Remote Property Monitoring at The Nature Conservancy in California
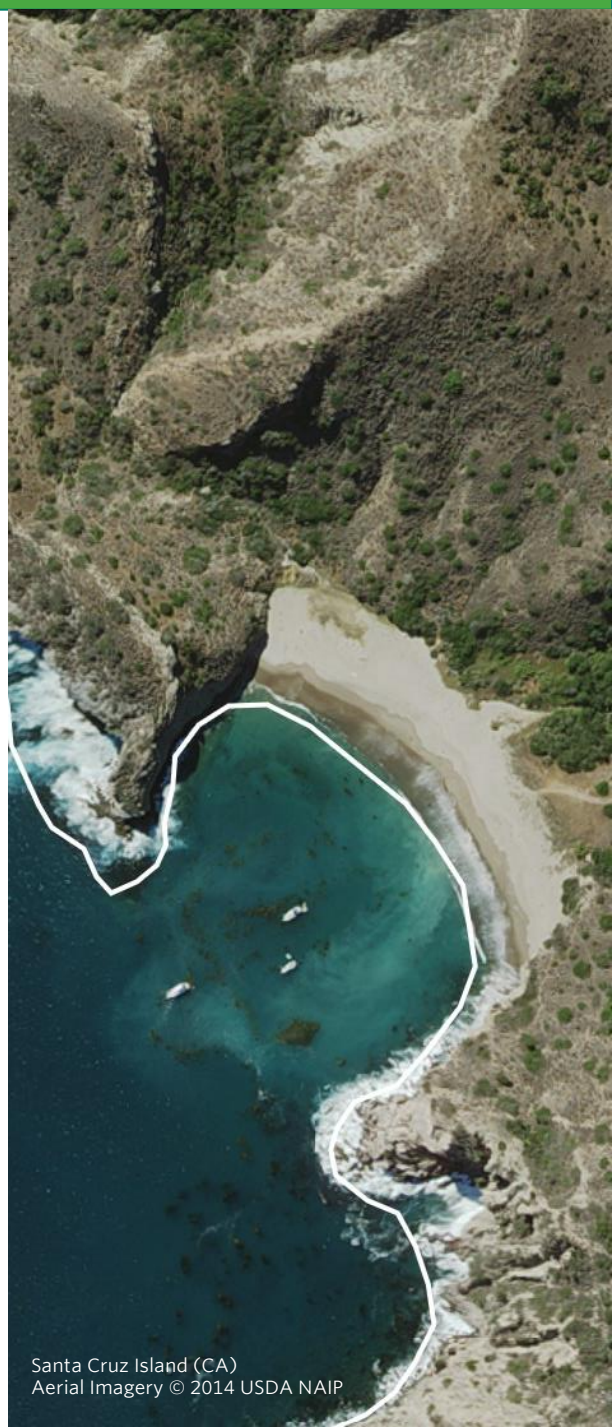
Summer 2020

The Nature Conservancy

Abstract

For nearly two decades, The Nature Conservancy's (TNC) California Chapter has explored the use of remote sensing to meet our annual property monitoring requirements. We've hired airplanes, used Google imagery, flown drones and automated the processing of multispectral imagery. While these are all valid approaches, they didn't fully meet our needs. In 2019 we tried something new: we collaborated with a third-party on their development of a web-based service tailored to support remote property monitoring. We've since integrated remote monitoring into our stewardship practice statewide using their web-based service, Lens. Now, all team members who perform monitoring have the option to monitor in-person, remotely, or a combination of both methods.

There are many ways to use remote sensing to support or replace in-person property monitoring, and the 'right' solution will depend on the goals, requirements and budget of the entity - whether land trusts or other - responsible for monitoring. This paper provides key information that we have learned in our exploration of remote property monitoring.

TNC refers to the global organization while TNC CA refers to The Nature Conservancy in California.

This paper will be regularly updated as we learn more.

Santa Cruz Island (CA)
Aerial Imagery © 2014 USDA NAIP

Table of Contents

1.0 Introduction

TNC CA has investigated the use of remote sensing for annual conservation property monitoring beginning in the early 2000s ([Bren School, 2004](#)). Our long-term goal is to incorporate a remote monitoring practice into our stewardship program statewide, and to increase the effectiveness and reduce the time and expense of our monitoring practice. Our early hypothesis was that the use of remote imagery would increase the efficiency of our monitoring program, saving money and freeing staff to focus on other critical stewardship work like restoration and outreach. We also speculated that by conducting both remote monitoring and in-person monitoring, perhaps alternating on some cadence, we would increase the overall effectiveness of our monitoring by benefitting from the unique qualities of each method. For example, in-person monitoring promotes landowner relationships and firsthand knowledge of properties, while remote monitoring promotes a broad assessment of conditions around the property including areas that would otherwise never be seen.

In 2020 we incorporated a formal remote monitoring system and practice into our stewardship program statewide. We now monitor our properties using either traditional in-person methods or remotely using a web-based service; in some cases, we use both approaches. This web-based service, named Lens, is well tailored to our remote monitoring needs in large part because we collaborated with the third-party who developed it, describing to them the monitoring requirements and workflows of an accredited land trust. Lens provides access to a range of imagery suitable for monitoring, a robust platform for visual and analytical monitoring techniques, and systems for documenting and recording our observations. We have also developed and implemented a set of best practices for monitoring and documentation use.

There are many valid approaches for remote monitoring, and we are certainly not the only organization to use or have experience in this area. We recently commissioned the UC Berkeley Geospatial Innovation Facility to conduct an assessment of the state of practice of remote sensing for conservation easement (CE) monitoring in the US land trust community ([Thomas 2020](#)). The UC Berkeley paper, which we strongly recommend, confirmed that our early experiments were similar to the approaches other land trusts have taken, and the pros and cons we found in our early approaches were in common with others.

This paper shares a conceptual framework for remote property monitoring, what we've learned about the **imagery** types and sources available for remote monitoring, the approaches and **platforms** we tried and advantages and disadvantages of each, and our '**best practices**' for remote monitoring. The examples draw from our primary use case, which is CE compliance monitoring.

Every organization has a unique portfolio of properties, financial resources, staff capacity and experience, and tolerance for technology. This summary of experimentation, learnings, and best practices is intended to benefit others working in this unique and growing practice at the intersection of conservation technology and management. We have organized the most relevant details here, in the hopes that they will give a head start to anyone considering how to remotely monitor their properties.

> Short on time? We've highlighted the most critical pieces of information in these Key Findings call out boxes.

TNC CA holds over 170 conservation easements (CEs) or deed restrictions comprising about 375,000 acres of private land. We also own or manage more than 150,000 acres in fee. These properties are distributed across all gradients and ecoregions of the state from coast to deserts to mountains, remote to wildland/urban interface, and wild open lands to farms and ranches. They range in size from a fraction of an acre to properties greater than 30,000 acres. Although all our fee owned properties are monitored annually, this paper will focus on and draw examples exclusively from CE compliance monitoring.

As an accredited Land Trust, TNC monitors "each conservation easement property at least once per calendar year" according to The Land Trust Alliance's (LTA) *Land Trust Standards and Practices* ([Land Trust Alliance, revised 2017](#)). Annual CE monitoring represents a significant amount of work for us due to the number of CEs, their distribution across all regions of the state, the uniqueness of each property and its CE terms, and the large size and remoteness of many of the CEs. TNC CA monitors with the work spread across 20+ staff and contractors. This effort costs an estimated $300,000 and requires a total of three full time equivalent employees (FTEs).

A CE is a legally binding agreement that limits certain types of uses or activities on a property in perpetuity. The terms of each CE selectively target only those uses and activities necessary to ensure the durability and resilience of conservation values, such as habitat and ecosystem services, and each CE is unique. It is our obligation as the CE holder to enforce the landowner's compliance with the terms of the CE.

CE terms that we monitor have a wide range of scope and scale, depending on the property. For example,

- Development of new infrastructure such as roads, trails, buildings, or energy facilities may be prohibited. Repair, maintenance, or replacement of existing infrastructure is often allowed.
- Recreational uses of properties are often restricted to specific locations (such as existing roads) and types of recreation.
- There may be limits on how natural, harvested, or cultivated lands are managed. Native oak trees may not be removed, unless they present a safety risk. Grasslands may be grazed to a level comparable with native species that use the grasslands but may not be over-grazed. Commercial forestry may occur with specific limits to assure sustainable practices.
- Certain exotic plant species are not allowed to be knowingly introduced to a property.

To ensure the efficiency and effectiveness of our annual monitoring program, TNC must meet its annual obligations in a way that balances human and capital resources with the quality of monitoring and maintenance of good landowner relationships.

An Opportunity for Remote Monitoring

The LTA *Land Trust Standards and Practices* provides some flexibility in *how* easement monitoring is conducted, allowing for the use of "aerial monitoring" in most years: "If the land trust uses aerial monitoring, conduct on-the-ground monitoring at least once every five years."

TNC's standard operating procedure and guidance therefore specifies that if a property is remotely monitored, <u>the imagery must be from the</u>

> Primary imagery used for annual conservation easement monitoring must be dated in the year that the monitoring is being conducted.

current calendar year. This pivotal detail formed a key requirement in our search for a remote monitoring solution.

Many of the uses and activities that we monitor on CE properties are observable in airborne and satellite imagery. We saw an opportunity to take advantage of the flexibility afforded by the LTA and began experimenting with ways to leverage remote sensing technologies for CE monitoring.

We established goals to try and improve both the efficiency and effectiveness of our monitoring.

1. Efficiency Goal

- Reduce overall costs of monitoring (personnel and fringe, travel, supplies, contracts).
- Reduce time spent by staff (so they can focus on other strategies and projects).

2. Effectiveness Goal

- Improve our ability to detect, quantify and document changes to properties.
- Improve communication and information flow between TNC and CE landowners to reduce CE violations and impacts to conservation values.

3.0 Considerations and Options for Remote Monitoring

In our exploration of remote monitoring over a period of several years, we compared available imagery and technology, evaluated different approaches to remote monitoring, and developed new practices and guidance needed to incorporate this monitoring technique into our stewardship program. This section describes the remote sensing considerations we see as most relevant for remote CE monitoring, some key characteristics and factors that differentiate imagery and qualify it as suitable (or not) for monitoring, the primary ways of accessing imagery, some detail about the platforms we tried, and various approaches to conducting remote monitoring to observe changes to properties.

3.1 Technology Consideration: Imagery

There is a wide range of imagery available. In this section we outline specifications of differing imagery sources, such as their spatial resolution, temporal frequency, image timing, and spectral characteristics.

