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PRACTICE AND TECHNICAL ARTICLE

Measuring and monitoring restored ecosystems: can remote sensing be applied to the ecological recovery wheel to inform restoration success?

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The commencement of the United Nations Decade on Ecosystem Restoration has highlighted the urgent need to improve restoration science and fast-track ecological outcomes. The application of remote sensing for monitoring purposes has increased over the past two decades providing a variety of image datasets and derived products suitable to map and measure ecosystem properties (e.g. vegetation species, community composition, and structural dimensions such as height and cover). However, the operational use of remote sensing data and derived products for ecosystem restoration monitoring in research, industry, and government has been relatively limited and underutilized. In this paper, we use the Society for Ecological Restoration (SER) ecological recovery wheel (ERW) to assess the current capacity of drone-airborne-satellite remote sensing datasets to measure each of the SER's recommended attributes and sub-attributes for terrestrial restoration projects. Based on our combined expertise in the areas of ecological monitoring and remote sensing, a total of 11 out of 18 sub-attributes received the highest feasibility score and show strong potential for remote sensing assessments; while sub-attributes such as gene flows, all trophic levels and chemical and physical substrates have a reduced capacity for monitoring. We argue that in the coming decade, ecologists can combine remote sensing with the ERW to monitor restoration recovery and reference ecosystems for improved restoration outcomes at the local, regional, and landscape scales. The ERW approach can be adapted as a monitoring framework for projects to utilize the benefits of remote sensing and inform management through scalable, operational, and meaningful outcomes.

Key words: airborne, drone, ecological recovery wheel, field assessment, satellite

Implications for Practice

- Remote sensing products derived from drone-airborne-satellite data will significantly contribute to monitoring restoration outcomes in the coming decade.
- The Society for Ecological Restoration (SER) ecological recovery wheel can be adapted as a monitoring framework for restoration projects using remote sensing.
- Mapping, quantifying, and tracking the success of 11 of 18 sub-attributes in the SER ecological recovery wheel show strong potential and can be achieved by using multiple drone-airborne-satellite sensors, and remote sensing derived, verified products.
- A user-focused approach rather than a technical producer approach is leading a new generation of restoration ecologists to remote sensing-derived products with a range of monitoring applications.

Introduction

As the biodiversity crisis intensifies, restoration stakeholders are facing the task of slowing and ultimately reversing ecosystem decline. Restoration initiatives are supported by a range of global and regional scale commitments such as the United Nations Declaration on Ecosystem Restoration (UN 2019), and the Bonn challenge, which aims to restore 350 million hectares by 2030 (IUCN 2020). It is clear that the challenges ahead will require widespread collaboration and sharing of knowledge to improve our understanding of ecosystem establishment, development, and transition (Holl 2017; Aronson et al. 2020). For this, a rigorous and robust monitoring program to inform

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management of restoration success is vital, starting with clear project objectives that are measurable and unambiguous (McDonald et al. 2016; Lindenmayer et al. 2020).

The Society for Ecological Restoration (SER) developed the five-star Ecological Recovery Wheel (ERW), providing a monitoring framework for restoration practitioners by defining six key attributes, with each attribute further divided into three sub-attributes (Gann et al. 2019; SERA 2021). The ERW is aligned closely with traditional ground-based monitoring of restored ecosystems including plot, transect, and quadrat assessments of flora and fauna, where monitoring data are compared to a reference ecosystem to demonstrate progress toward ecological targets. Since its development, the ERW has been utilized by restoration practitioners to broadly determine the biophysical recovery of terrestrial projects (McDonald & Dixon 2018), demonstrating the value of an adaptable and comprehensive monitoring tool for practitioners. However, the tool is relatively new and is yet to be widely implemented.

Although there has been an exponential increase in studies within the restoration ecology field since its emergence in the 1980s and 1990s (Ruiz-Jaen & Aide 2005; Wortley et al. 2013; Evju et al. 2020), the monitoring of restoration success at multiple spatial and temporal scales to inform management and improve practice has been lacking (Holl & Brancalion 2020). This led to calls to standardize ground survey methods of collecting, analyzing and reporting ecological monitoring data to improve comparability across restoration projects and reduce uncertainty when assessing restoration success (Evju et al. 2020). While restoration studies employ a highly diverse array of ground-based methods to measure a range of attributes and indicators (Evju et al. 2020), ground-based assessments often cover only limited areas, frequently trading off spatial and ecological detail over local scales (<1 km^2), against covering larger representative areas (>10 km^2) (Holl 2017). In some cases, field programs may be expensive to implement and maintain over time, making regular medium and long-term monitoring of restored ecosystems rare. For example, a review by Martin et al. (2021) found that out of a total of 174 organizations involved in forest restoration in tropical and sub-tropical forests, only three have implemented detailed, robust, transparent, and ongoing monitoring programs. The lack of long-term monitoring programs reduces our understanding of restoration progress, the achievement of restoration goals, and represents a lost opportunity for corrective action to reinstate a trajectory toward restoration success (Holl & Brancalion 2020).

