak surveys showing the kayak survey site off North Beach Park (white lines) over the combined DNR polygons (pink) along the coastline.

3. Project Engagement

The use of satellite imagery could be beneficial for multiple purposes beyond detecting floating kelp. Volunteers with JMRC are also testing opportunities to use satellite imagery and Synthetic Aperture Radar (SAR) to count vessels anchored in areas of eelgrass in partnership with San Juan County and MRC.

4. Project Methods/Actions

All imagery in this report was collected during the peak bull kelp season from July 1 and September 30. Sentinel satellite 10 m resolution imagery was obtained at no cost from the EO browser website for the years between 2015-2022. For comparison, 3 m resolution satellite imagery was obtained from the Planet Dove satellite constellation at no cost from the Planet website. This required establishing an educational account that one volunteer was able to do (Kelley) through his affiliation with the University of Hawaii. Both sites allow users to inspect the available images and download the ones that appear most useful. Accounts were established with the satellite imagery resellers Skywatch and Apollo, both of which sell sub-meter imagery from multiple satellite companies. Since there was a lack of funds to support this project, we purchased a small number of 0.5 m Pleiedes satellite images from Skywatch to use in comparisons as well. Finally, DNR staff provided 2021-2022 Ridder 0.5 m aerial imagery that included an NIR band and we located and obtained previous high resolution aerial imagery back to 2015 that had only RGB bands. However, kelp beds were still visible on these images and therefore they were also included in the study.

All the imagery was imported into ArcGIS with some of the earlier aerial images requiring georeferencing. These were converted to geotifs similar to the other images that came with existing geotags. To make comparisons between data types, various tools in ArcGIS were used to extract the pixels in the images that corresponded to kelp. While this process in general was like that of Cowdrey & Claar (2024), we instead manually identified threshold values for kelp using the software's Pixel Inspector tool. The process isn't perfect since there were always pixels in the water of the same value as the kelp but by separating and only working with the NIR band imagery significantly increased precision. Once the pixels were extracted, square area estimates were made however these are not included in this report until we acquire a greater understanding of what subtidal and nearshore pixels represented since multiple species of algae exist in those zones.

Kelp pixels from the imagery were also layered individually for year-to-year comparisons, but also together to identify persistent patterns of abundance and location along the coast. All data were layered onto 5 m resolution bathymetry obtained from the USGS and examined for patterns indicative of substrate preferences. Original imagery was furthermore examined for clues as to where sediment and rocky substrates existed. Still grabs were obtained from a current model created by Tarang Khangaonkar of PNNL. These were georeferenced in ArcGIS and layered onto the data to look for persistent patterns related to differences in current direction and velocity along the coastline. Based on all these comparisons, the coastline was divided into 5 areas that appeared to represent kelp beds that were at least semi-autonomous to each other. The areas are numbered 1 to 5 from McCurdy Pt to Point Wilson, respectively.

4.1. Project History and Existing Data Sources

An advantage to using satellite imagery to monitor bull kelp is that the coverage is not restricted to areas where it is practical or safe to survey by kayak. It could therefore be used to evaluate the state of bull kelp along the entire northern coast of the Quimper Peninsula. The JMRC spent time researching various sources of remote imagery. There are many commercial and government multi-spectrum satellites that make images available. Some of the images are free, some archived images are available for purchase at a low cost, and some require the commanding of the satellite to capture an image. Satellites like Sentinel and Planet Doves are designed to capture almost all of the planet continually and archive the images. Higher resolution images usually need to be ordered in advance, and the satellite will be tasked with taking an image of a specific area. Custom orders are much more expensive, but sometimes a high-resolution image may be available on the secondary market at a much low price. Unfortunately, there are few images of the nearshore available from satellite image resellers.

The constellation of imaging satellites circling the earth has expanded exponentially during the last decade, with many of them having multi-spectral capabilities. The European Space Agency (ESA) launched the Sentinel 2A in 2015, which is an optical imaging satellite with 13 spectral bands and 10-meter resolution. In 2017 the ESA launched a second similar satellite, the Sentinel 2B, into orbit. The ESA has made all the images from both satellites available at no cost through the EO browser website. One of the two Sentinel satellites capture images of the peninsula's northern shore every 10 days. The images have 14 spectral bands including the standard 3 RGB bands and a 4th near infrared (NIR) band that has proven to be the most important for visualizing bull kelp. This is because kelp reflects NIR frequencies but water rapidly absorbs them, making it easier to differentiate kelp pixels from the background water pixels. The 10 m resolution of these images is sufficient to see the denser kelp beds, and the revisit rate, while not optimal, has provided enough usable images to see changes in the beds that are not monitored by kelp surveys. Additionally, the ESA provides derived bands that been mixing the NIR with other bands that has improved the resolution of detecting features such as kelp beds. Particularly useful for monitoring kelp is the Native Difference Water Index (NDWI) made by mixing the green band with the NIR band.

Appendix A provides a more detailed history of the projects assessment of different imagery sources.

Appendix B includes further details on the value of assessing kelp bed density using satellite imagery.

5. Results

5.1. Assessing different satellite imagery sources and tidal/current stages

JMRC volunteers began accessing remote sensing data in 2016 to evaluate the use of multi-spectral satellite imagery with a near infrared (NIR) band to expand and complement JMRC's kelp kayak surveys. In 2018 it was shown that Sentinel imagery could be used to determine the area of the North Beach survey site that was comparable to the size determined by kayak. It was further determined that both methods appeared to detect a ~20% decline in bed area from 2016 to 2018 even though the values from these 2 methods were derived differently.   Kayak survey bed sizes were based on perimeters calculated from tracks between plants whereas the satellite bed sizes were based on visible floating kelp density.

Viewing all available data before 2017 indicated that the entire kelp complex from McCurdy Point in the west to Point Wilson in the east was stable, with McCurdy Point, Fort Warden, and Glass Beach in the middle having the densest beds. This was true in all images regardless of tide level apart from those captured during periods of high current flow. The reason is because high currents will push at least some of the typically exposed parts of the plants underwater making them undetectable to NIR frequencies (Fig. 2).

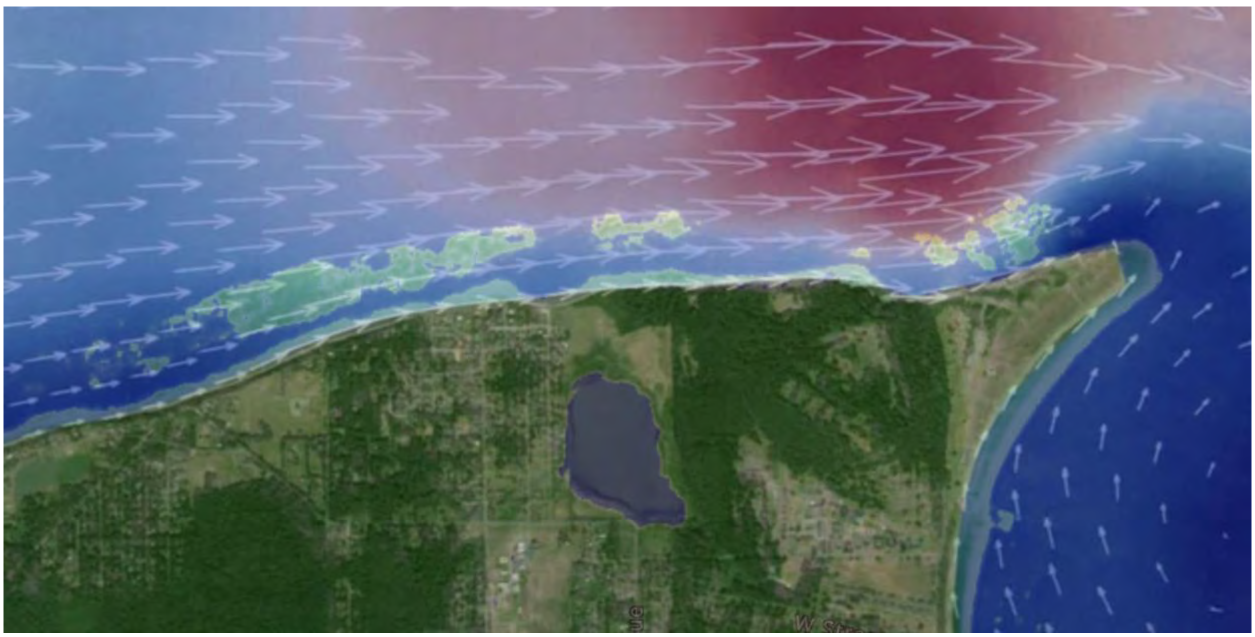


Figure 2: PNNL current model overlaid on the satellite image with higher intensity current shown as red and with larger current vector arrows. Bull kelp beds are the green areas off shore from the coast. Point Wilson on the right and compare the kelp off this point shown in this image to that shown in Figure 3.