The specifications of imagery determine **suitability**, **availability** and **affordability** for monitoring. These key imagery factors are interrelated. For example, free imagery may permit monitoring, but may not be available every year. Timely suitable imagery may be very expensive. And free, frequently available imagery may not be suitable for monitoring some CE terms. The graphic below illustrates the interplay of suitability, availability and cost. For our program, we prefer spatial resolution finer than 1m for monitoring important CE terms such as infrastructure

management. We also require imagery from the current calendar year. The filled gray area indicates the 'sweet spot' where these requirements overlap. Within the 'sweet spot', we've found archived high-resolution satellite imagery to be the only moderate-cost option (unless a free source such as Google or National Agriculture Imagery Program (NAIP) imagery happens to be available within the current monitoring year). Although DIY Unmanned Aerial Vehicles (UAV) or drone imagery might seem to be 'free', we faced costs for hardware and training, and had to deploy staff or contractors to capture imagery in person, We found those costs and capacity requirements to be equivalent to in-person monitoring.
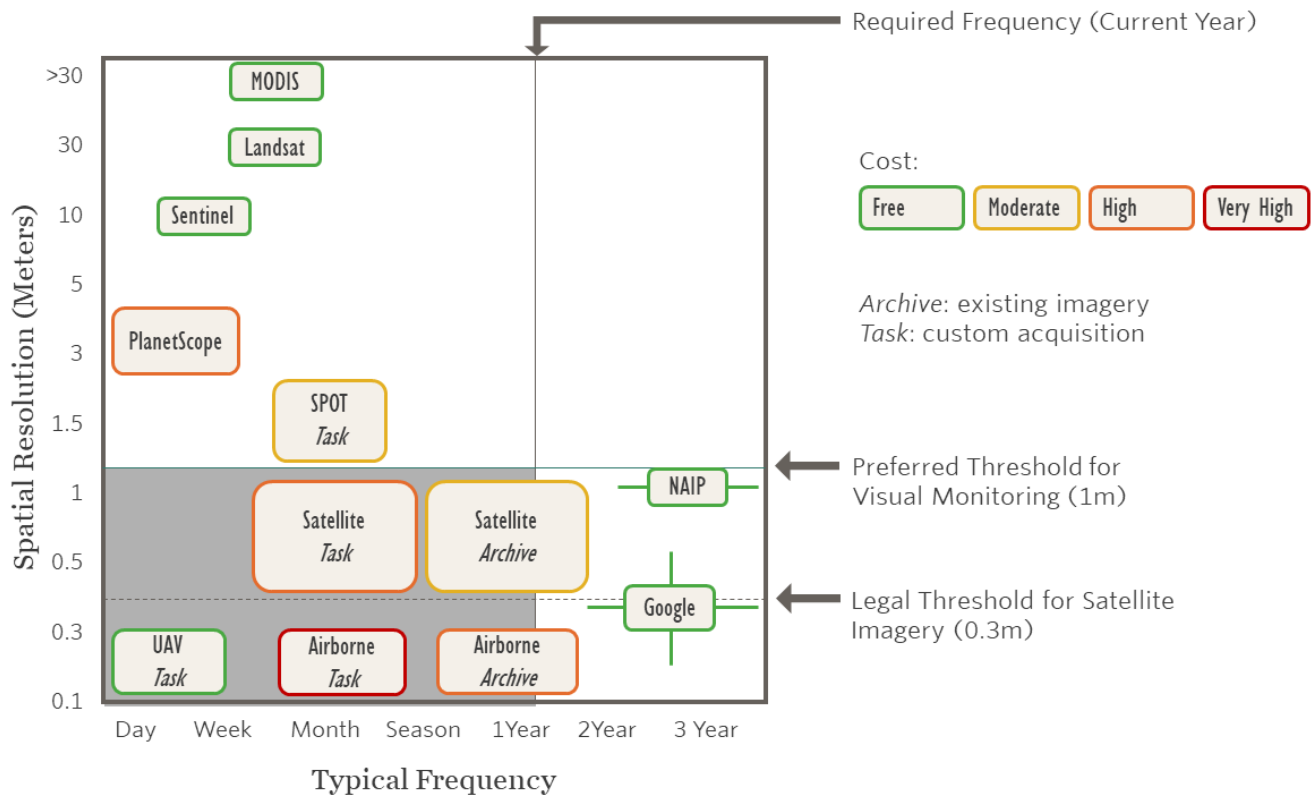
Interplay of suitability, availability and cost of imagery for conservation easement CE monitoring.

3.1-a Image Suitability

Remote imagery must be suitable for monitoring CE terms and must have suitable specifications to identify and track activities, uses and other changes over time. As described earlier our CEs often include a wide range of prohibited and permitted uses and activities that vary in their spatial scale, from very small footprints to entire landscapes. Imagery suitable for detecting small phenomena may have different specifications than imagery suitable for detecting landscape-scale phenomena. The following specifications influence the suitability of imagery for our monitoring.

> Imagery must be suitable for remote CE monitoring. Considerations include:
>
> - spatial resolution
> - temporal frequency
> - spectral characteristics
> - seasonal timing
>
> The relative importance of each depends on what you are monitoring.

SPATIAL RESOLUTION   This refers to the size of an individual pixel in the image and is related to the smallest feature that can be detected when viewing the imagery. There is no consensus concerning spatial resolution classes or nomenclature. What might be 'high resolution' in one application area may well be 'low' in another. For the purposes of this paper, categories of spatial resolution are defined based on the end use of the imagery, which is CE monitoring. Categories include low (>30m), moderate (30m to 5m),

high (5m to 1m) and very high (< 1m) (Thomas, 2020). The spatial resolution of imagery must be appropriate for the phenomena being observed. 0.5m may be necessary to detect new structures or trails. 1.5m may be adequate to ensure no new structures.
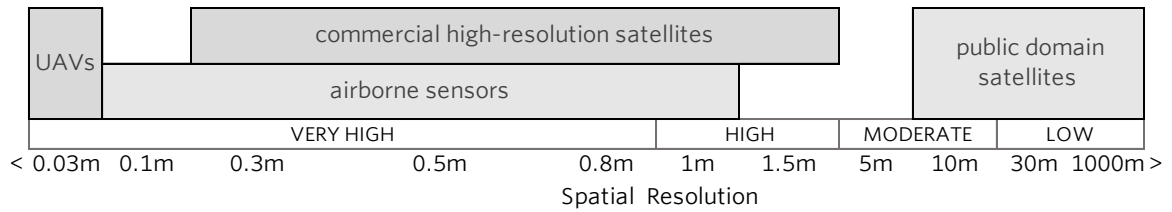
Common spatial resolutions for commercial satellites straddle the high to very high spatial resolution categories including 0.3m, 0.5m, 0.8m, 1.5m, and 3m. The finest spatial resolution for US commercial satellite images is 0.3m; this is a legal limit, not a technical limit, with US government satellites likely capturing imagery in the ballpark of 0.1m. Airborne platforms typically range from 0.1m to 1m. The highest spatial resolution for airborne imagery sources is finer than 0.1m. We have produced our own imagery from UAVs at about 0.03m spatial resolution for some of our small properties. Additional examples can be viewed at this link.

0.5 meter spatial resolution	1 meter spatial resolution	10 meter spatial resolution

Example of images with varying spatial resolution.

In terms of what resolution is necessary to detect CE-related phenomena, Bren 2004 identified the spatial resolution needed to monitor various types of features and activities. And more recently, TNC CA staff identified a similar list based on a standard template of CE prohibited and permitted uses.

SPATIAL RESOLUTION	Example permitted or prohibited uses and activities	Min. spatial res. needed to detect presence/ absence	Min. spatial res. needed to detect specific characteristics or details
	Harvesting timber	10m	10m
	New stock ponds	10m	1m
	Expansion of irrigated acreage	10m	1m
	Plowing, disking, alteration, of topography	10m	1.5m
	Gravel mines	10m	1m
	Crops	10m	1m
	Installation of towers, antennas	1.5m	0.8m
	New roads, trails and bridges	1.5m	0.5m
	Removing existing improvements	1.5m	0.5m
	Commercial greenhouses, plant nurseries	1.5m	0.5m
	New buildings, dwellings	1.5m	0.8m
	Maintaining, repairing, replacing existing structures	1m	0.5m
	Improving or replacing existing roads and trails	1m	0.5m
	Orchards	1m	0.5m
	Bee keeping	0.8m	0.5m
	Off-road vehicle use	0.8m	0.5m
	Keeping horses and mules	0.5m	0.5m

TNC CA's draft guidance on spatial resolution needed to detect and characterize changes related to specific sample CE terms.

These are initial findings. Individual monitors (anyone who looks at conservation easements to ensure compliance) or organizations should ensure they are using imagery at a spatial resolution fine enough to support their needs, comfort level for monitoring and risk tolerance for missing violations.

TEMPORAL FREQUENCY

Some imagery is captured on a set cadence - every day (PlanetScope), every week (Sentinel) or two (Landsat), others every two or three years (NAIP, County assessor programs, Google). Other sensors capture imagery on demand, or when requested by a paying customer - this is covered in detail in the Image Availability section below.

SEASONAL TIMING OF IMAGERY CAPTURE

This is related to temporal resolution for on-demand imagery. Remote monitoring of some properties relies on imagery captured during a specific season. In California, many of our CEs are on annual grasslands, and monitors often want to monitor the property during the growing season in order to evaluate grassland productivity or spread of invasive weeds. In other cases, imagery from after the growing season helps us to assess how much dry vegetation was left on grasslands following grazing. For properties with deciduous vegetation, the timing of leaf-on or leaf-off may make the difference in suitability of imagery for monitoring. Timing related to snow cover is an additional consideration.