Earth Observation (EO) and remote sensing have a significant role to play in achieving global restoration commitments, including monitoring and measuring a number of the Sustainable Development Goals (SDG) (Anderson et al. 2017). Several papers have explored the opportunity for remote sensing to contribute to the assessment of terrestrial ecosystem biodiversity and the monitoring of changing ecological communities. At the global scale, Pettorelli et al. (2016) proposed a framework for satellite-based remote sensing to measure essential biodiversity variables (EBVs) as defined by The Group on Earth Observations—Biodiversity Observation Network (GEO—BON) (Pereira et al. 2013). The authors suggest that indicators within EBV classes, such as ecosystem

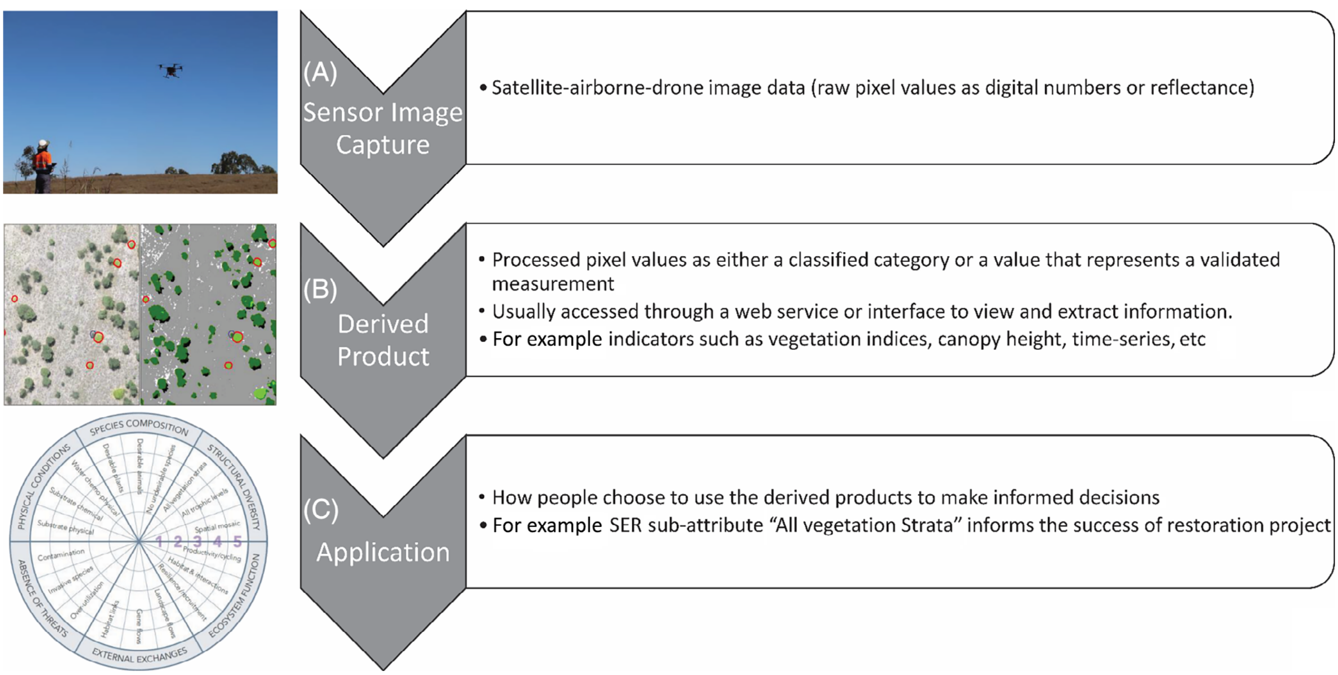


Figure 1. Workflow of remote sensing data for monitoring using raw images captured from (A) a mounted sensor to (B) a derived fit-for-purpose product for consumers, to (C) the application of the product. The coming decade offers ecologists the opportunity to use derived products to better inform management with a focus on a user approach (B and C), rather than a producer approach to remote sensing (A). Monitoring choices will always be a trade-off between cost and appropriate technology, but trade off decisions can be improved with clear restoration goals and success criteria.