Imagery obtained each year since 2017 showed an apparent significant decline of bull kelp in the middle Glass Beach section of the coastline starting in 2019 (Fig. 3).   In 2017 this section had the most bull kelp along the coastline whereas in 2021 it is almost entirely missing. This decline is not visible from the DNR perimeter mapping and in fact, the DNR floating kelp indicator continues to label the area as “no trend”.

Another finding from the Sentinel satellite imagery was the persistent lack of bull kelp from the area just east of McCurdy Pt (Fig. 3). This same pattern is evident from the DNR polygons from aerial surveys dating between 2009 and 2018.

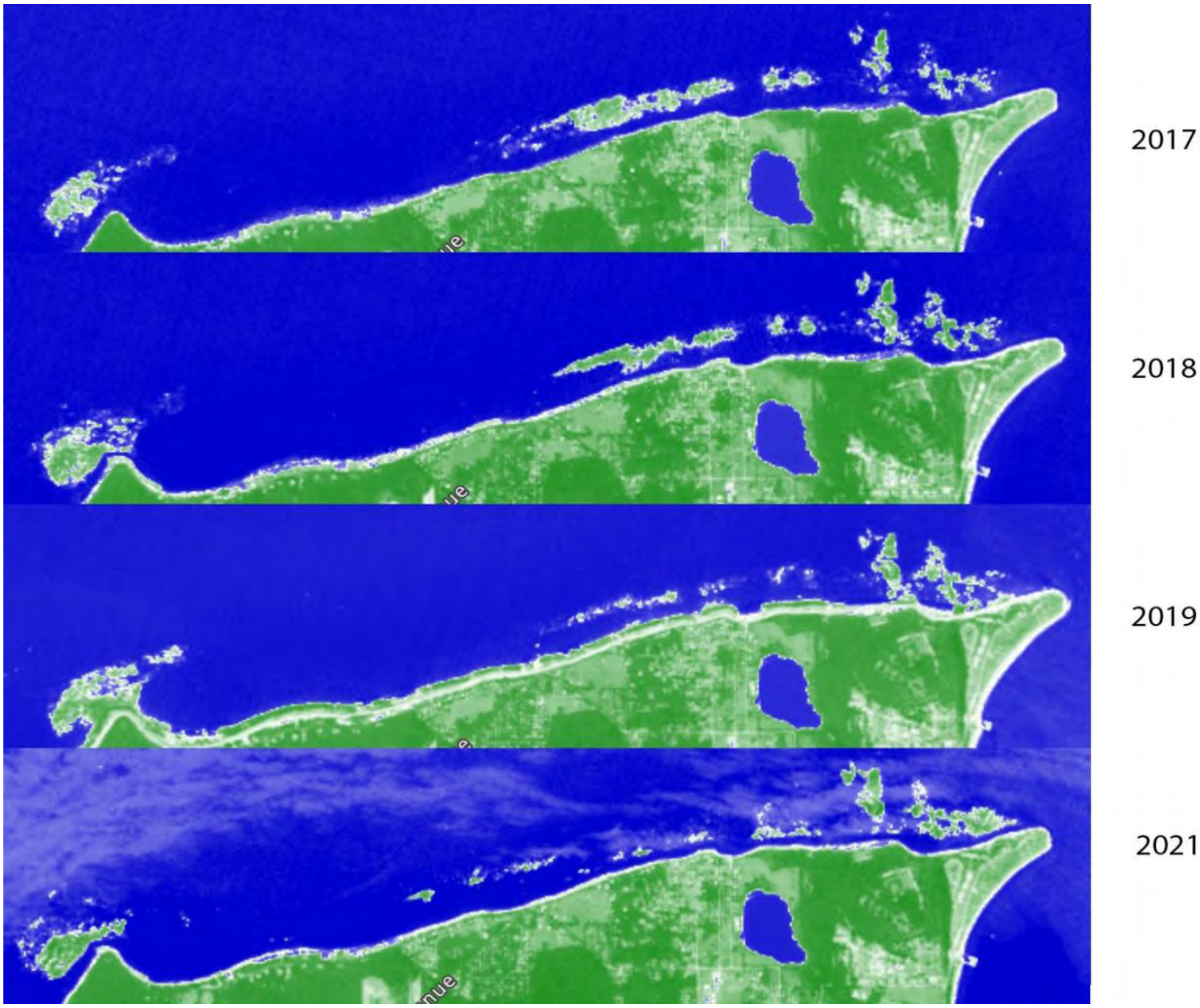


Figure 3: Five-year trend in the appearance of kelp along the northern coast of the Quimper Peninsula from Sentinel 2 NDVI images. McCurdy point is west and Point Wilson the east. Glass Beach is the middle right area of the coastline.

One of the disadvantages of using satellite images is the lack of control of the capture time and conditions. The images in figure 3 were taken at tide levels of 7, 4, 0, and -1 feet from top to bottom. This would make it difficult to calculate bed area, but there is still information about the kelp that can be deduced from the images. The tide level is the same for the entire kelp complex, but while the beds at McCurdy Point and Point Wilson are relatively unchanged, the beds in the middle section look like they are losing kelp every year. This same patten is visible in all of the available images.

Appendix C includes further details on assessing the relationship between tides, currents, bathymetry and substrate along the Quimper Peninsula using satellite imagery.

5.2. Qualitative assessment of floating kelp trends using remote sensing imagery

Figures 4, 5, and 6 provide comparisons between extracted kelp pixels from 2017 and 2021 for 10 m Sentinel satellite imagery, 3 m Planet satellite imagery, and 0.5 m Aerial imagery. The 2017 imagery was chosen to show kelp abundance before the apparent decline and 2021 imagery was the last available year of DNR polygons. Aerial imagery coverage from 2017 did not include McCurdy Pt, and for that reason no kelp pixels for that point in Area 1 are shown. Several patterns are apparent from each set of data. First, the two most consistently robust areas of kelp along the coastline are Areas 1 (McCurdy Pt) and Area 5 (Pt Wilson). Secondly, Area 2 located adjacent and east of McCurdy Pt was consistently sparse between the years. The aerial and Planet satellite data shows pixels close to shore but as mentioned before, it is unclear if these represent bull kelp, understory kelp, other types of algae with similar reflective properties, or a combination of algae, with this latter possibility most likely. However, offshore kelp pixels were almost completely absent from this area during these years. The third pattern was that Area 3 showed the most variability of all areas along this coastline, showing a consistent declining trend for all imagery sources and resolutions. Whether this decline is part of a natural cycle or whether it indicates a problem with this area is unknown since this area has not been the site of any previous studies to our knowledge.

These patterns were further investigated using 2022 data with Figure 7 providing extracted kelp pixels from Sentinel 2, Planet, and Aerial imagery. Like the period from 2017 to 2021, bull kelp in Areas 1 and 5 remained relatively stable and robust, Kelp in Area 2 was sparse to non-existent, and Area 3 continued to show a decline from 2017. Finally, the only 2023 imagery we had available was from the Sentinel 2 satellite so the kelp pixels from that source and from that year are provided in Figure 8. Again, Areas 1 and 5 were stable and robust, while Areas 2 and 3 were sparse except for near shore pixels.

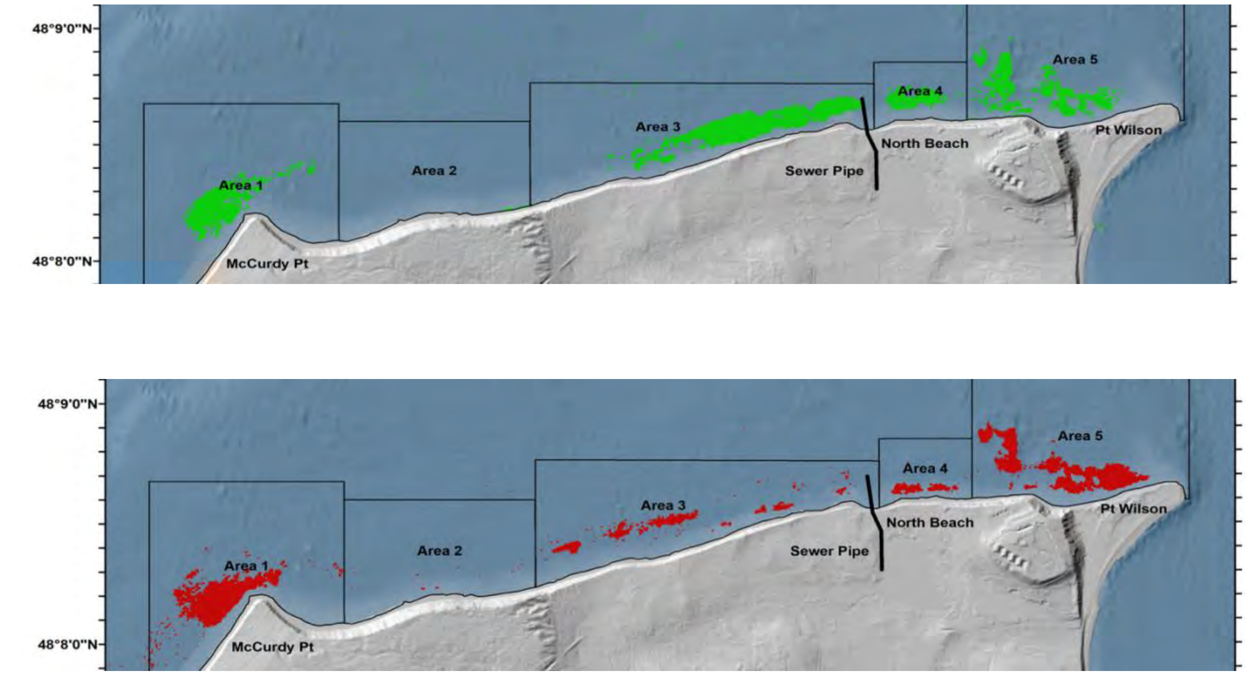


Figure 4: Kelp pixels extracted from 10 m Sentinel 2 satellite imagery from 2017 (top) and 2021 (bottom).