SPECTRAL CHARACTER- ISTICS

This refers to the wavelengths of light that an imaging sensor can detect. "True color" imagery products appear similar to a normal color photo. Panchromatic images appear as a grey scale. Multispectral images contain measurements of visible and/or shortwave infrared light. Depending on its spectral characteristics, multispectral imagery can be processed to appear as true color imagery, or to convey differences in vegetation, water, snow, soil or other materials that are not visible in true color imagery; these images can be helpful for detecting and quantifying changes to features and landscapes on CEs.
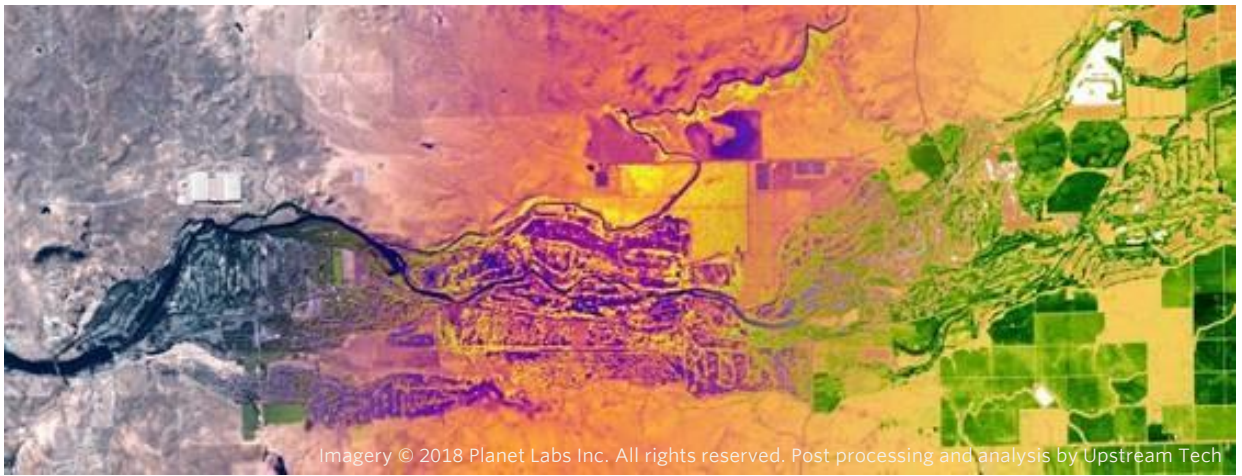
This image illustrates a gradient from left to right of true color to water (Normalized Difference Water Index, or NDWI) to vegetation (Normalized Difference Vegetation Index, or NDVI). This image sample can be found [here](#).

3.1-b Image Availability

As described above, the imagery used for CE monitoring must be from the current calendar year. This pivotal requirement is a significant constraint when sifting through all the imagery available for free or in the marketplace. While older 'historic' imagery captured in previous years is useful for comparing conditions on the property and changes over time, it is not suitable for assessing current-year CE compliance. The temporal frequency of an imagery source can dictate the availability of imagery for use in a current year.

> The requirement of **current calendar year** imagery for remote monitoring can be a barrier to using free imagery sources like Google Earth and NAIP.

FREELY AVAILABLE HIGH-RESOLUTION Remote imagery, such as NAIP, are captured roughly every one to three years. Publication of NAIP imagery often lags several months behind its capture date and into the following calendar year, rendering it unusable for current year monitoring. Imagery viewed in Google Earth typically also has similar latency issues and can be an unreliable source for meeting monitoring requirements.

COMMERCIAL HIGH-RESOLUTION Airborne and satellite imagery is typically captured routinely in areas where there is an expectation of market demand, or otherwise when specifically **tasked** by a client. After commercial satellite imagery has been captured, it becomes available in an image **archive** for anyone to purchase at a lower rate. While tasking commercial high-resolution imagery is more expensive, it does improve the certainty that suitable imagery will be captured in the date range needed for monitoring.

Archive refers to the full inventory of images that has already been captured and is available for resale. **Task** is a term used to describe the action of capturing an image (the provider will task the satellite to capture an image).

The availability of archive imagery varies widely and there are many factors that drive its availability. Weather is a major factor, so cloudy areas like the Pacific Northwest usually have smaller archives than clear areas like Arizona. In California, we find that properties near urban centers tend to have many archived images each year which allows us to select an image from the optimal season. But in more remote areas, there may only be a couple of archived images for the year, or sometimes none. Commercial satellite companies usually have strategic priorities to build their image archives, with more frequent updates in areas of higher

demand. This increases the likelihood that any given property might have one or more archive images available for the calendar year of monitoring (though not necessarily at the ideal timing or weather conditions). Anecdotally, we are noticing a general trend toward increased availability of archive imagery.

FREELY AVAILABLE MODERATE TO LOW RESOLUTION This imagery is typically collected on a one to two week interval. As more satellite systems or "constellations" (both government and commercial) become operational, this interval is decreasing. These images are published promptly and are often processed by the managing agency so that images from week to week are calibrated to each other.

3.1-c Image Affordability

The cost of purchasing or licensing imagery is perhaps the most important specification. The cheapest imagery is free, but as discussed above, free imagery is often from a prior calendar year (NAIP, Google) or too low a spatial resolution (Landsat) for monitoring specific and critical CE terms.

The cost for paid imagery cannot be described in simple dollars per acre, because there are several factors that go into the total cost. In addition, every provider, vendor and reseller may have different cost sheets.

The biggest driver of commercial satellite image cost is whether a suitable image exists in the imagery archive, or whether it's necessary to task an image. The cost for tasking is more expensive than the cost for an existing archive image. Most providers and resellers require a minimum area when purchasing an image from the archive, and all providers and resellers require a minimum area and swath width with a custom task order.

Purchasing high-resolution commercial satellite imagery from the provider's archive typically has a lower price per area, and a smaller minimum area requirement, but you may still pay for imagery beyond your subject property boundary, again this varies by seller. Based on our experience, here are some generalized costs for commercial satellite imagery:

- Archive high-resolution satellite imagery, $0.05 - $0.10 per acre
- Tasking high-resolution satellite imagery, $0.15 - $1.20 per acre
- Tasking *airborne* imagery for a specific property, $0.50 - $1.50 per acre

We've learned that we must dig into the specifics of this pricing in order to truly understand the cost and return on investment of tasking imagery or purchasing archive imagery.

Choctawhatchee River Delta Preserve (FL)
Aerial Imagery © 2017 USDA NAIP

3.2 Technology Considerations: Platform

Remote property monitoring occurs on a digital platform. Remote property monitoring requires, at a minimum, the user to be able to view relevant imagery, pan around, zoom in and out, and document observations. There is a wide and growing range of platforms. Remote monitoring could be conducted in Google Earth or another free streaming platform, in an organization's GIS with imagery loaded or streamed in, or in a satellite provider or secondary vendor's remote monitoring platform. The major commercial satellite imagery companies each have their own platform, and some have application programming interfaces (APIs) that can be used for custom integration with existing systems.

> A platform that facilitates both image acquisition and the monitoring workflow is a key part of realizing efficiency with remote monitoring.

Through several years of experimentation, we identified the ideal criteria for a remote monitoring platform that would meet our needs:

1. **Image acquisition**
2. **Data management**
3. **Functionality** to support our monitoring workflows
4. **System Integration** or compatibility with our monitoring reporting system

1. Image Acquisition: Figuring out what imagery is available for each property can be time consuming; there are many providers to track. Having an easy way to determine when imagery is available for a set of properties is critical for implementing a remote monitoring program. We could not have implemented remote monitoring statewide if it were staff's responsibility to determine if suitable imagery existed for their properties.

2. Data Management: Remote sensing imagery can be computationally intensive. The imagery are large datasets (file size) that must be displayed quickly and dynamically. These large imagery files must also be backed up and stored. Our staff are widely distributed, so imagery must be served to monitors over the cloud. An ideal platform would handle these essential management requirements.

3. Functionality: The purpose of a remote monitoring platform is to put information and tools in the hands of monitors to maximize their ability to efficiently and effectively identify, measure, understand and document changes to properties over time. There are many tools that can assist the monitor with visual inspection of imagery. Visual monitoring can also be augmented with spectral analytical tools and even automated systems to detect changes.

OVERLAY   A monitor must be able to overlay the property boundary on imagery. Ideally, other layers can also be overlaid, such as specific zones or envelopes within CEs, agricultural management units such as pastures or fields, or locations of previous monitoring observation (field or remote).

COMPARE IMAGERY   Monitoring is partly an exercise in change detection. The ability to detect changes over time is greatly enhanced by interfaces that allow the monitor to view and compare imagery from differing dates. This might include viewing historical high-spatial resolution imagery, or rapidly scrolling through moderate and low-resolution imagery (which is typically multispectral and captured at a high temporal frequency) to visually detect the timing of changes.

DOCUMENT-ATION

A monitor must document not only their observations of the image, but the metadata required to accompany their documentation including image source and date, and the location of their observation. A platform that makes this process easy and consistent is ideal.

Image

CAPTURE DATE
October 14, 2019

SOURCE
Maxar WorldView (0.5m)
Includes copyrighted material of Maxar Technologies Inc. 2019

Interpretation

CENTER
-XXX.08298, XXX.59228

AREA
.49 acres

INTERPRETER
Person's Name

INTERPRETATION DATE
November 22, 2019

NOTE
Possible location of bee boxes. This area is consistent with landowner's description of bee box location. Visual Queues indicate 25 or more objects

Screenshot from Upstream Tech Lens.

Example of documentation fields required: geographic location, image source and spatial resolution, image date, interpreter name, interpretation date.

MEASURE-MENT TOOLS

Simple tools that allow the monitor to measure distances and area, and determine locations (x,y) are key for understanding features or characteristics of a property, how those change, and for documentation.

SPECTRAL ANALYTICS

For moderate and low-resolution imagery, which is typically multispectral and captured at a high temporal frequency, analytical tools can be just as valuable as tools that aid visual monitoring. The multispectral characteristics of these datasets means they can be used to assess changes to phenomena including vegetation, soils, and wetlands. The high-temporal resolution and long-term archive mean that both rapid and long-term changes can be characterized. Spectral analytical tools can produce graphics and statistics to aid the monitor in identifying and understanding changes. The RDMapper summary below is an example of this type of spectral analysis).

AUTOMATED CHANGE DETECTION

The high-temporal moderate to low resolution satellite programs, like Landsat for example, have long-term archives of imagery for all landmasses on Earth. This record facilitates computational methods for detecting and quantifying changes over time. Many landscapes exhibit predictable seasonal or annual cycles of change (annual fluctuations in vegetation greenness, pond volume, etc.). The deep history of these archives can be leveraged to detect changes that are outside of the cyclical pattern.

4. System Integration: the ideal monitoring platform will facilitate efficient workflow for monitors, such that monitoring observations and documentation conducted in the remote monitoring platform can be easily incorporated into annual monitoring reports. This can be accomplished if the platform includes an API.

3.3 Monitoring Approaches and Options

In this section we'll describe the remote monitoring options we've tried using, including visual and analytical approaches. For each option in the list, we'll provide a description, relevant technical details and the advantages and disadvantages from our perspective. Each organization should view advantages and disadvantages through their own lens, based on their needs and goals.