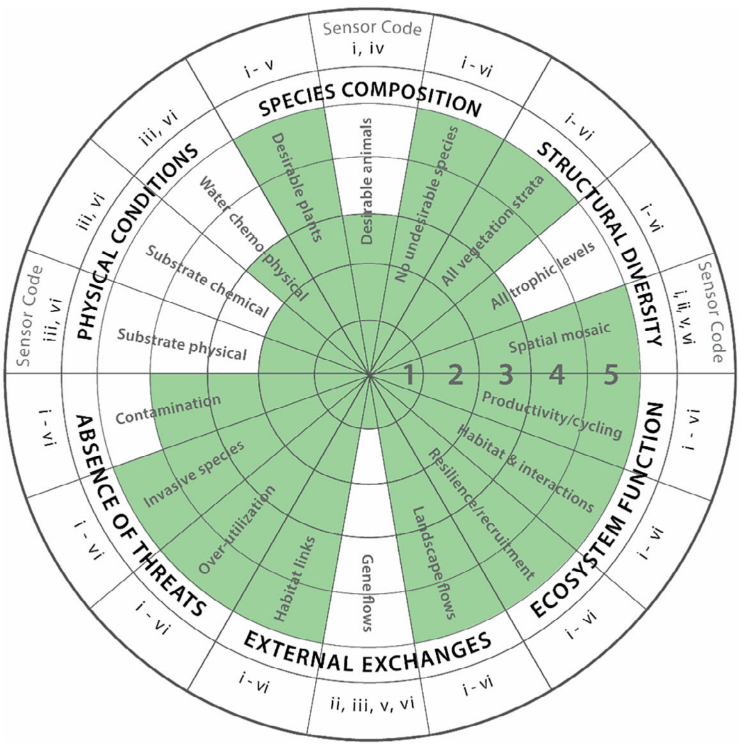
structure, and ecosystem function are currently measurable using EO, and future assessments have the potential to target other indicators to monitor genetic composition, species populations, species traits, and community composition. The development of indicators for EBVs is ongoing, including the recent proposal of 38 headline indicators to fulfill the shared 2050 vision of the Convention on Biological Diversity's post-2020 biodiversity agenda (2021*a*, 2021*b*). This work targets monitoring at the national and global scale. At present, there is no consensus on EO frameworks or indicators for biodiversity or ecosystem change, particularly at the local to regional scales (Skidomore & Pettorelli 2015; Anderson et al. 2017).

Table 1. Summary of feasibility levels for a remote sensing (RS) approach to contribute to the assessment of each sub-attribute for terrestrial restoration projects. See Table S1 for more details on the descriptions and ranking of each sub-attribute.

No. Stars	*Feasibility*	*Application for Restoration Assessments*
1	Very low	Limited indicators/methods and rarely applied in RS (e.g. gene flows [Scribner et al. 2001])
2	Low	Not commonly applied or measured (e.g. substrate chemical [Götze et al. 2016])
3	Moderate	Occasional studies but methods require further work (e.g. desired animals [Gonzalez et al. 2016])
4	High	Occasional studies limited to a few sensors and methods (e.g. contamination [Weiersbye et al. 2006; Arellano et al. 2015])
5	Very high	Multiple methods, products, and indicators. Can be measured using multiple sensors, repeatable and robust (e.g. spatial mosaic and desirable plants [Asner et al. 2017; Reif & Theel 2017; Hamberg et al. 2020; Lechner et al. 2020; McKenna et al. 2020])

The range of observational tools and the increasing role that EO can play in the assessment of the flora, fauna, and biodiversity components of natural and restored ecosystems has been discussed in great detail in a range of remote sensing reviews (Reif & Theel 2017; de Almeida et al. 2020; Lechner et al. 2020). Recently, Ustin and Middleton (2021) identified that industry and government routinely complete operational estimates of a range of ecological parameters, especially those related to vegetation composition, structure, physiology, and phenology from a selection of satellite-airborne-drone image datasets, combined with field data as part of several environmental monitoring applications.