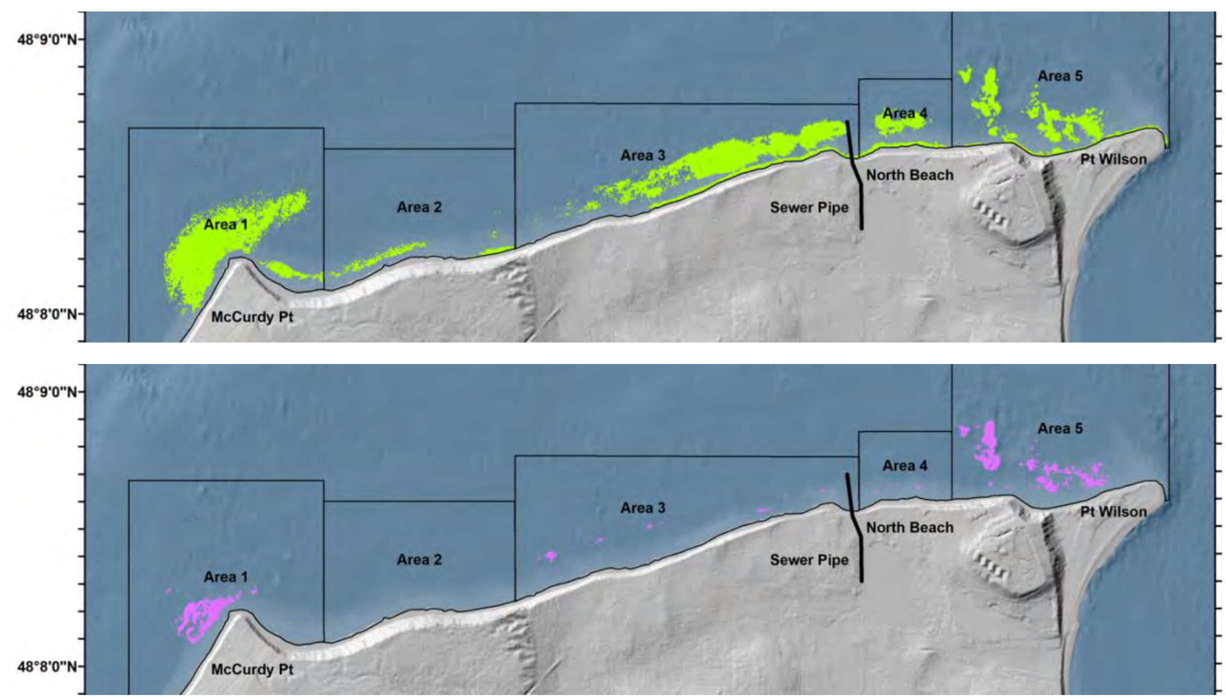


Figure 5: Kelp pixels extracted from 3 m Planet satellite imagery from 2017 (top) and 2021 (bottom).

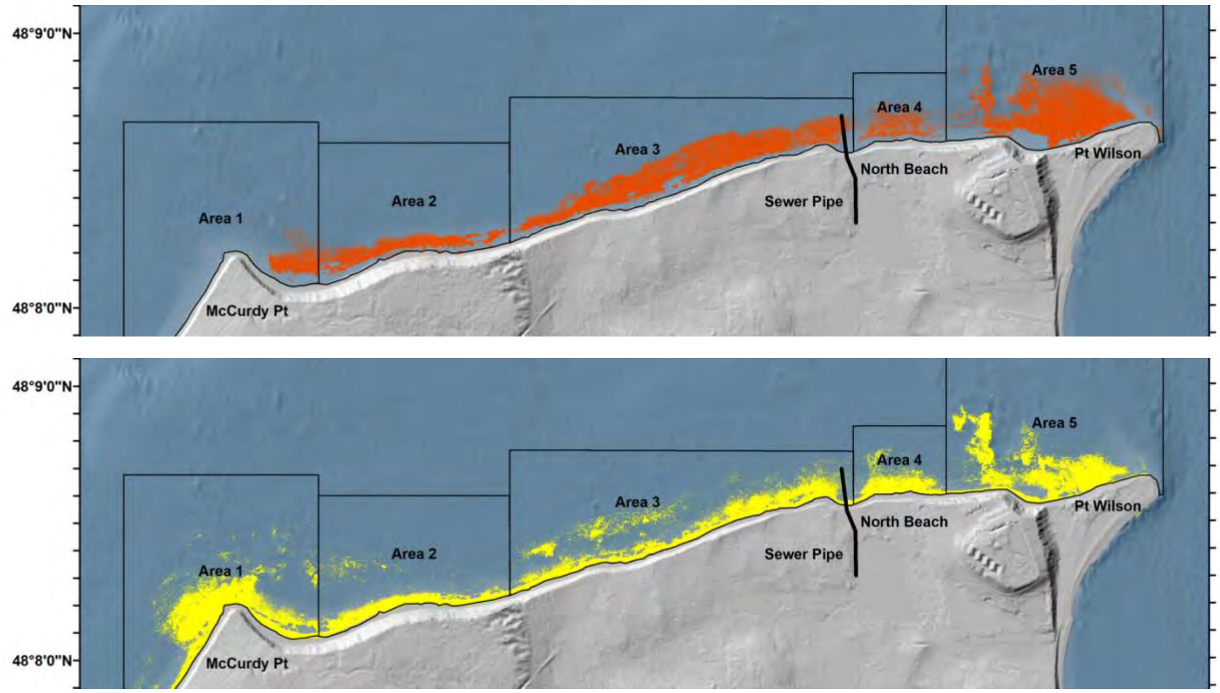
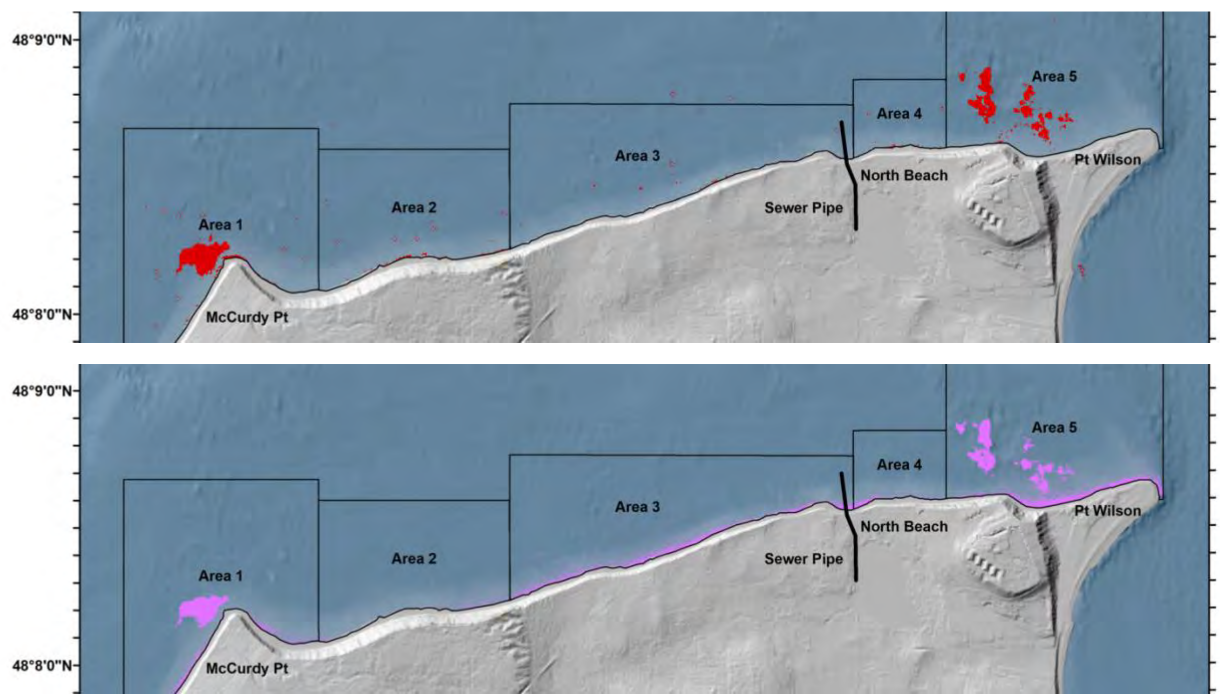


Figure 6: Kelp pixels extracted from 0.5 m Aerial imagery from 2017 (top) and 2021 (bottom).