3.3-a Visual

Visual monitoring is just what it sounds like. It involves a person looking at an image, observing and interpreting phenomena and drawing conclusions from what they see. We've experimented with different approaches for remotely monitoring our CEs. Here we describe the approaches we tried that rely on human eyes, intelligence and experience to inspect and interpret imagery.

> **Visual** remote monitoring is done by looking at a high-resolution image and drawing conclusions.
>
> **Analytical** tools extract information from multi-spectral imagery and can aid the monitor in understanding change.
>
> The two **approaches are complimentary** and are ideally used together.

3.3-a1 Google Earth

Our earliest attempt with remote monitoring was using Google Earth. Google Earth aggregates and displays imagery from a wide range of sources including both airborne and satellite sources. For California, most of what is available is airborne imagery exhibiting high spatial resolution and image clarity.

First, we converted our property boundaries to the Google format KML for upload to Google Earth. Then, in order to determine whether calendar year imagery was available for our properties, we zoomed to each boundary and checked the date of the underlying image. Where we found current calendar year imagery, we monitored the property. Monitoring involved visual review of the image, comparing the image to historic dates using the History tool in Google Earth and noting changes and findings using pins and polygon graphics. To complete the remote monitoring process, we then manually uploaded our documentation to the system we use for CE monitoring (Salesforce), including description, lat/long, screenshot and image source and date for each observation.

We found the quality of imagery available in Google Earth exceptional. In most cases, we could identify patterns and phenomena that related to many CE terms (new structure, disturbed dirt, new trails, potential encroachments, new cattle troughs, etc). The caveat here is that we preliminarily tested Google Earth with the easier test cases like grasslands and open oak savannah.
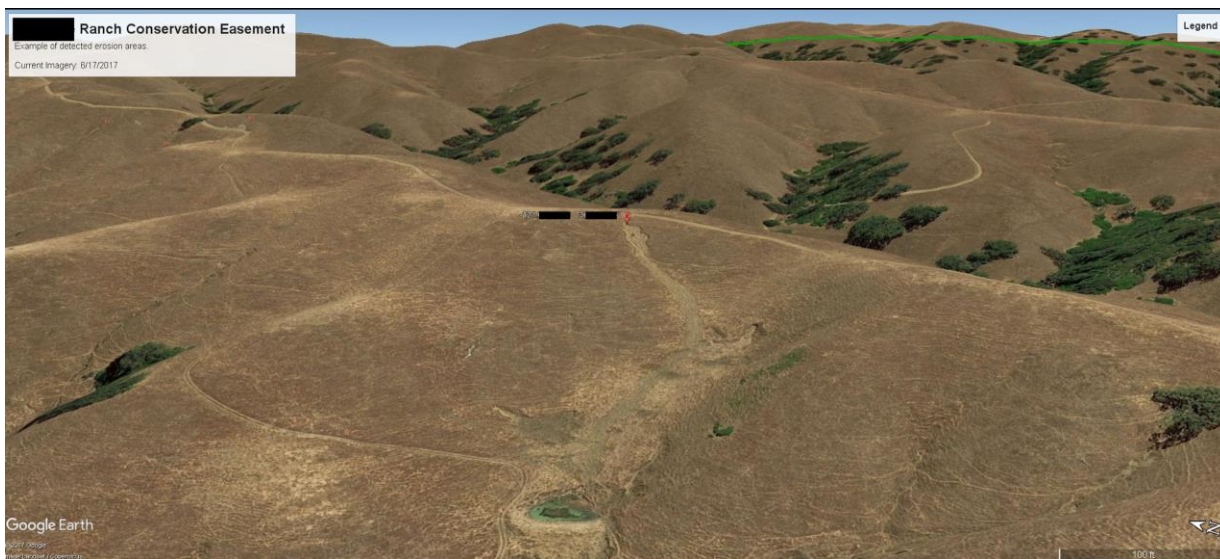
Google Earth	
Description	Imagery accessed using the web-based Google Earth or Google Earth Pro application which is freely available for download.
Image type	Airborne. Google Earth uses both airborne and satellite imagery; but at the scale of CE monitoring it's typically airborne imagery in the U.S.
Image products	Google Earth displays an amalgamation of airborne and satellite imagery from a wide variety of sources. The base map fuses capture from multiple dates and sources to obtain the clearest picture. The Google Earth platform makes it possible to determine the capture date at any location.
Image resolution	Generally, 15 to 30cm at scale of CE monitoring. Can fluctuate with zoom

|	scale and latitude.
Access	Accessed via Google Earth or Google Earth Pro.
General workflow for CE monitoring	Manual: user collects and organizes screen clips of imagery, metadata and documentation.
Advantages	1. Free. 2. Very high-resolution imagery. 3. History tool allows for easy comparison with past years' imagery. 4. Navigation functions are great, and 3D tilt rendering of imagery provides a unique interpretability.
Disadvantages	1. Current year imagery is rarely available for most of our properties. 2. Manual hunt for imagery. 3. Timing of Google Earth image acquisitions is not transparent and not predictable for planning. 4. No API to automatically determine if new imagery is available or to build integrations with our internal business systems, so all extraction of data and export to our platform is manual.

Example: Remote property monitoring in Google Earth. Monitoring year imagery (2017) was compared to older imagery in Google Earth using the History tool. Viewing the imagery in a 3D tilt mode helped to enhance the visual inspection of imagery. Red placemarks were created by the monitor to flag locations of interest. In this case an area of erosion was detected along the ridgetop dirt road, which appeared to flow to a stock pond. The property name and precise geographic coordinates are blacked out here to maintain privacy of the landowner. The coordinates shown explicitly in the screen-captured image ensured that metadata regarding the observation was documented.

3.3-a2 Commercial *Airborne* Imagery

Because we had no control over imagery timing or availability of free imagery such as Google Earth or NAIP, we explored tasked airborne imagery. We commissioned a California-based airborne imagery provider, TerrAvion, to capture imagery for a few of our properties. Their products are geared toward agricultural use cases and their flight schedule is driven by the needs of the agricultural industry (but within our preferred season). They capture multispectral imagery at approximately 0.15m spatial resolution and offer an online platform to view imagery in true color and a suite of common indices including the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI). Some purchases also included thermal infrared imagery. Once we acquired imagery, the mechanics of conducting monitoring was similar to what we did in Google Earth: review parts of the property, screen grab images and manually compile notes and metadata into our system.

Commercial airborne imagery	
Description	Images captured by sensors mounted on aircraft hired for custom image capture.
Image type	Airborne.
Image products	This varies by provider; typically, 4-band RGB imagery + panchromatic.
Image resolution	Very high but varies by provider and sensor; the imagery had 10cm pixel resolution.
Access	1. Find a company that operates in your area. 2. Gather info about their area of operation, pricing and minimum capture area, image product: bands, resolution and standard post-processing; delivery format, platform functionality. Request samples!
General workflow for CE monitoring	Manual: user collects and organizes screen clips of imagery, metadata and documentation.
Advantages	1. High spatial resolution, a range of contrast stretching tools for viewing multispectral vegetation indices, measurement tools and histogram viewers. 2. Control over when imagery is captured.
Disadvantages	1. In our case, the company's flight schedule was based on demand from the ag sector and didn't fit with our needs, and we couldn't commit ahead of time to which properties we wanted flown each year. 2. Their online platform lacked specific functionality to support CE monitoring (e.g. documentation, reporting, analytical tools). 3. Their lack of an API meant we could not configure an integration with our systems. 4. For us, the return on investment was too low, costing approximately $1 per acre.
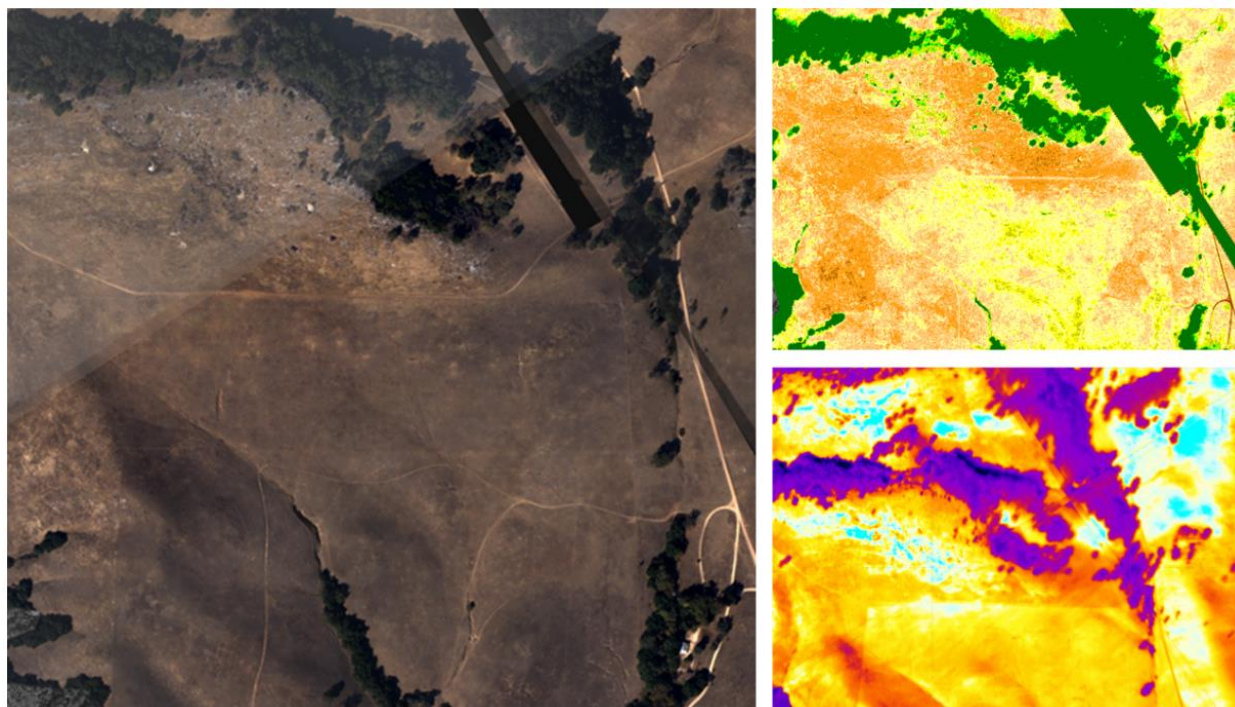
Aerial Imagery © 2018 TerrAvion.

Example of tasked airborne imagery. (Clockwise from left) a true color image, followed by a vegetation index, and a thermal infrared image. The upper right quadrants of the true color and vegetation index images reveal issues with 'stitching' together individual image tiles and color balancing.