The above studies represent the ongoing global movement to verify a range of ecological variables that are observable and measurable using remote sensing methods. In parallel, the past decade has seen a significant uptake of EO that has been driven by technological advancements resulting in a revolution in aerial, satellite and drone platforms, sensor miniaturization,



Sensor Code	Sensor	Platforms
i	Red Green Blue (RGB)	a Drone
		b Aerial
ii	Multispectral	a Drone
		b Aerial
		c EO (High, Med, Low)
iii	Hyperspectral	a Handheld
		b Drone
		c Aerial
		d EO (High, Med, Low)
iv	Thermal	a Drone
		b Aerial
		c EO (High, Med, Low)
v	LiDAR	a Terrestrial laser Scanner
		b Drone
		c Aerial
		d EO (High, Med, Low)
vi	Imaging RADAR/SAR	a Drone
		b Aerial
		c EO (High, Med, Low)

Figure 2. Modified SER ecological recovery wheel showing suggested sensors that are capable of measuring each ecological attribute at a range of spatial scales. The Sensor Code on the outside concentric circle corresponds with the "Sensor Code" column in the table. The Platforms column shows the potential options which will influence spatial and temporal scales. See Table 2 for further information on Platform choice.

Table 2. Remote sensing derived products/indicators, ideal sensor/platform for the measurement of each sub-attribute, and current limitations. LC, land cover; RS, remote sensing; VC, vegetation cover (includes fractional vegetation cover). For ideal sensor/platform code, refer to Figure 2. *Assuming local to regional scale restoration project.

Attribute	*Sub-Attribute*	*RS-Derived Products and Indicators (What to Measure)*	*Ideal Sensor/ Platform**	*Current Limitations*
Structural diversity	*All vegetation strata*	Vegetation height and structure, canopy shape and color, midstory and ground layer metrics, VC, woody species density and composition	v(b), ii(a, b)	LiDAR sensors such as drone mounted and terrestrial laser scanners can be expensive and labor intensive
	All trophic levels	VC (producers), fauna presence (herbivores and predators), litter presence (decomposers)	i(a) ii(c), iv(b)	RS monitoring of decomposers, small mammals, reptiles, arthropods is not possible using airborne sensors
	Spatial mosaic	VC, openness, vegetation clumps/gaps, bare areas	ii(b,c)	Increased processing. RS measurements of VC require ground surveys to validate. VC may not be the desired restoration vegetation types
Ecosystem function	*Productivity/ cycling*	Vegetation biomass, carbon cycle, chlorophyll	ii(a-c)	Site-specific relationships require ground data to validate models. Empirical models (e.g. biomass) may only apply to the derived image.
	Habitat & interactions	VC, vegetation strata, habitat connectivity/corridors (FRAGSTATS, connectivity models such as Circuitscape)	ii(a-c)	Plant–animal interactions may not be possible to quantify and can be inferred only
	Resilience/ recruitment	VC, fire severity/recovery, woody density	ii(a-c)	Requires temporal scale, recruitment requires high-res spatial imagery
External exchanges	*Habitat links*	VC, vegetation strata, habitat connectivity/corridors (frag stats, connectivity models such as Circuitscape)	ii(a-c)	Requires temporal scale
	Gene flow	VC, habitat amount, habitat connectivity, patch size, fragmentation, migration patterns	ii(a-c)	Requires temporal scale, genetics inferred from other indicators
	Landscape flows	Temperature, fire presence/fire severity, heat exchanges	ii(a-c), iv(c)	Requires temporal scale, site and ecosystem specific
Absence of threats	*Contamination*	Vegetation vigor/stress, Minerals (based on spectral properties), seepage, chlorophyll change	ii(a-c), iii(b-d)	Requires ground validation including spectral signatures
	Invasive species	VC, presence/absence, leaf traits, ID vegetation features (e.g. phenology, flowering, color)	ii(a-c)	Understory species and those occurring under the canopy may be difficult to measure (only the top-most veg layer can be used)
	Over-utilization	VC, vegetation biomass	ii(a-c)	Requires temporal scale
Physical conditions	*Water chemo-physical*	Chlorophyll, moisture, pH, salinity, soil type	vi(a-c), iii(b-d)	Not possible when covered with vegetation. Processing hyperspectral imagery requires RS expertise
	Substrate chemical	Salinity, soil moisture, pH, minerals (based on spectral properties)	vi(a-c), iii(b-d)	Not possible when covered with vegetation. Processing hyperspectral imagery requires RS expertise
	Substrate physical	Soil type, soil texture (% clay, silt, sand), bare ground, compaction, erosion	vi(a-c), iii(b-d)	Not possible when covered with vegetation. Processing hyperspectral imagery requires RS expertise
Species composition	*Desirable plants*	VC, vegetation height, leaf traits, plant features (e.g. phenology, flowering, canopy shape/color/texture)	ii(a-c), iii(b-d)	Very small understory species (e.g. inch flora) and those occurring under the canopy (only the top-most veg layer can be used unless understory targeted specifically)
	Desirable animals	Presence/absence/count, heat signature/contrast, auto detection where fauna is large and visible	iv(a), i(a-b)	No detectability of small or mobile mammals and reptiles, low detectability of medium to large reptiles, complex processing of imagery.
	No undesirable species	VC, vegetation height, leaf traits, plant features (e.g. phenology, flowering, canopy shape/color/texture)	ii(a-c), iii(b-d)	Understory species and those occurring under the canopy (only the top-most veg layer can be used) may be difficult to measure