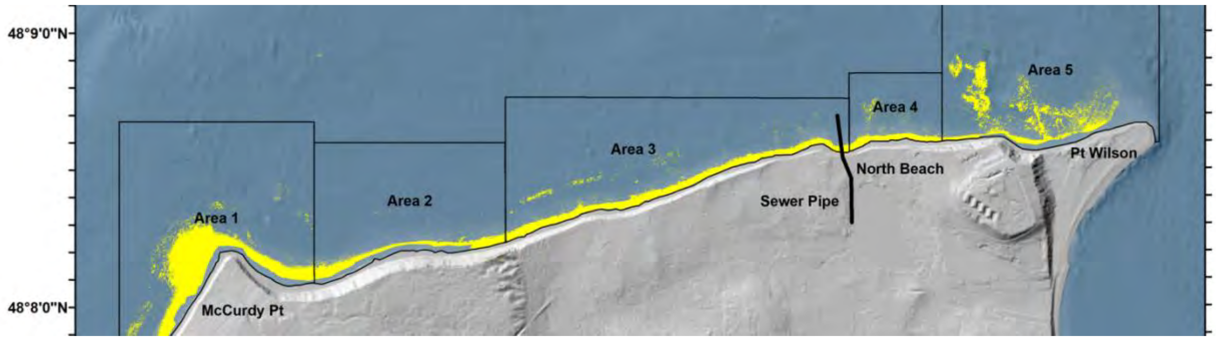


Figure 7: Kelp pixels extracted from 2022 imagery from Sentinel 2 (top) Planet (middle) and Aerial surveys (bottom).

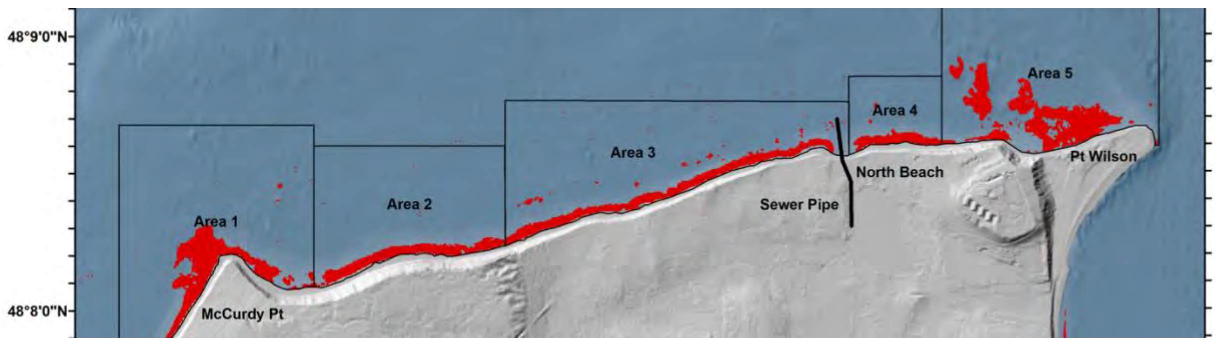


Figure 8: Kelp pixels extracted from 2023 Sentinel 2 imagery.

6. Project Highlights, Innovations & Stories

The JMRC has a particular interest in understanding the status and trends of bull kelp along the Quimper Peninsula and has the ability to test various methods to monitor that larger stretch of shoreline and expand upon the kayak surveys happening at North Beach. This project demonstrated the pros and cons of using satellite imagery in a qualitative assessment to find additional areas that could warrant more in-depth studies.

7. Lessons Learned

- We would recommend that this type of imagery is not used for precision estimates of kelp abundance but rather to identify large scale trends in kelp beds along the coast. If used appropriately, satellite imagery could provide a very useful tool for kelp monitoring efforts in Washington counties.
- The inexpensive 3 and 10 meter resolution satellites are not capable of seeing the relatively smaller beds and fringing beds that are common in Puget Sound. We have

demonstrated that it is possible to detect significant changes in floating kelp beds even with the inherent limitations of satellite image capture timing.

8. Next Steps

The project demonstrated the pros and cons of different sources of satellite imagery and its applicability to be used as a qualitative tool to identify potential large scale shifts in kelp distribution. Next steps could include:

- Continuing to use remote sensing to both track kelp distribution and trends along a larger stretch of shoreline in Jefferson County, as a complement to site specific kayak-based monitoring.
- Purchase higher resolution satellite images to monitor other areas with sparse kelp beds.
- Qualitative assessment of the remote sensing data suggests that Area 3 has gone from a large dense bed to a sparse one in 5 years. This bed is bracketed by beds that are stable. Area 3 is a region that could make a good case study site in need of further data collection to better understand the status of bull kelp and potential causes of observed declines.

Appendix A: Project History and Assessing Satellite Imagery Sources

In 2016 a member (Taylor) of the MRC kayak survey team began testing an approach with imagery from the Sentinel 2A satellite to complement the kayak bull kelp surveys by evaluating the beds that are not part of the kayak surveys. The European Space Agency (ESA) launched the Sentinel 2A in 2015. It is an optical imaging satellite with 13 spectral bands and 10-meter resolution. In 2017 Sentinel 2B was launched. The ESA has made all the Sentinel images available for free.

One of the two Sentinel satellites captures images of the peninsula’s northern shore every 10 days. The images have 14 spectral bands including the standard 3 RGB bands and a near infrared (NIR) band that has proven to be the most important for visualizing bull kelp. This is because kelp reflects NIR but water absorbs it, making the kelp stand out. The resolution of these images is sufficient to see the denser kelp beds, and the frequent revisit rate has provided enough usable images to see changes in the beds that are not monitored by kelp surveys. Furthermore, mixing the NIR with other bands can create images with better definition of the kelp beds. Particularly useful is the Normalized Difference Vegetation Index (NDVI) made by combining the red band with the NIR band and the Normalized Difference Water Index (NDWI), using the NIR and green bands.

In 2018, QGIS was used to calculate the areas of the kelp beds. Using satellite images for area calculations has all the documented problems of not being able to control the image capture time, cloud cover, sea state etc.

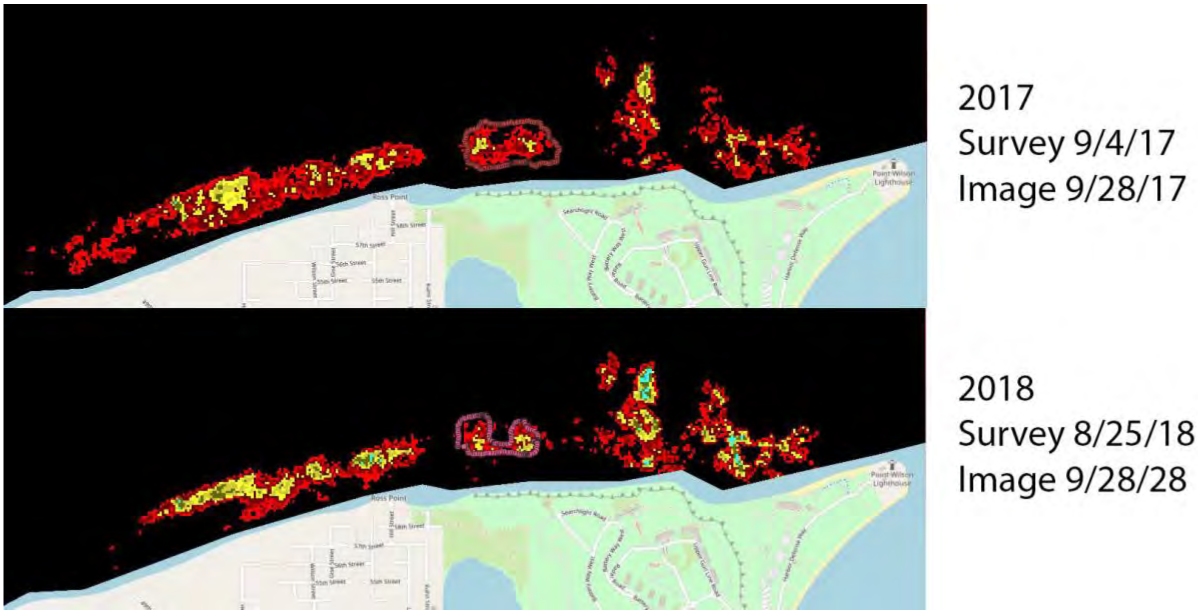


Figure 1) Sentinel 2 NDVI image of canopy kelp at North Beach in 2017 and 2018. The purple tracks are the kayak surveys.