3.3-a3 National Agriculture Image Program (NAIP)

The NAIP imagery program is a great source of regularly captured high-resolution imagery. Unfortunately, even though imagery is captured every three years, it isn't publicly released until post-processing is complete which can take a long time considering the large extent of image capture. For this reason, it does not meet our calendar year imagery requirement of calendar year and we are unable to use it for annual CE monitoring. Presently, we use NAIP imagery to compare current year imagery to past years.

NAIP	
Description	NAIP is a national imagery program run by USDA. Imagery is captured roughly every three years and is publicly available. The NAIP archive dates back to 2003.
Image type	Airborne.
Image products	Natural color, and more recently near-infrared.
Image resolution	0.6 to 1m.
Access	There are myriad ways of accessing NAIP e.g. download from USDA, access within the Esri ecosystem, and many more.
General workflow for CE monitoring	Depends on the platform being used, but most likely the process of documenting observations and related locations will be a manual endeavor similar to what's described in the Google Earth table above.
Advantages	1. Free. 2. Relatively high spatial resolution. 3. Viewable in many platforms, including ArcGIS.
Disadvantages	1. The NAIP program's recurrence schedule and publication timing make it challenging as a primary image source for remote monitoring. 2. The manual workflow, like with Google Earth imagery, was an issue.

Example: Aerial Imagery © 2018 USDA NAIP viewed in ArcGIS Online Living Atlas.

3.3-a4 Commercial *Satellite* Imagery

The commercial satellite industry became a viable potential image source in the 2010s as their spatial resolution approached that needed for CE monitoring. We experimented using imagery from providers like Airbus, Planet and Maxar with resolutions that included 0.3m, 0.5m, 0.72m and 1.5m. The general consensus among our stewardship team is that sub-meter imagery is preferred for CE monitoring. This is because monitors can better inspect and detect phenomena that represent easement terms with sub-meter resolution (not all CE-related phenomena certainly, but enough to justify the use of remote means for monitoring). Using sub-meter resolution imagery, our monitors have detected unauthorized beehives, counted individual trees to ensure compliance with construction plans, located unauthorized pond construction and spotted authorized trails. Though sub-meter is preferred, we have used Airbus SPOT 1.5m imagery on occasion when finer resolution is not available, the location and facts strongly suggest a low risk of violation, and the landowner has a long history of compliance. The coarse 1.5m resolution is not detailed enough to notice small features or patterns, such as prohibited beehives.

There are a few ways to access commercial satellite imagery: work directly with satellite providers, go through an image reseller, or work with a reseller that *also* offers a viewing platform with analytical capabilities.

We first used a reseller without a platform to obtain imagery, but as with the earlier trials we found ourselves with ad hoc manual workflows for accessing imagery and monitoring so there was no gain. Perhaps by serendipity, we'd been working with a remote sensing/machine learning company around that time on an unrelated project, and we began talking with them about the CE monitoring use case. It aligned with their mission (they are a Certified B Corporation) and they were interested in tailoring their existing platform to serve the CE monitoring use case. The result is a web-based application named Lens, and it's what we've used for the last two years.

Commercial satellite imagery	
Description	Three well known commercial earth observation satellite providers are Airbus, Planet Labs and Maxar (formerly DigitalGlobe). Many other commercial satellite providers exist, these are the three with which we have some experience.
Image type	Satellite.
Image products	Each provider owns multiple satellite constellations whose sensors capture different imagery products; examples include: Airbus Pleiades (0.5m), Airbus SPOT (1.5m), Planet SkySat (0.72m), PlanetScope (3.7m), Maxar WorldView (0.3m and 0.5m).
Image resolution	Each sensor has its own specifications which will likely evolve after this paper is published but has a legal limit of 0.3m.
Access	There are many ways to access commercial satellite imagery: 1. Directly from the provider. Each provider has its own subscription service whereby you can sign up to purchase imagery from their archive, or task a specific capture. 2. From a reseller. Authorized resellers will find and sell images from the archives of the providers with whom they have contracts. Buying imagery this way requires purchasing a minimum area, on the order of 6,000 acres (25km^2). Some authorized resellers are able to place task orders for customers (again, minimum areas apply, typically 24,000 acres (100km^2)). 3. Using an end-to-end application or service designed to support CE

	monitoring, e.g. Lens. The Lens service supports CE monitoring with automatic image search, ordering and viewing; monitoring, documentation and reporting; analytics and change detection; and an API for integration with a user's own systems.
General workflow for CE monitoring	Can range from fully supported to fully manual depending on where/how imagery is accessed.
Advantages	1. Multiple satellite providers exist, and this appears to be a growing industry. 2. Several satellites capture imagery at 1m spatial resolution or finer, which we've found suitable for monitoring many CE terms. 3. There are many methods for accessing imagery. 4. Some image products are multispectral, affording the opportunity to create indices to glean information beyond what can be seen with the eye.
Disadvantages	Cost (see our return-on-investment analysis in the "Our Monitoring Program" section below.)

Example: Satellite imagery © 2019 Maxar Technologies (0.5m spatial resolution).

3.3-a5 UAVs for CE Monitoring

UAVs or drones represent an emerging technology with increasing interest and use for property monitoring. Despite the very high resolution offered by UAV (ballpark of 3cm), it does not provide us gains in efficiency with personnel time or travel costs. This is because UAV use requires purchasing and maintaining hardware, a commercial drone pilot, and often also a spotter. We are fortunate to have five drone pilots on staff; they capture orthogonal imagery (as opposed to oblique) then later orthorectify in using DroneDeploy. We do this for targeted use cases rather than ongoing property monitoring, for example, as baseline documentation for new CEs (well suited for smaller CEs).

UAVs	
Description	Unmanned Aerial Vehicles, or drones, can capture very high-resolution imagery.
Image type	Airborne, low altitude.
Image products	Natural color, near-infrared, depends on the user's sensor capabilities.
Image resolution	Depends on equipment. TNC staff can obtain 3cm imagery from 400 feet above ground level.

Access	UAVs require a pilot, and often a spotter. Once imagery is captured it must be post-processed using software like DroneDeploy or Drone2Map.
General workflow for CE monitoring	1. Commercial drone pilot prepares an automated flight route, captures UAV imagery, and processes the images into an orthoimage. 2. Viewing methods can range from fully supported to fully manual depending on where/how imagery is accessed. For example, the orthoimage could be viewed in ArcGIS Online as a base map service or uploaded to the Lens application.
Advantages	1. UAV-based orthogonal imagery is very high spatial resolution, in the ballpark of 3cm in these cases. 2. The optional augmented reality system provided the monitor with a unique perspective, and the ability to access a rugged property safely. 3. UAVs can offer unique use cases. A UAV flight may be worthwhile for capturing ultra-high-resolution imagery to document a property's condition around the time a CE is acquired, even if annual UAV monitoring is not worthwhile.
Disadvantages	1. UAV-based monitoring requires one or more personnel to conduct field work (not a con in and of itself!), which eliminates one remote monitoring efficiency gain. 2. UAVs typically cover less than 800 acres in a day, which is a relatively small area for our property portfolio. Line-of-sight and other FAA requirements may also limit the usefulness of UAVs in certain geographies. 3. Monitoring any property with a UAV involves more staff time, expenses, and equipment risks than ordering archive commercial imagery.

*Example: UAV imagery flown by a TNC pilot for property baseline assessment.*

3.3-b Analytical

In addition to the visual monitoring approach described above, we have also used analytical methods to extract information from multispectral imagery. From computer-generated information, we interpret graphs and visualizations to detect meaningful changes on the landscape.

3.3-b1 RDMapper

Over 65% of TNC's property portfolio in California is in working cattle ranches. On many of these properties, our CE terms ensure that grazing does not negatively impact native vegetation, habitat quality, and water quality or runoff. We use the CE term residual dry matter (RDM) to represent required annual grazing conditions. It measures the amount of dry forage that is left remaining on pasture at the end of the grazing year (in late summer to early autumn). RDM is also the lease term for TNC fee owned properties with a tenant grazer. Based on science research conducted in part by TNC staff, we developed an in-house software application to help our monitors predict RDM compliance by interpreting graphs and statistics of several standard indices including Normalized Difference Vegetation Index (NDVI), Fraction of Absorbed Photosynthetically Active Radiation (FPAR) and Leaf Area Index (LAI) from bi-weekly 1km and 0.25km Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. This approach was a proof of concept for how we could leverage remote sensing of multispectral imagery to monitor properties. While true-color rendering of this low-spatial resolution imagery would be useless for detecting the types of phenomenon we can see with high-spatial resolution imagery (e.g. infrastructure and trails), its multispectral bands and high-temporal cadence contain valuable information about landscape scale grassland conditions we monitor at our rangeland properties.