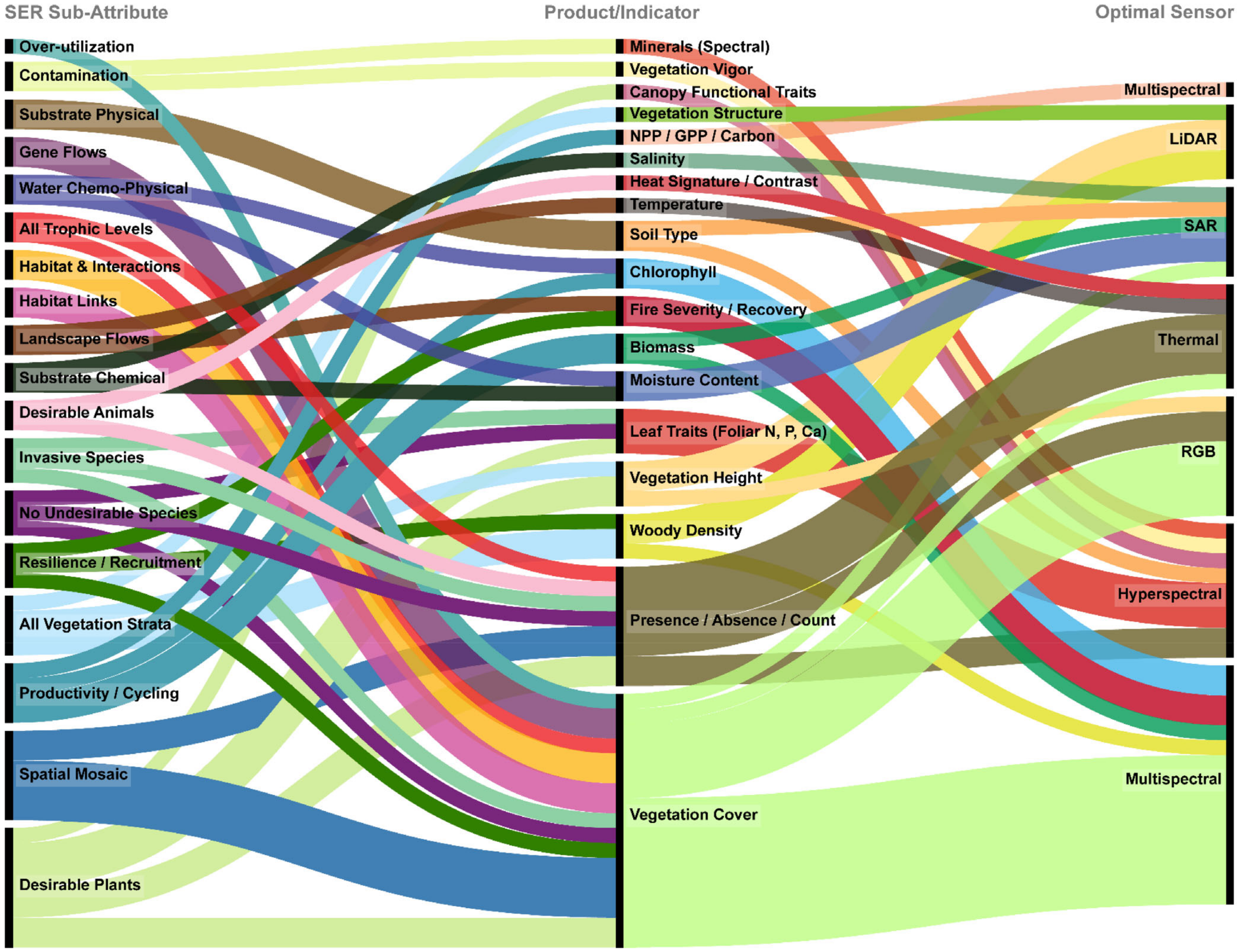


Figure 3. Alluvial chart showing product/indicators derived from remote sensing, and the suggested sensor for restoration projects from local to regional scales. Choice of appropriate product and sensor will be determined by project scale and objectives. Note that this is not an exhaustive list, but rather commonly applied approaches. Height of vertical lines based on author's opinions, expertise, and experience. Data are available in Table S2.