Figure 1 is an example of how satellite images can complement the kayak survey. The first disadvantage of the kayak survey is it only covers a portion of the North Beach complex; the large area covered by the satellite allows observation of the entire North Beach. The second problem with the kayak survey is it does not consider kelp density. The biomass of the bed was not significantly different in 2017 and 2018, but the area calculation showed a 30% loss. The main reason for the difference is there was kelp along the north edge of the bed which caused a very sparse section to be included in the area calculations Although bed area is easy to calculate and gives a quantifiable result, it can be misleading because it does not include any density information.

The two main disadvantages of the satellite images are resolution and the inability to control when the images are taken. Although the Sentinel 2 satellites capture images every 10 days, cloud and smoke cover makes many of the images unusable. Usually only about 5 images are usable each season, and they do not align with the tide cycle.

Instead of trying to work around the limitations of the satellite to fit in existing methodologies, another option was to start with what can be seen in the satellite images and deducing what is happening to the kelp. The goal of kelp surveys by the MRC is to use local resources to monitor how kelp beds change. Quantifying small changes for research is one use, another is to detect large changes and to monitor areas not covered by the kayak survey. The kelp beds around Protection Island went away rapidly which would be easy to detect by satellite imagery. Early detection of rapid changes could lead to more focused monitoring of the areas while they are changing.

The following two images are Sentinel 2 NDWI images of Glass beach taken two years apart. The first was taken September 28, 2017 at a tide level of 7, and the second on August 4, 2019 at a tide level of 0.

9/28/17

8/4/19

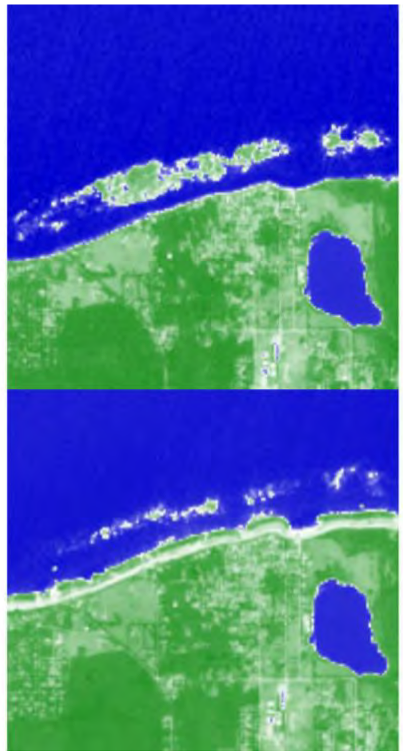


Figure 2) Glass Beach 2017 vs 2019

The two month difference in growing season and the 7 foot difference in tide level would make it impossible to use these images to compare the area this bed. Just looking at the Glass Beach section of the complex at North Beach, it is not possible to speculate about trends in kelp density.

However, using the same image but including all of the kelp beds in the North Beach complex provides more information and by using relative changes in different sections it is possible to deduce that some areas are likely in decline.

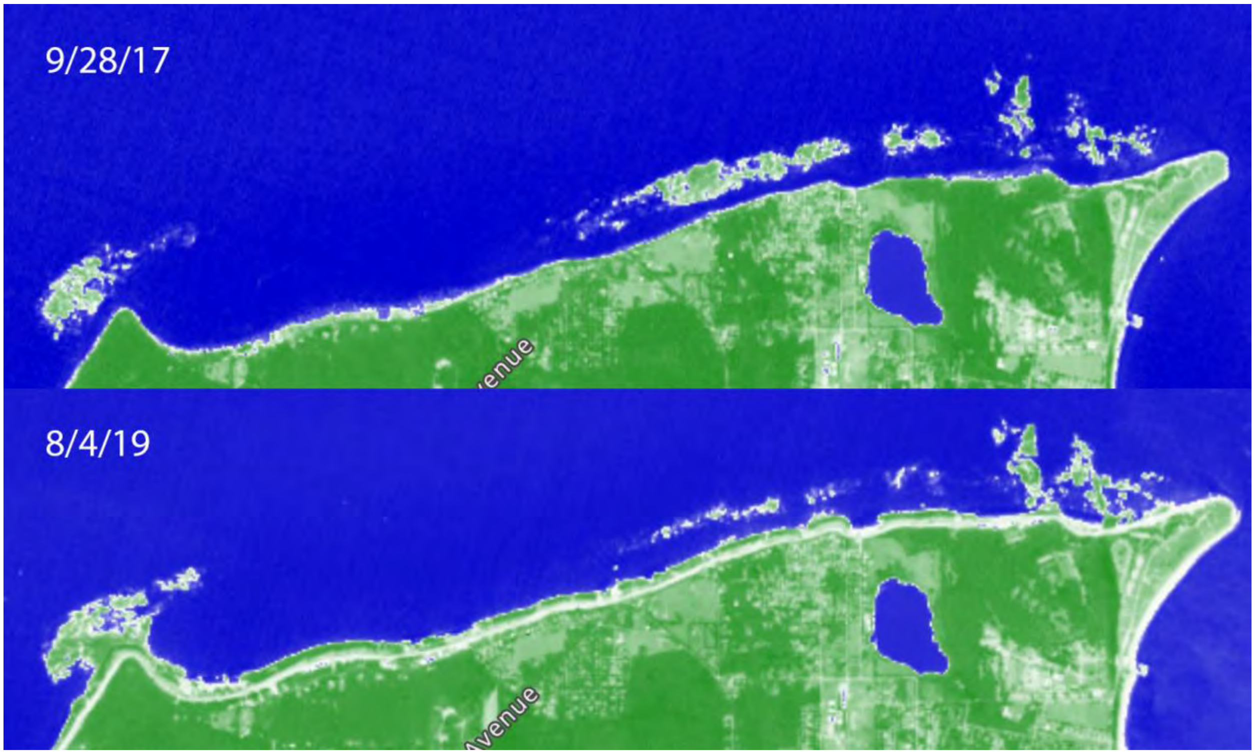


Figure 3) The same image as figure 2, but now cropped shows the relative changes at Point Wilson, McCurdy Point along with Glass Beach.

The kelp beds at Point Wilson in the east and McCurdy point in the west both look slightly larger in 2019. This could be because of the lower tide level, or because there is more kelp. What is unusual is the kelp in the middle, west of the Chinese Garden pond looks like it is significantly less dense in 2019. This is unexpected and the most likely reason is significant loss of kelp by Glass Beach. These two unusable images indicate significant changes in kelp density in large kelp bed that is not being monitored.

The first step is to rule out other reasons why the kelp at Glass Beach would be less visible that the nearby beds on either side. It is not the tide difference because it is the same for the area and the other beds are not affected. Currents can push kelp under and make different sections of a kelp complex invisible in NIR band. One advantage of survey satellites like Sentinel and Planet is they provide multiple photos every year. Looking at many images it is easy to see the fingerprint of high currents on the bed.

The next image was taken on August 17th 2017, and the second 5 days earlier.

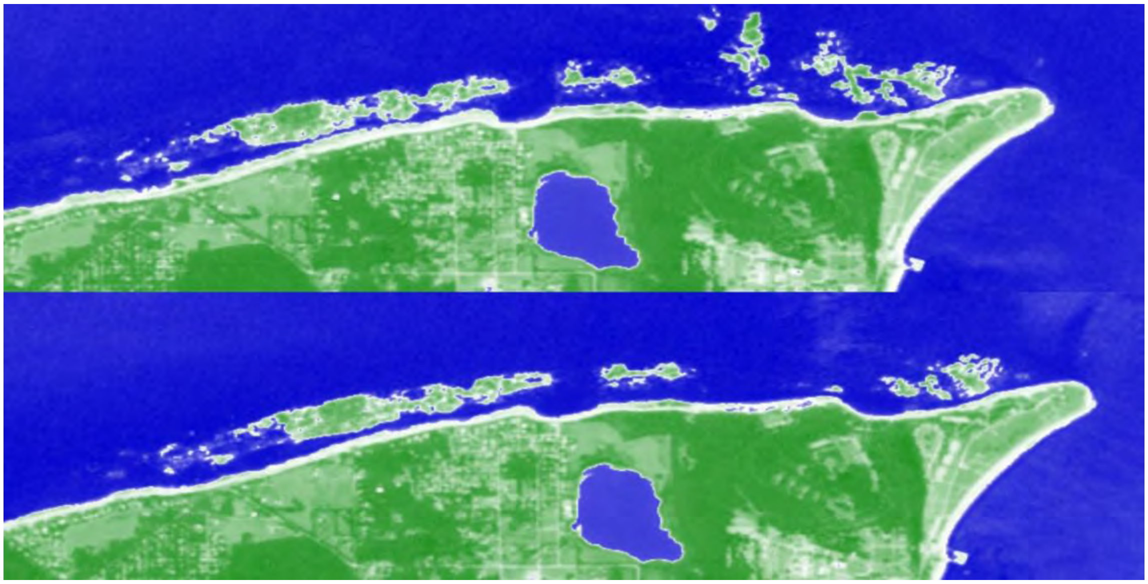


Figure 3) The kelp north of Fort Warden pushed under by currents. 5 days separate the two images.