The application, named RDMapper, helped us to streamline field monitoring. We predict compliance for some of our properties by interpreting the graphical and analytical outputs. For those, we confirm conditions in the field by simple visual inspection, rather than the time-intensive traditional field sampling of RDM. On properties with a strong record of RDM compliance, and where we predict a high likelihood of current year compliance, we often forgo field monitoring of RDM altogether. Our high-confidence predictions of 'in-compliance' are correct 99% of the time. The incorporation of RDMapper into the monitoring protocol has reduced RDM monitoring costs by an estimated 40% on this large subset of properties.
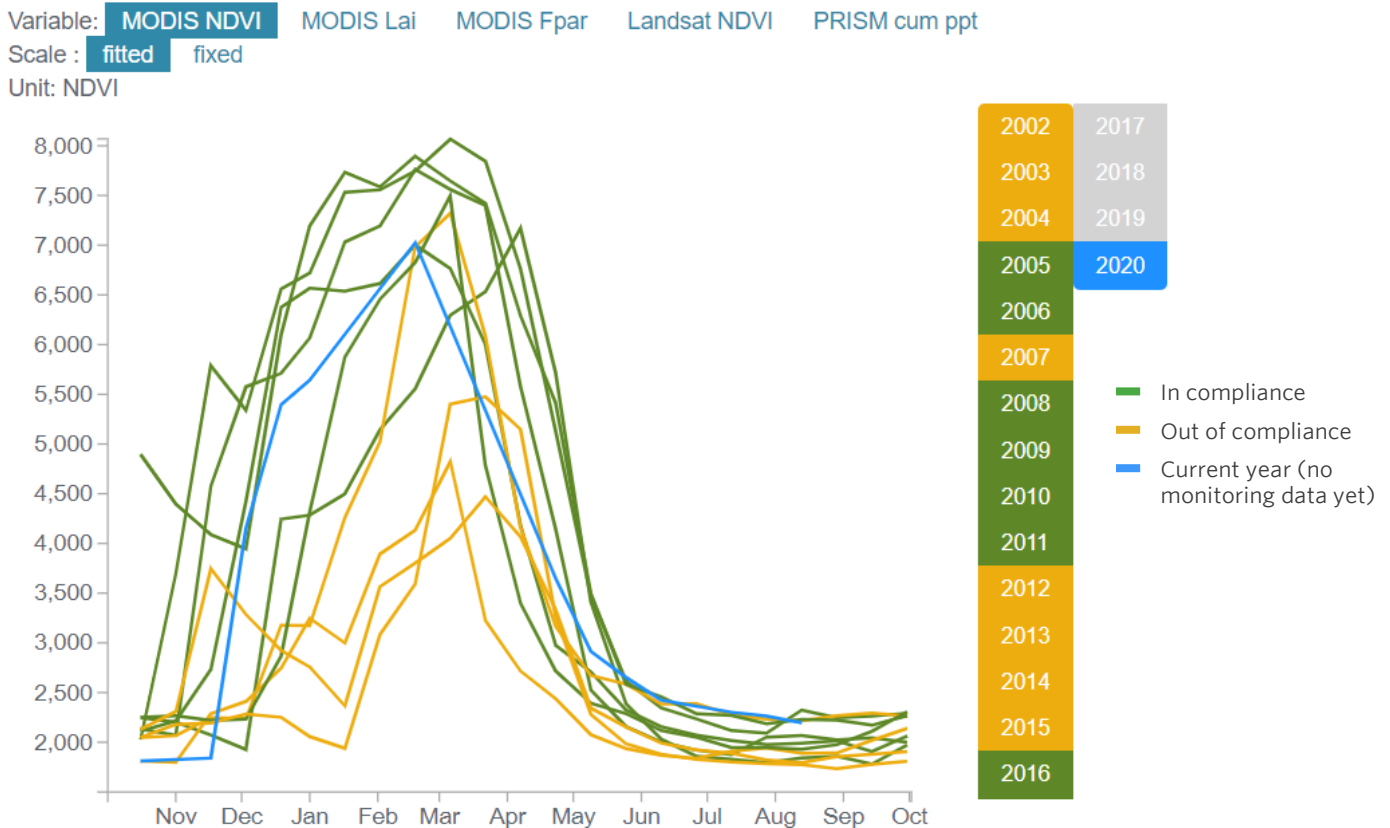
Example of RDMapper. By comparing the current year vegetation index (blue line) with past years that were both in compliance (green) and out of compliance (yellow), we can predict fall compliance during the growing seasons. If signs are pointing to non-compliance, we can work with the rancher to alter the grazing practices.

3.3-b2 Google Earth Engine

In Google's Earth Engine, users can program in JavaScript to access and perform analyses on a massive catalog of satellite imagery and geospatial datasets. We experimented in Earth Engine to see if we could examine NDVI change over time to flag areas where relevant changes may have occurred on the ground. While the concept was promising, the level of effort and expertise needed to see the work through to completion was beyond our capacity. However, this automated change detection concept is now released in Beta form in the Lens platform.
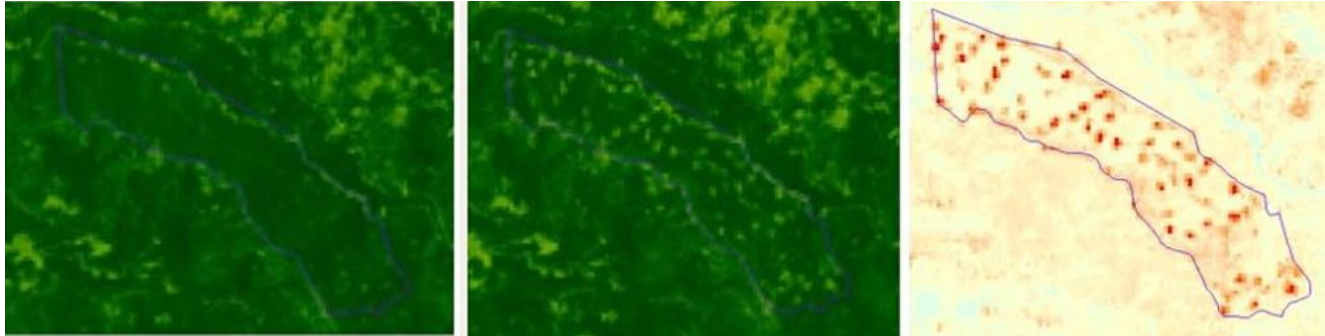
Google Earth Engine example: change over time detecting using Landsat NDVI images from two different dates (left and center) and the difference image (right). This is a commercial timber harvest with small stand-openings of one acre or less.

4.0 Our Current Remote Monitoring Program

Our current remote monitoring program in California utilizes the web-based service named Lens, developed in 2019 by Upstream Tech (https://upstream.tech) in coordination with our team.

By mid-2018 we were stalled with our goal of developing a systematic and scalable remote monitoring program due to the challenges and 'cons' of various approaches described above. We'd already spent several years learning about and experimenting with remote monitoring. Despite having identified options for suitable imagery as well as a set of practices, we needed to reach scale by moving away from manual workflows and towards a systems approach.

Our two biggest challenges were:

1. How do we generate an efficient pipeline of suitable current high-resolution imagery?
2. How can we integrate remote monitoring observations and their related images into our systems in an automated way?

Partnering with a third party, Upstream Tech, removed these barriers for us. Upstream Tech's existing contracts with commercial satellite providers paired with their platform provided an efficient image pipeline. Their API allowed us to integrate the remote monitoring observations we made in Lens directly into our own system of record (we

use Salesforce), thus solving the problem of "how do we integrate remote monitoring into the same business system we use for in-person monitoring".

Throughout 2019, we realized the full benefits of using a third-party application. In addition to solving our two challenges to scaling, Upstream Tech focused their engineering, development and product team to rapidly develop and deliver a suite of functionality that made the product an end-to-end solution for CE monitoring. We frequently coordinated with their development team by describing our monitoring requirements and workflows from the perspective of an accredited land trust. They would then build functionality into the product to support monitoring workflows.

As we used the service and evaluated whether it would work for TNC CA, we made several leaps in our remote monitoring evolution:

- We remotely monitored 40% of our CE portfolio (23 CEs totaling nearly 140,000 acres), either by augmenting an in-person visit with remote imagery or replacing the in-person visit altogether; eight staff participated in this 2019 pilot.
- We were able to validate the value of lower-resolution data for monitoring landscape-scale changes. This was because Lens offers seamless access to Sentinel 10m imagery, which has a high capture cadence of roughly every one to two weeks. Using Sentinel vegetation indices for monitoring drove home the value of having access to both high-spatial resolution imagery for visual inspection <u>and</u> the derived layers plus analytics of multispectral information at a high temporal cadence to assist the monitor.
- We developed best practices for conducting remote monitoring and documenting remote observations.
- We initiated work with Upstream Tech to incorporate the rangeland remote sensing monitoring tools from our RDMapper application into Lens. Having multiple monitoring tools in the same interface streamlines use and reporting.
- We initiated work with Upstream Tech on an automated change detection tool in Lens that leverages Sentinel satellite imagery. This work is still in Beta within Lens, but the idea is that non-seasonal changes detected in the imagery's spectral signature are flagged within Lens to alert monitors of a potential change on the landscape.
- By the end of 2019, we began implementing automated transfer of remote monitoring observations, along with their associated image and metadata, directly into our system of record using their API.

In 2020, Lens is available to all our monitors for our entire CE portfolio as well as our fee and managed properties. Loading our entire portfolio of properties into Lens allows each monitor to take advantage of remote monitoring if they choose, based on available imagery, suitability of the property, and the monitor's schedule and constraints. Lens became a critical tool for us in March 2020 as quarantines began, and throughout the monitoring season as COVID-19 led to travel constraints and health concerns. Upstream Tech continues to improve the functionality of Lens on regular cadence, incorporating feedback from us as well as from other land trusts who use the service.
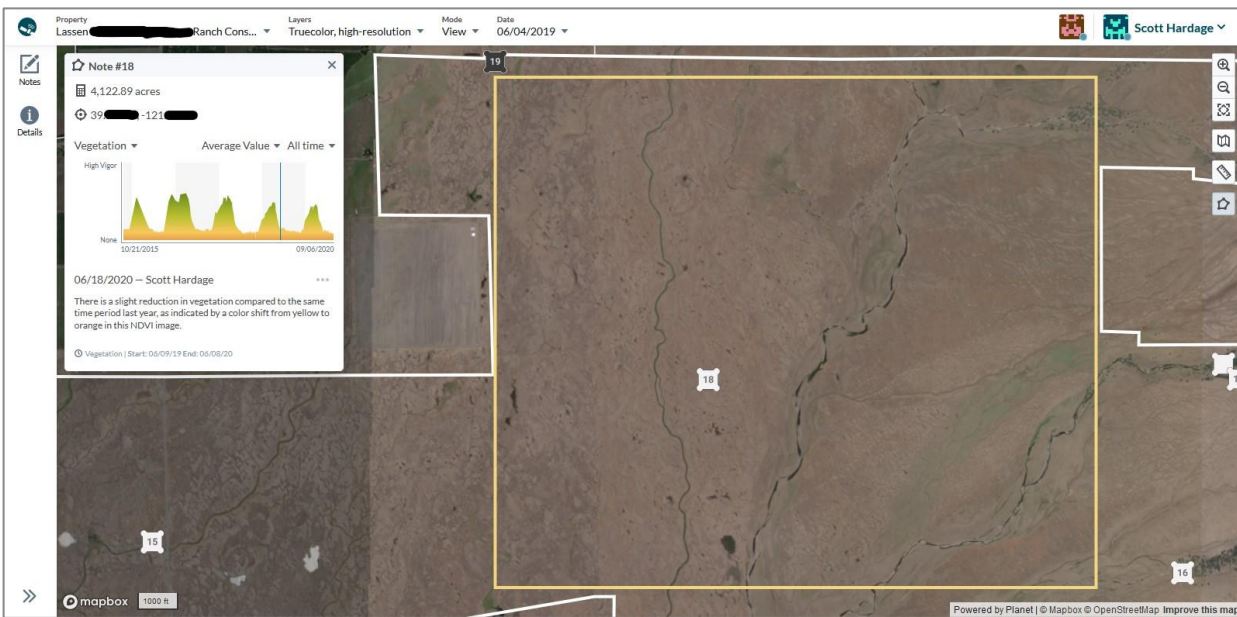
Screenshot from Upstream Tech Lens. The user has access to purchase current year high resolution commercial satellite imagery, access historic NAIP imagery, and Sentinel imagery indices, and analytics. Users can make observations, take notes and generate reports, or build their own reports via the API.