and data availability (Kwok 2018; de Almeida et al. 2020). Indeed, given the rise in web services and free and open access of remote sensing products, users have increasing capacity to access image data to inform applications such as the SER ERW for improved management outcomes (Fig. 1). However, there still exists a knowledge gap for restoration ecologists who on the one hand see enormous opportunities for the applications of remote sensing, but currently lack the training and resources to find the middle ground between what is desired for project outcomes and what is technically feasible.

The aim of this paper is to assess the operational potential for remote sensing to measure the ecological attributes at the local (1 km^2), landscape (10 km^2) and regional (100 km^2) scale as defined by the SER ERW (Gann et al. 2019; SERA 2021). We re-interpret the original intention of the ERW to (1) provide a feasibility analysis on remote sensing sensors, products, and workflows for measuring each ERW sub-attribute and (2) discuss the practicality of operationalizing the ERW using remote sensing from a restoration ecology end-user perspective.

Feasibility Analysis: Which SER Sub-Attributes Can Be Monitored Using Remote Sensing?

The SER ERW provides a template to monitor flora and fauna development by using a five-star gradational scale ranked from very low to very high. This tool has been designed primarily for ground survey teams to semi-quantitatively compare sub-attributes of restoration project with its paired reference ecosystem (McDonald et al. 2016; Gann et al. 2019; SERA 2021). Based on our expertise, we reinterpreted the ERW and assessed the feasibility of using data derived from airborne, drone, and satellites to monitor each sub-attribute. Firstly, we evaluated the criteria listed in Tables 1 and S1 and ranked each sub-attribute on a scale of 1–5. Sub-attributes that scored the highest rank (5 stars) can be considered "operational" and can be measured to a high degree of