The north most bed is exposed to very high currents, and we have seen the current push it under. It was unexpected to see the bed closer to shore also missing when beds to the east and west the same distance from shore not affected. When the PNNL Salish Sea current model is overlaid on the NDVI image it shows the highest current in the area is where the kelp is missing from the image.

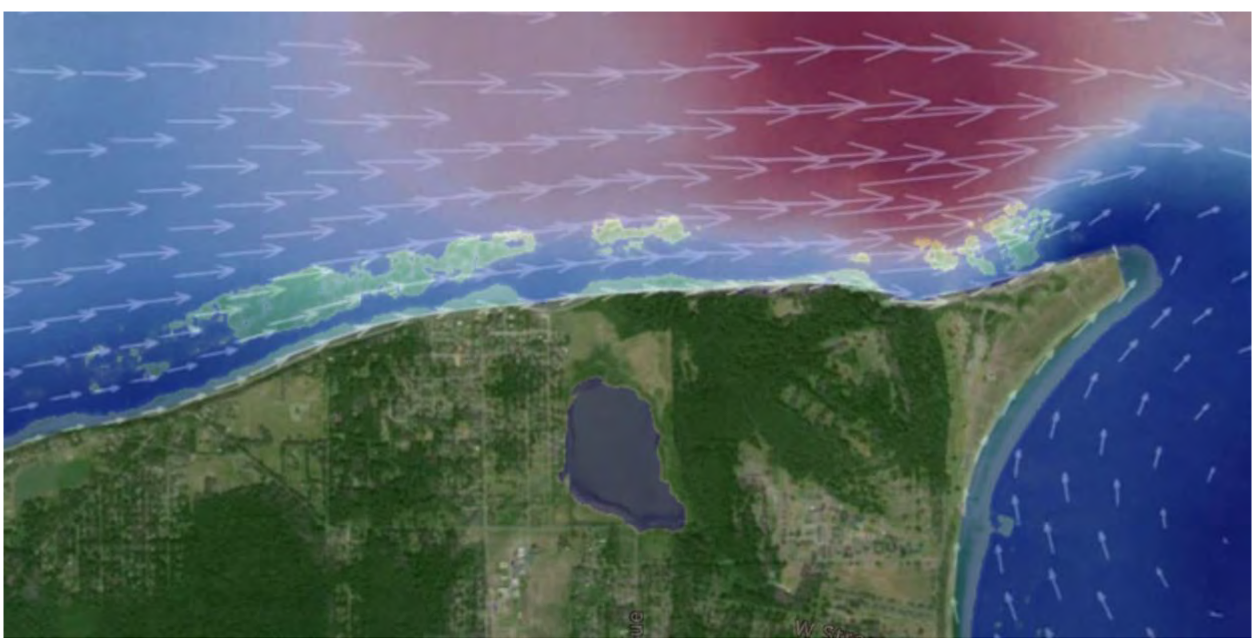


Figure 4) PNNL current model overlaid on the satellite image

Viewing multiple images and applying local knowledge about the currents makes it possible to know how currents affect the local kelp complex. There are no known condition where the local currents at Glass Beach are significantly higher than McCurdy Point and Point Wilson.

The periodic image capture by the Sentinel satellite means it is not necessary to rely on a single image. All of the images in 2019 had the same pattern showing less relative kelp in the Glass Beach section.

Looking at multiple years indicates the kelp in the middle section is losing density and the nearby beds at McCurdy Point and Point Wilson are stable.

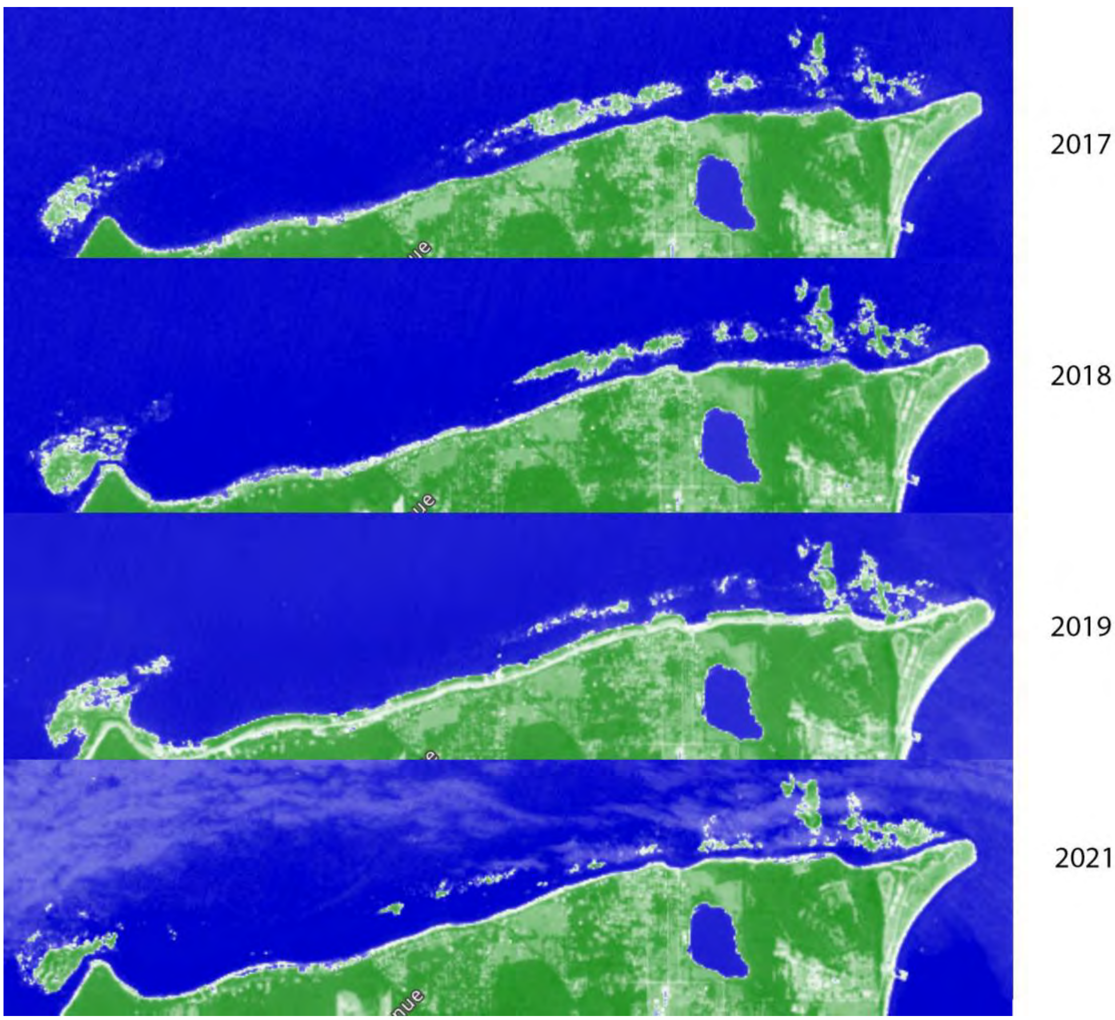


Figure 5) 5 year trend of kelp at North Beach. Sentinel 2 NDVI images.

Appendix B: Assessing the use of satellite imagery to better understand bull kelp density

Current data sources such as DNR's aerial surveys and the JMRCs kayak-based monitoring document bull kelp bed extent but do not assess the density of those beds. There is some concern that only monitoring the extent of the bed will miss shifts in bull kelp population dynamics.

Bed density as estimated from surface coverage cannot be obtained easily using kayak surveys but can be derived from overhead imagery created by satellites, aerial surveys, or drones, which collectively can be considered remote sensing techniques. The process of extracting density estimates requires sophisticated software such as ArcGIS and each of these techniques has drawbacks. For example, aerial imagery is the most expensive while offshore drone imagery is both expensive and is the most difficult to render into geotifs. With respect to satellite imagery, it is very difficult to get quantitative results because of the lack of control over when or at what tide level the images are collected. Furthermore, cloud cover reduces the number of usable images and the resolution is often not adequate to see sparse beds. This is particularly true for using no-cost 10 m resolution images from ESA that only reveal the larger and denser beds.