5.0 Monitoring Best Practices

Below is a summary of TNC CA's remote monitoring best practices; this is guidance we provide to our monitors. These practices were informed through years of experimentation and informed by the experiences of other organizations. The relevance of these practices to other organizations will vary depending on your portfolio of properties, CE terms, landowner relationship, staff knowledge, budget, organizational history, and other factors. These practices are applicable regardless of which imagery or platform is used for conducting remote CE monitoring. For the complete document in its current form, go [here](#).

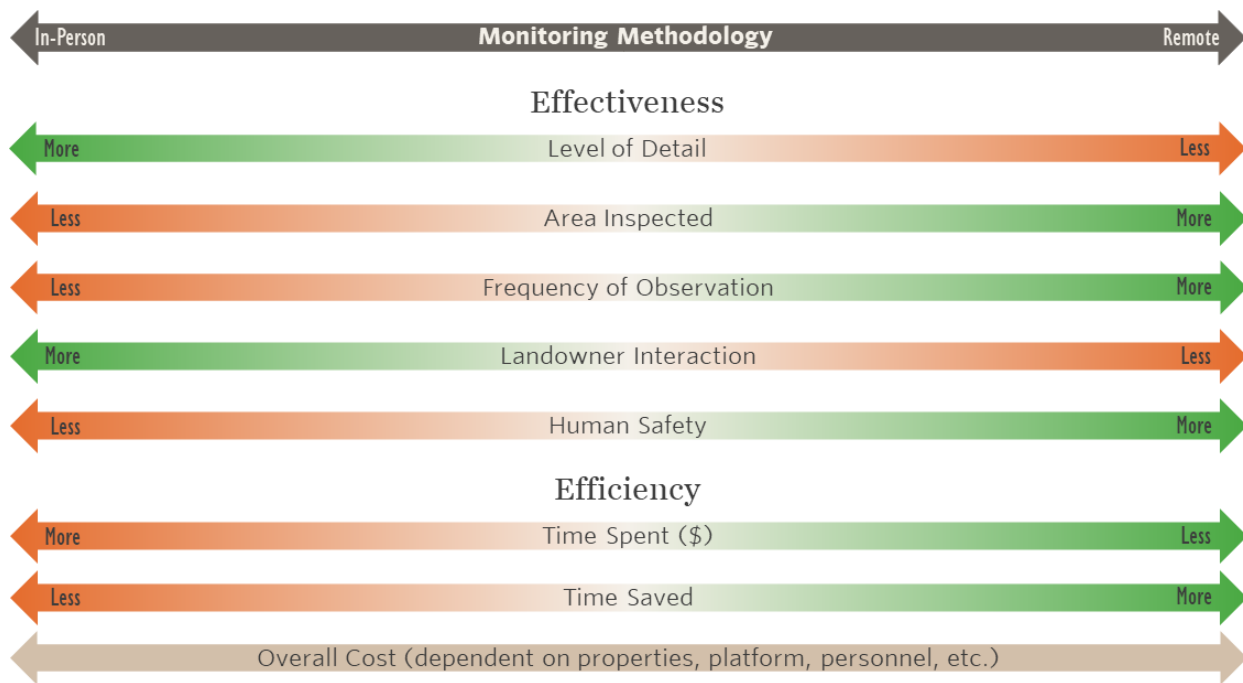### 5.1 Selecting Properties for Remote Monitoring

Criteria

Different organizations, TNC business units, monitoring teams and individuals will have differing criteria or processes for determining which properties should be remotely monitored versus field monitored. Some of these characteristics may be inherent to the property, such as CE terms, remoteness or size. Other characteristics may vary year to year, such as recent violations or catastrophic events, imagery availability, or pandemic shelter-in-place orders like in 2020. At a minimum, per LTA standards and TNC's standard operating procedure, we monitor each property in-person on site at least once per five years.

Tradeoffs

Remote monitoring and on-site monitoring each have tradeoffs in terms of the effectiveness, efficiency, and human elements of the monitoring effort. The biggest trade-off in effectiveness is the higher level and range of detail seen in-person vs. the greater total area inspected in remote imagery. Typically, time and travel costs decrease for remote monitoring but incur new costs for imagery and platform licensing. With regard to human elements, typically in-person landowner interactions are better,

but remote monitoring ensures greater safety when faced with dangerous conditions (weather, topography, access, pandemic) and also creates capacity for other work.

In-Person	Monitoring Methodology	Remote

Effectiveness

More	Level of Detail	Less
Less	Area Inspected	More
Less	Frequency of Observation	More
More	Landowner Interaction	Less
Less	Human Safety	More

Efficiency

More	Time Spent ($)	Less
Less	Time Saved	More

Overall Cost (dependent on properties, platform, personnel, etc.)

Graphic depicting trade-offs of in-person vs. remote property monitoring.

5.2 Conducting Remote Monitoring

Preferred prerequisites for remote monitoring include the monitor having on-site familiarity with the property, availability of historic imagery to compare to current year imagery, and digital property boundaries that can be overlaid with imagery.

Prior to remote monitoring, the monitor should review the CE, baseline reports, and previous annual monitoring reports. They should have an extensive conversation with the landowner or property representative about activities and changes to property conditions since the previous monitoring effort. Pre-monitoring conversations are common with in-person monitoring also. But with remote monitoring, the conversation becomes more crucial.

While conducting remote monitoring, there are several considerations. Because monitoring is fundamentally a change detection exercise, the monitor should keep in mind that geospatial map layers, including boundaries and various images, may not be perfectly co-registered. This could lead to an object appearing to be inside a boundary when it is actually not, an object appearing to move when viewed in one image vs another, etc. Ideally monitors will review every portion of the property at a relatively high detail zoom level. They can zoom in and follow the entire property boundary looking for encroachments or trespass issues. Human-constructed features such as buildings, roads, trails, agricultural infrastructure, as well as natural features, can be inspected for changes.

5.2-a Documentation of Remote Observations

Documentation needs to address the CE's terms and an assessment of compliance with those terms, both in choice of images and in description of the observation. That means looking to see if something has changed or is not in compliance. Enough images need

to be included to show that monitors looked carefully across the property, and especially around infrastructure; we require a minimum of six images.

It is important that monitors clearly document the observations they make when monitoring remotely. They should make clear, articulate notes about what they observe in imagery that leads them to their conclusions. They should assume that the report reader and reviewer is unfamiliar with the property or the context of the change observed. It is equally important for monitors to document if they reviewed a portion of the property and did not detect any natural or any human induced changes. This indicates that the portion of the property was indeed monitored.

IMAGE DATE
September 10, 2019

IMAGE SOURCE
Maxar WorldView (0.5m)
Includes copyrighted material of
Maxar Technologies Inc. 2019

LOCATION
-XXX.03762, YYY.48295

INTERPRETER
Person's Name

INTERPRETATION DATE
March 27, 2020

NOTE
This path has seen a recent increase in usage. Landowner reports that the neighbor used this route for construction access to the new airstrip site (which lies on the neighbor's property 200+ feet west of the easement boundary).

This temporary access is not a concern of violation. Landowner has already addressed this by speaking with the neighbor about this unapproved access and requesting that they replace any rocks that were moved out of the way.

IMAGE DATE
June 08, 2019

IMAGE SOURCE
Maxar WorldView (0.5m)
Includes copyrighted material of
Maxar Technologies Inc. 2019

LOCATION
-XXX.67316, YYY.82390

INTERPRETER
Person's Name

INTERPRETATION DATE
April 22, 2020

NOTE
Typical dirt access roads for utility towers throughout the northern and eastern portions of property. No changes to distribution or condition of the network of dirt roads in this area compared to images from previous years.

Top graphic is an example of documentation of a compliance related issue and bottom graphic is an example of documentation of no change.

5.2-b Considerations for new acquisitions

With remote monitoring integrated into our program, there are several considerations we make when considering acquisitions of new properties. We promote securing high-spatial resolution imagery as close to the closing date as possible. For small properties, we can capture the imagery 'in-house' with the use of UAVs. Tasked or archive airborne or satellite imagery may be suitable, depending on availability and the spatial resolution deemed suitable by the stewardship or science teams. For CE properties,

this imagery can serve as an exhibit to the property baseline report. <u>When writing and negotiating terms for new CEs, the use of remote property monitoring should be contemplated.</u> Terms that are monitorable from a remote perspective are preferable from a monitoring standpoint.

6.0 Return on Investment

Because 2020 is the first year TNC CA has adopted remote monitoring capabilities across our entire property portfolio, we must understand the costs and benefits associated with these capabilities in relation to our program goals of improving efficiency and effectiveness of monitoring.

6.1 Effectiveness

Consensus among our monitors and program leadership team is that the effectiveness of our annual CE monitoring is greatly enhanced with the implementation of remote monitoring. With remote property monitoring, we find that:

- Our monitors have greater flexibility to manage their workloads by having the option to remote monitor.
- Monitoring is a safer activity. We are doing less driving to access properties. We are doing less traversing of steep and rugged properties. We are completing our monitoring obligations despite the travel challenges and risks from COVID-19.
- Our monitoring is often more thorough and complete than in-person monitoring. We can observe every portion of large remote properties, much of which we had never visited on the ground.
- We have detected and documented many changes, including a handful of violations, that we had historically missed with in-person monitoring.

6.2 Efficiency

We have made a preliminary effort to quantify the personnel time and expenses incurred with the adoption of RPM, and how those relate to solely in-person monitoring. We conducted this analysis of 6/30/2020, halfway through our monitoring year (we will update the analysis and this document at the end of the calendar year).

> A thoughtful ROI analysis is an important step in learning how to optimize remote monitoring for an organization interested in remote monitoring.
>
> Download a sample ROI template **here**.

We've done this by comparing in-person monitoring to remote monitoring in terms of travel cost and hours spent. We do this for as many properties as possible to capture a range of property sizes and travel distances for our monitors. For properties that have been remote monitored, we asked our monitors to estimate the following: amount of time they spent completing the entire monitoring effort including preparation reading and landowner calls, monitoring in Lens, and report writing); amount of time they would have spent completing all steps of in-person monitoring, which would also include travel time; and travel expenses that would have been incurred with in-person monitoring, including vehicles, lodging, and meals. We include the expenses associated with remote monitoring, including a portion of our Lens annual license, and the cost of tasked or archive imagery, depending on which imagery we used.