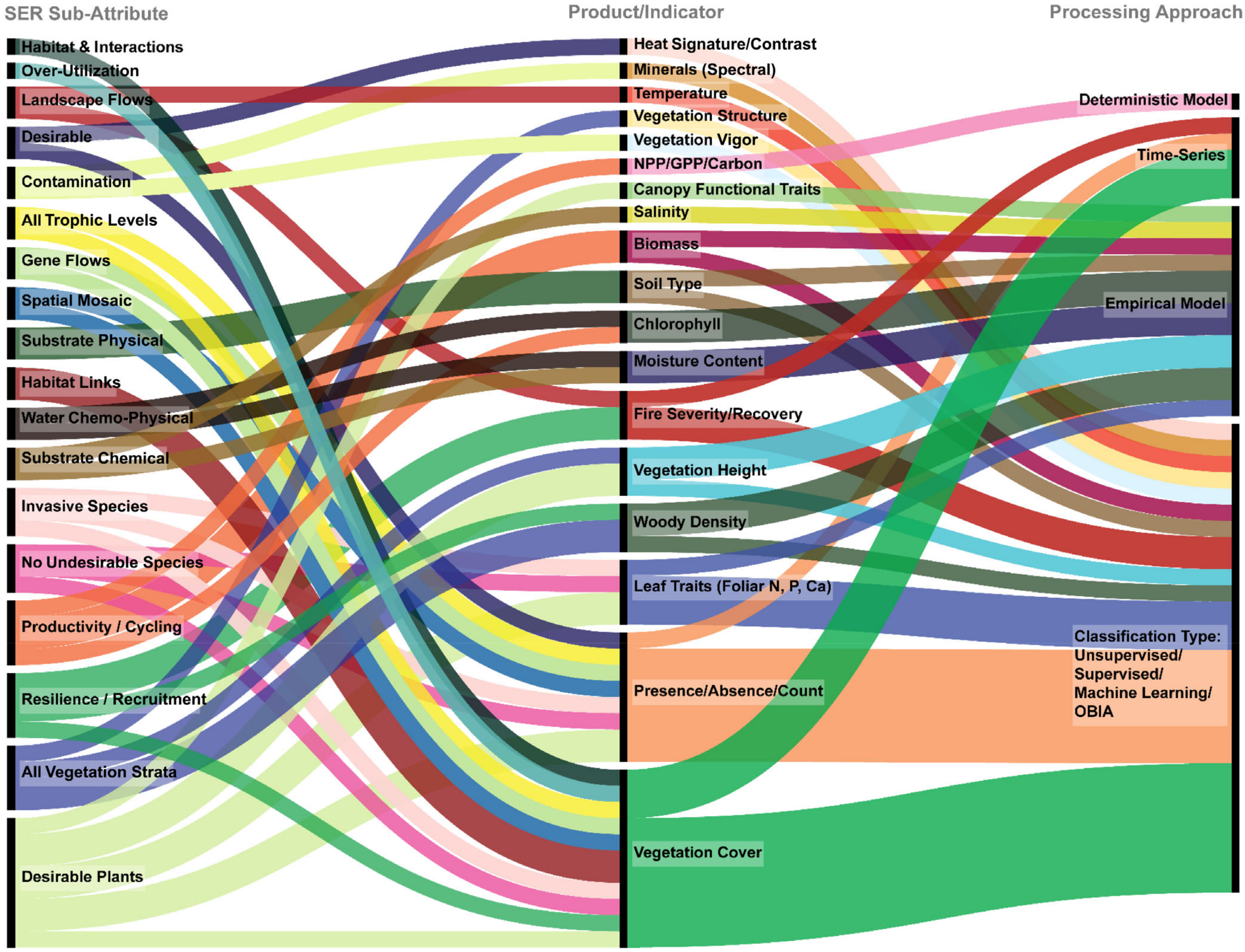


Figure 4. Alluvial chart showing product/indicators derived from remote sensing, and the suggested processing approach for restoration projects from local to regional scales. Choice of appropriate product and processing approach will be determined by project scale and objectives. Note that this is not an exhaustive list, but rather commonly applied approaches. Height of vertical lines based on author's opinions, expertise, and experience. Data are available in Table S3.

confidence using robust, repeatable, and proven remote sensing methods. A total of 11 out of 18 sub-attributes (61%) received the highest rank. In contrast, sub-attributes that were given the lowest rank (1 star) were judged to have a very low potential for remote sensing methods; or remote sensing methods have rarely been applied. Only one sub-attribute received 1 star (Gene flows) and the average ranking of sub-attributes was 4.1 with a mode of 5 (Fig. 2).

Secondly, we listed the sensors and platforms that could be used to measure each sub-attribute at the local, landscape, and regional scales. While not an exhaustive list, they represent a range of common approaches for terrestrial ecosystems and are graphically represented as an outer concentric circle around the ERW (Fig. 2). For each sub-attribute, there is a choice of multiple sensors to measure, map, and quantify restoration outcomes and make direct comparisons with reference ecosystems. For example, "Desirable plants" can be measured using five possible sensors, whereas "Desirable animals" can be measured with two possible sensors: high spatial resolution RGB and thermal imagery and video from drones/aerial. Other sub-attributes such as "Resilience/recruitment" have a choice of up to six different sensors depending on the temporal and spatial scale of the restoration project.

Table 2, Figure 3, and Figure 4 show the suggested products/indicators, combinations of sensors, and processing approaches for restoration projects with a particular focus on terrestrial restoration projects at a local to regional scales. The alluvial charts demonstrate the relationships between variables (columns) and categories (rows); and the height of each category node (black vertical line) indicates a greater proportion of options for the subsequent variables. In general, those sub-attributes with the most options for products and sensor/processing approaches also received the highest score of 5 on the ERW. For example, sub-attributes such as "Desirable plants," "Spatial Mosaic," and "All vegetation Strata" had the most options for derived products, sensors, and processing approaches and are represented by longer nodes (vertical lines). Similarly, the products "Vegetation cover" and "Presence/absence/count" were the most commonly represented and have the highest potential to be used to measure multiple sub-attributes (Table S2; Figs. 3 & 4).

Discussion

Our feasibility analysis highlights the selection of possible sensors, processing methods, and products that are currently available to practitioners for terrestrial restoration monitoring. Although this analysis does not deliver an exhaustive list of remote sensing options, the process highlights the commonly used approaches, and the potential for future operationalization of ecosystem monitoring using the ERW and remote sensing.