Bull kelp is also called floating kelp and it is extremely difficult to determine the density of these plants in a given area because the seafloor cannot be seen from the surface at depths where most are found. Surface coverage by exposed fronds, bulbs, and stalks are instead being used as a proxy for density and that is what we are referring to when we use the term density in this report. The lack of density estimates means that potentially important changes to the amount of kelp within the beds have gone undetected. Earlier this year, Cowdrey & Claar (2024) reported results from drone surveys of bull kelp conducted in various counties including Jefferson. Using the hyperspectral imagery collected by their drone along with analyses in ArcGIS and other software, they were able to evaluate changes in the surface coverage of kelp over a 2-year period within the North Beach Park bed, concluding there had been a significant decrease between 2021 and 2022. However, logistical considerations again constrained their surveys to the same small area annually surveyed with kayaks by JMRC members.

Satellite imagery coupled with GIS analyses has the potential to provide a relatively inexpensive means to do this. This project was initiated in 2024 to test whether these data could be used to adequately detect changes in bull kelp in Jefferson County and if so, provide a more significant contribution to the state's efforts in protecting this important resource.

Appendix C: Assessing the relationship between kelp extent, bathymetry, and substrate using satellite imagery

The extraction of kelp pixels from the imagery allowed for examining the relationship between the kelp beds along this coastline and seafloor bathymetry. Figure 11a shows the 5 m resolution bathymetry along the northern coast with the 8 m depth contour line shown in white. We were unable to locate backscatter or sidescan sonar data to help identify the nature of the substrate. However, what can be seen from the shore, boats, and from RGB imagery from Google Earth indicates that there are rocky patches, sediment patches, and mixed patches at various locations. The 5 m contour line extends out primarily from McCurdy Pt and Pt Wilson, and parallels the coastline in Areas 2,3, and 4. Figure 11b shows the combined kelp pixels from both Aerial and Planet satellite imagery for the years 2017 to 2022 over this bathymetry. Almost all of the kelp during this period has been found between the shore and 8 m depth. The Area 1 and Area 5 beds follow the contour out from the shoreline and are where the densest and most stable beds of bull kelp are located. Together, these observations are suggestive of the presence of rocky reefs in these areas. Kelp has been conspicuously absent from much of area 2 and the eastern side of area 5, which could be indicative of sediment substrate. These “conjectures” however need to be confirmed by either SCUBA or towed camera surveys. Areas 2 and 5 are of particular

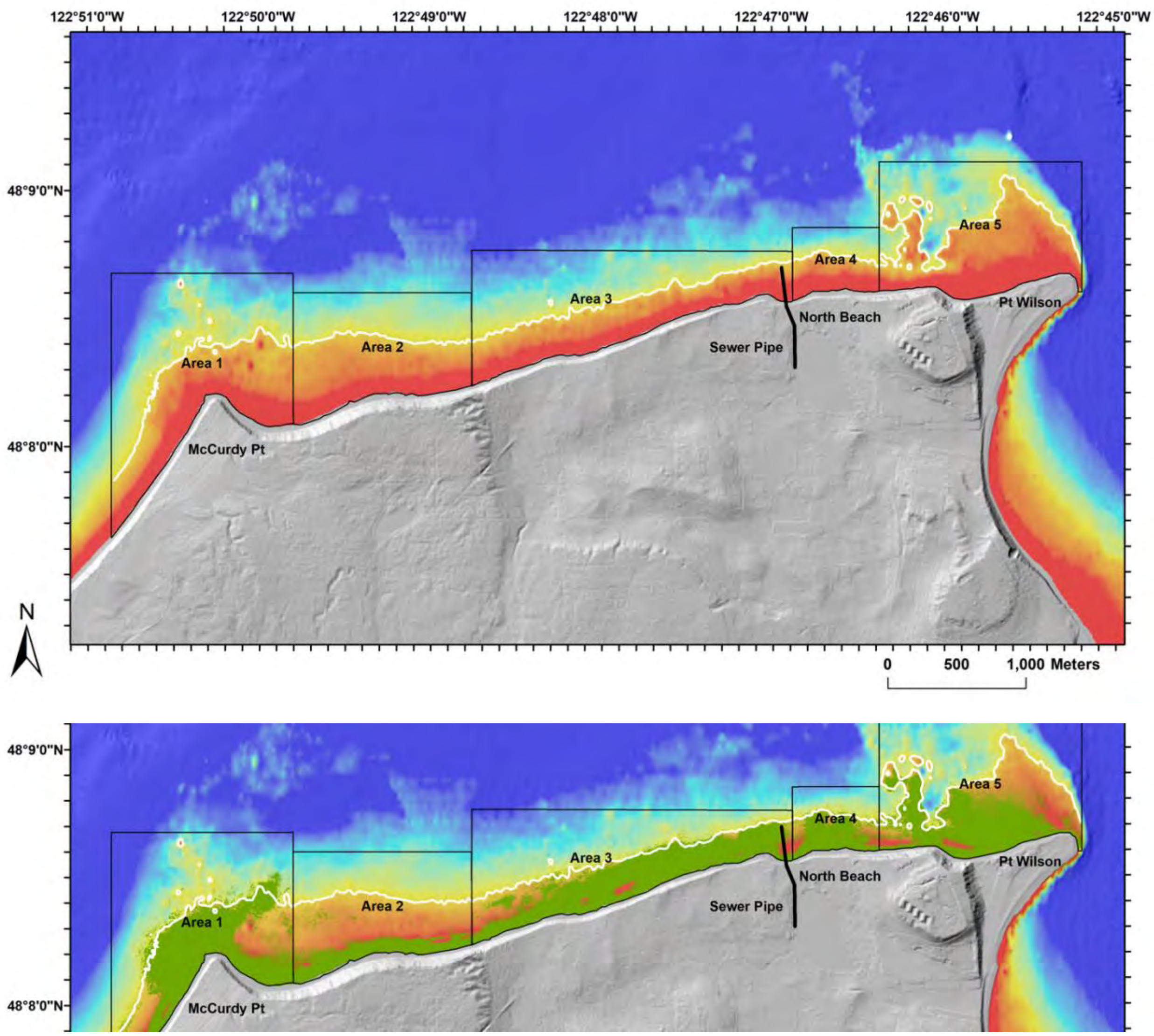


Figure 11: Five-meter bathymetry of the Quimper Peninsula northern coast (top) overlain by combined kelp pixels (green) from 2017 through 2018 Aerial and Planet Satellite imagery (bottom).

interest for opposite reasons. The bathymetry and GoogleEarth images in Area 2 are suggestive of at least some rocky substrate that could provide attachment sites for bull kelp (Fig. 12a&b). Low relief promontories extend out from shore but do not appear to provide adequate attachment substrate for bull kelp or there is some other reason for why kelp is absent there. Heavy sedimentation is one possibility because this area is immediately seaward from the highest feeder bluffs along this entire coastline (Fig 12c). Figure 13 provide a screen grab of a single moment in a current model along this coastline showing a gyre and low current flow vectors in Area 2 that are present at least some of the time. The potential presence of a major sediment source coupled with periodic low current flow might be causing increased sedimentation in this area in comparison to other areas.