By June 30, 2020 we had completed annual monitoring on 110 of our 173 CEs, 59 of which (54%) were completed solely with remote monitoring. These 59 properties comprised 89% of the total acreage of CE properties monitored.

| Property | | In-Person Monitoring Time (Hours) | | | | | | Expenses | Total | Remote Property Monitoring Time (Hours) | | | | | Expenses | | Total | Efficiency Difference | | |
ID	Acres	Pre-Monitor	Travel	Monitor	Report	Sum	Subtotal	Fuel / Food / Lodging	Total	Pre-Monitor	Monitor	Report	Sum	Subtotal	Imagery	License		Time	$	Note
A	80	1	6	2	2	11	$550	$ 200	$750	1	1	1	3	$150	$ 6	$45	$ 201	8	$ 549	Distant travel
B	132	1	1	3	3	8	$400	$ 40	$440	1	3	3	7	$350	$ 11	$45	$ 405	1	$ 35	
D	1,470	1	7	4	3	15	$750	$ 90	$840	1	3	3	7	$350	$ 118	$45	$ 512	8	$ 328	Distant travel
E	1,500	1	3	6	4	14	$700	$ 30	$730	1	3	4	8	$400	$ 120	$45	$ 565	6	$ 165	
F	2,310	1	3	6	4	14	$700	$ 5	$705	1	4	3	8	$400	$ 185	$45	$ 629	6	$ 76	
G	7,584	1	3	8	4	16	$800	$ 40	$840	1	4	4	9	$450	$ 607	$45	$ 1,101	7	$ (261)	Large property
H	36,045	1	2	2	2	7	$350	$ 100	$450	1	2	2	5	$250	$ 2,884	$45	$ 3,178	2	$ (2,728)	Very large property

RPM more efficient
In-Person more efficient

On the properties that were solely remotely monitored, we estimate that our staff reduced their time invested in monitoring by 37%. For the subset of 29 of these properties that are monitored by contractors, we reduced our contract costs by 30%. We estimate that the overall cost of monitoring these properties remotely was 7% higher with the largest driver of cost being the purchase of imagery. We estimate that on properties smaller than 10,000 acres, remote monitoring saves money, and on properties greater than 10,000 acres, it is more expensive. When we removed the single largest property monitored from this analysis (36,000 acres), remote and in-person monitoring carried the same cost.

When our monitors spend less time monitoring, they have more time available to work on other important conservation strategies and tasks. Our staff are our most valuable resource. In most cases, remote monitoring is less expensive than in-person monitoring. But on larger properties, remote monitoring costs are significant, and we have not yet completed annual monitoring for a number of our large properties. We are working to mitigate this issue by identifying portions of properties where we need to purchase high resolution imagery, and portions where Sentinel imagery, or other moderate resolution imagery, is adequate. Upstream Tech is working to accommodate this segmented approach (currently we purchase imagery for the entire property or not at all), and we hope it will drive the costs of remote monitoring down to break even with, or even be below in-person monitoring costs. We will re-evaluate our cost analysis at the end of the year.

Sand Sage Short Grass (KS)
Aerial Imagery © 2015 USDA NAIP

"Learning and Innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow." - William Pollard

We began this paper with an overview of our journey in remote property monitoring. Throughout, we've laid out what we learned along the way, and how we are standardizing our use of remote property monitoring at The Nature Conservancy in California. COVID-19 lent urgency to our wanting to author this; we saw how this way of working is helping our staff to continue despite pandemic-initiated restrictions and hoped that our knowledge would contribute to others' learning.

That said, we believe that remote property monitoring even in non-pandemic times helps to save resources and keep staff safer. While it cannot ever replace "boots on the ground", it does offer benefits that in-person visits do not. As we push forward in our learning, and as technological advances open up new possibilities, we look forward to exploring those as well and hopefully updating this white paper as we go. And, we hope that others' explorations will likewise lead to new insights and best practices. We are pleased to be a part of the remote property monitoring practitioner community and look forward to pushing the boundaries of innovation together.

Jack & Laura Dangermond Preserve (CA)
Aerial Imagery © 2014 USDA NAIP
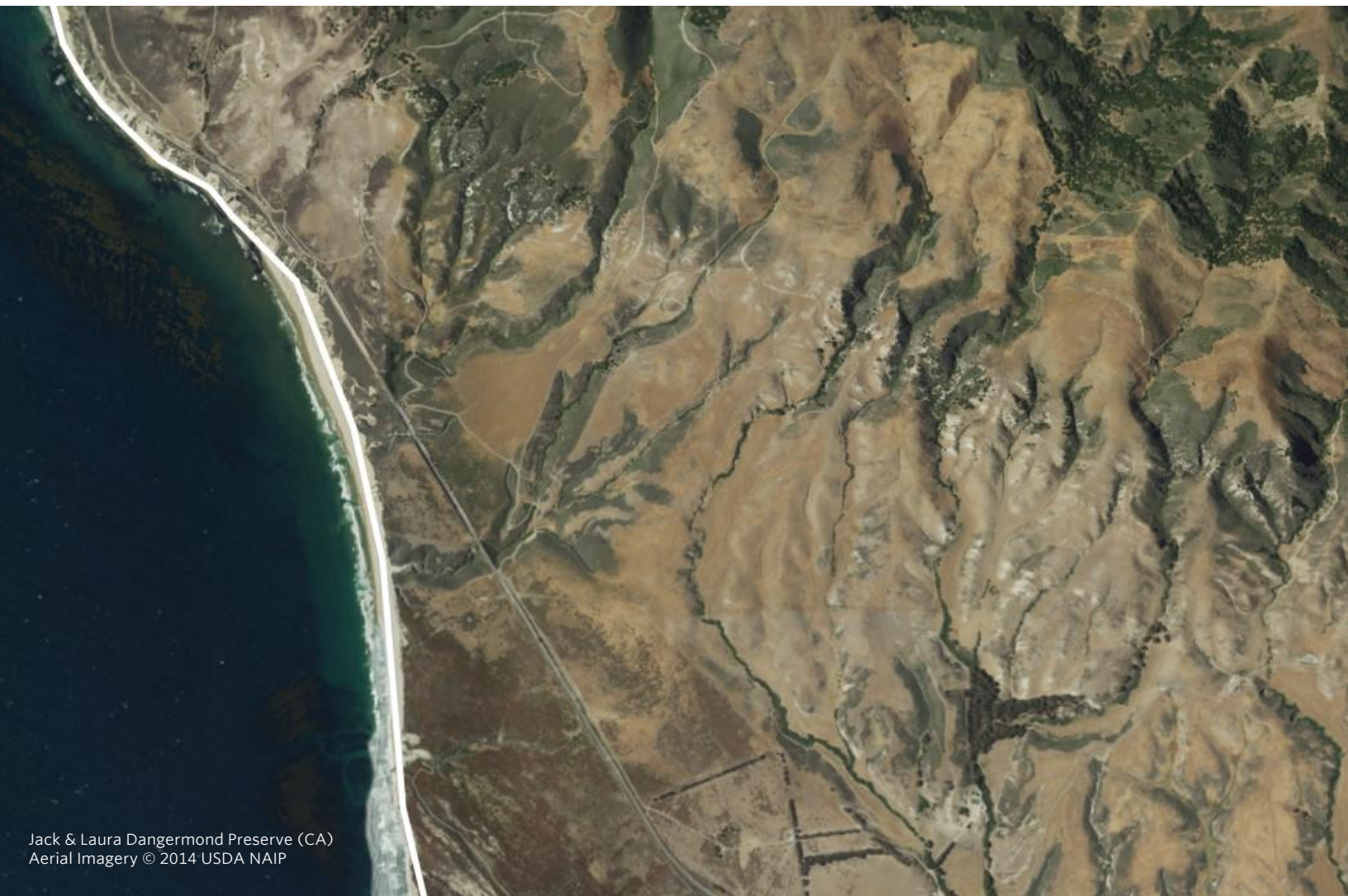
Citations

Grant, Jessica, et al. "Developing a Compliance Monitoring Framework for Conservation Easements: Case Study - The North Irvine Ranch." Donald Bren School of Environmental Science & Management, Master of Environmental Science & Management Class of 2004, http://trapdoor.bren.ucsb.edu/research/documents/easements_brief.pdf.

Thomas, Nancy. "Remote Monitoring of Conservation Easements." UC Berkeley, 2020, https://ca-science.s3-us-west-1.amazonaws.com/Report+on+Remote+Monitoring+of+Conservation+Easements+FINAL+2020-06-24.pdf.

Land Trust Alliance. "Land Trust Standards and Practices (Revised 2017)." *Land Trust Alliance*, 17 Feb. 2017, www.landtrustalliance.org/publication/land-trust-standards-and-practices-revised-2017.

Boyle, Alan. "DigitalGlobe's Satellite Pics Are So Good They're Almost Illegal." NBCNews.com, NBCUniversal News Group, 25 Feb. 2015, www.nbcnews.com/science/space/digital-globes-satellite-pics-push-legal-limit-n313026.

Upstream Tech. "Imagery Options in the Lens™ Library." Upstream Tech Knowledge Base, Upstream Tech, 14 Sept. 2020, https://support.upstream.tech/article/10-imagery-options-in-the-lens-library.

The Nature Conservancy. "Monitoring Rangelands from Above." The Nature Conservancy | California Conservation Science, 1 Feb. 2017, www.scienceforconservation.org/science-in-action/monitoring-rangelands-from-above.

Inlander, Ethan, and Scott Hardage. "Remote Monitoring Best Practices for The Nature Conservancy in California." The Nature Conservancy California Chapter, Accessed Sept 2020, https://ca-science.s3-us-west-1.amazonaws.com/TNC+CA+Monitoring+Best+Practices+2020.pdf.

The Nature Conservancy

Ethan Inlander, Stewardship and Restoration Project Director, California Chapter
Katie Andrews, Systems Architect, California Chapter

The following individuals contributed to this exploration and paper:

Jennifer Chin, Director of Conservation Innovation, New York Chapter
Sue Pollock, Product Innovation Manager, California Chapter
Mike McFadden, Lands Program Associate Director, California Chapter
Scott Hardage, Stewardship Project Coordinator, California Chapter
Scott Butterfield, Senior Scientist, California Chapter
Tod Rubin, Consulting Conservation Scientist