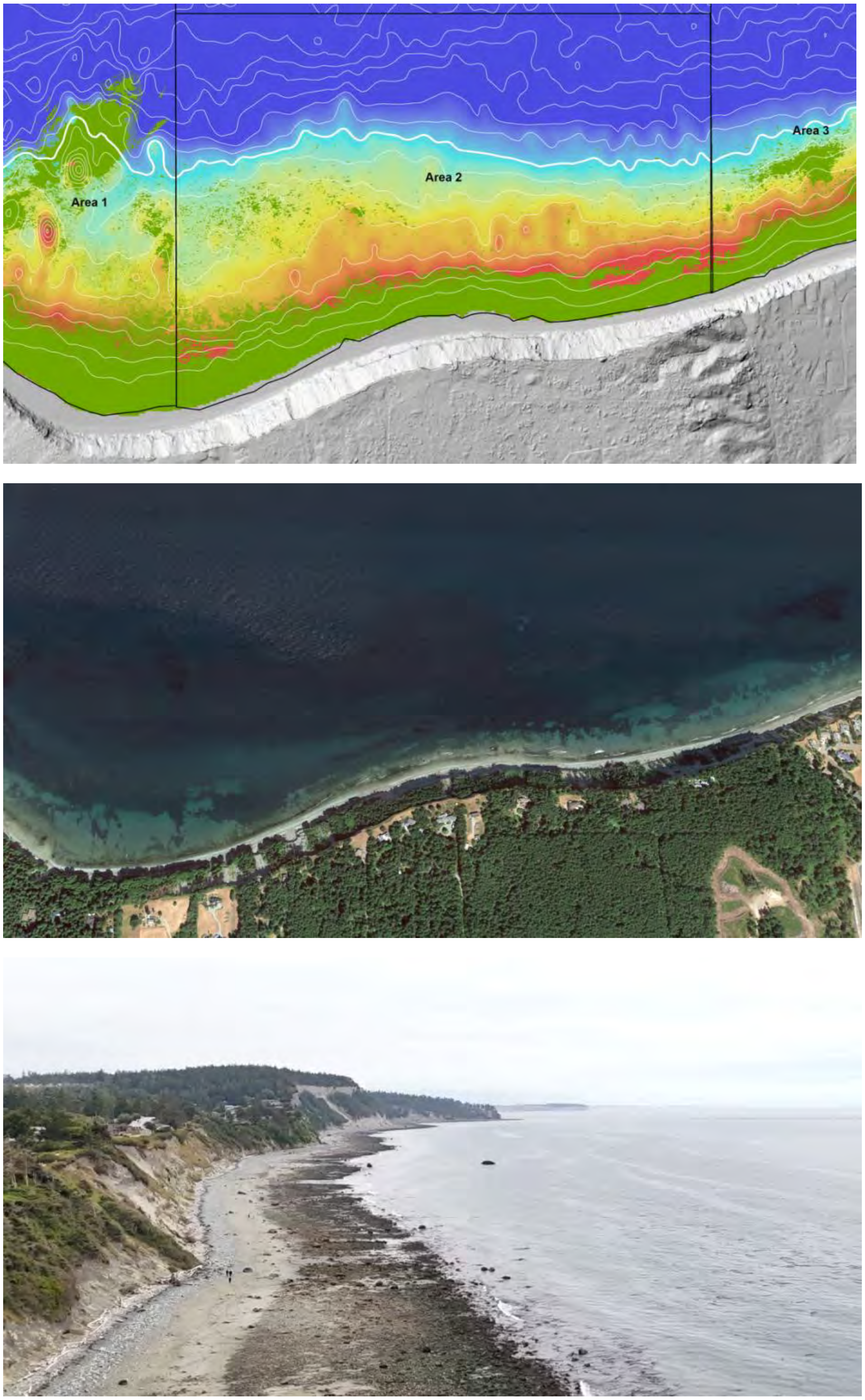


Figure 12: Five-meter bathymetry of Area 2 overlain by combined kelp pixels (green) from 2017 through 2018 Aerial and Planet Satellite imagery (top). Google Earth image of Area 2 (middle) and a drone image of the feeder bluffs landward of Area 2 (bottom).

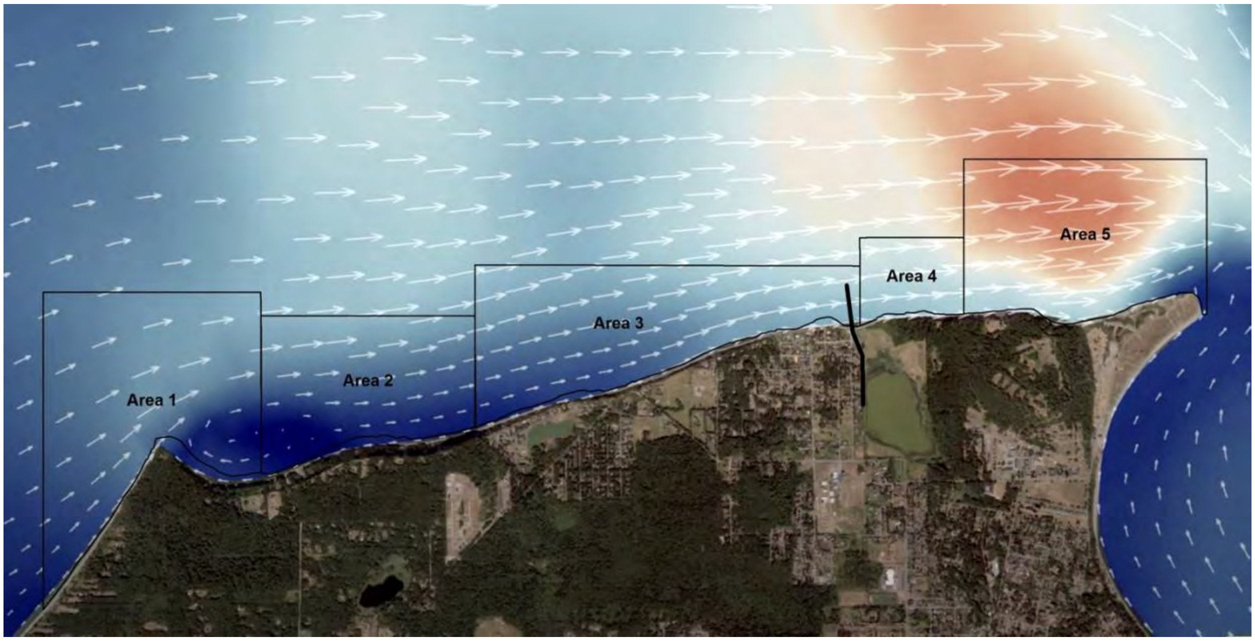


Figure 13: A screen grab from a single moment in a current model created by Tarang Khangaonkar of PNNL. Current intensity is shown by blue (low) to brown (high) colors as well as the size of the current vector arrows.

Area 5 is of considerable interest because of the apparent rocky reef or shoal extending out from shore that bull kelp is closely associated with (Fig 14a). Furthermore, this is the site of the most intense current flow along the coast as was shown in Fig. 13. We suggest that because of the current flow, this keyhole-like substrate feature may be routinely swept clear of sediment providing ample hard rock surfaces for kelp attachment.

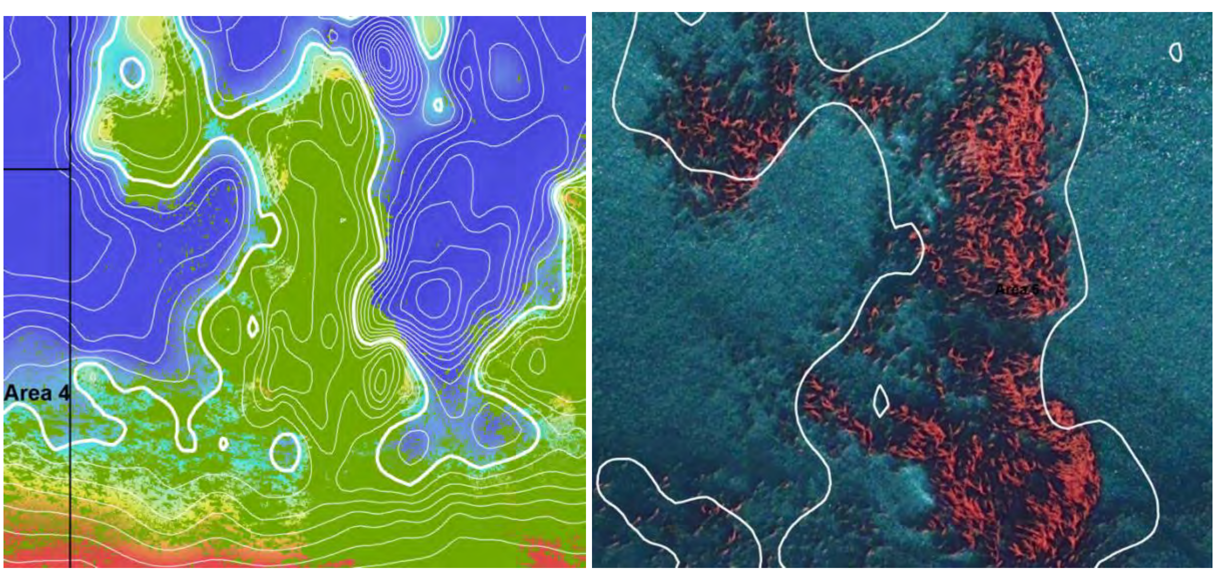


Figure 14: *Five-meter bathymetry of the keyhole feature in Area 5 overlain by combined kelp pixels (green) from 2017 through 2018 (left). Pleiedes satellite image of the feature (right).*

When increased current conditions occur along this coastline, the kelp on the keyhole feature can be pulled completely underwater and become undetectable to optical satellite. For this reason, we suggest that this feature could be used as an indicator of suitable current conditions for obtaining satellite imagery. As mentioned earlier, researchers using satellite imagery for monitoring bull kelp have no control over when an image is collected and under what type of current and tide conditions. Instead of just assuming that these obstacles are too difficult to overcome, we need a visual way of assessing suitable conditions from the images themselves and identifying indicator areas provide a means to do that.