It is important to note that the choice of user product, sensor, and processing approach for monitoring purposes will always be considered through the lens of a trade-off between the level of detail (spatial, radiometric, and temporal resolutions [i.e. frequency and historical data availability]) relevance of data and accuracy of measurement. Additionally, the recent increase in sensor and platform availability (e.g. drone mounted LiDAR) introduces additional trade-off decisions for users such as instrument weight, technology, flight time, and altitude of sensor. All sensors have a unique combination of spatial, temporal, and spectral resolution and users are required to work through a level of technical detail and assumptions to decide on the appropriate sensor. Therefore, while users aim to find the middle ground between financial and technical limitations, it should be noted that there is not one perfect sensor or platform suited to each project, but rather a series of options, advantages, and disadvantages to consider.

The objectives of the restoration project will also be a key driver when it comes to monitoring choices for appropriate sensors and methods. When a restoration project has a set of clearly defined end land use conditions, success criteria, and thresholds for corrective action, a remote sensing monitoring framework can be developed to match the most appropriate spatial and temporal technology with the metrics of interest.

How Can Remote Sensing Be Applied to the ERW?

It is our opinion that the ERW can be adapted as a monitoring framework for restoration projects that employ remote sensing. The ERW can be used in its current form, or it can be amended to encapsulate the complexity of a project and sub-attribute of interest (SERA 2021). For example, if "spatial mosaic" is measured by the indicator "vegetation cover," then it makes sense to rescale the ranking to 0–100%, and restoration can be directly compared to reference values to demonstrate progressive recovery. Similarly, established projects with clearly defined success criteria can be incorporated into ERW assessments. For example, post-mineral sand mine rehabilitation in Queensland, Australia, is required to meet woody species density values ≥75% of reference site values (Gravina et al. 2011). Here, a score of 0–100% for the "All vegetation strata" sub-attribute would be appropriate and could be an aggregate of species density or scored on an individual canopy species cover as defined by the criteria. Such assessments could provide cost effective local to landscape scale monitoring data and offer greater insights into restoration development over time compared with ground surveys. Other sub-attributes such as "Resilience/recruitment" can be quantified using temporal datasets to show (1) pre-disturbance trends and (2) post-disturbance resilience. Gathering relevant data through archival imagery has enormous value for ecological monitoring, particularly when it may be impossible to assess these metrics using ground surveys once the window for monitoring has passed, for example, in the case of disturbance from wildfire.

One of the key tenets of long-term ecological monitoring is maintaining consistent methods through time. However, new monitoring approaches may be incorporated into established programs provided there is a suitable period of calibration to maintain the integrity of historical data (Lindenmayer et al. 2020). It is feasible, therefore, that remote sensing and the ERW can be employed for restored ecosystems via an integrated approach with traditional ground surveys, or as standalone remote sensing monitoring.

What Are the Limitations to Using the Ecological Recovery Wheel for Remote Sensing?

This feasibility assessment highlights that several sub-attributes are poorly suited to measuring and monitoring using remote sensing. Most notable of these is "gene flows," which can only be assessed using proxies for genetic characteristics such as habitat metrics or phenology (e.g. flower color). It is noted that genetic composition is listed as a key EBV and Pettorelli et al. (2016) indicate that this could be measured using satellite remote sensing in the near future. However, Navarro et al. (2017) suggest that there is a lack of understanding of the appropriate variables that can be used to measure genetic composition, due in part to the limited genetic knowledge of populations from a temporal and spatial perspective. Our review found only two relevant studies that addressed the concept of gene flow. Madritch et al. (2014) used canopy spectral signatures derived from hyperspectral imagery (AVIRIS) to map *Populus tremuloides* (trembling aspen) and distinguish between canopy genotypes at the regional scale, while Scribner et al. (2001) correlated habit characteristics (mapped using Landsat imagery) with the population genetics of the common toad (*Bufo bufo*) in Great Britain. Future assessment of gene flows would likely rely heavily on the use of proxies, and while proxies are commonly used in remote sensing, they require the careful choice of indicator and targeted field measurements to derive meaningful information (Pettorelli et al. 2018).

When applying a remote sensing approach, it is apparent that some ERW sub-attributes contain data that significantly overlap; risking duplicating data and adding additional work for no reward. For example, the two sub-attributes "non-desirable species" and "invasive species" may result in monitoring (1) the same species and (2) duplicating data within the ERW. This may also occur when using the ERW for ground assessments and is not necessarily specific to remote sensing monitoring, but a characteristic of the ERW itself.

Finally, it was noted that several ERW sub-attributes were broad in definition and their practical use would require further refinement. For example, "desired plants" and "no undesirable species" could be improved by specifying target species for the restoration project and including these in the ERW. Remote sensing methods are currently capable of identifying and mapping a wide range of plant species and, as a result, these sub-attributes scored a very high value of 5. However, the practicality of identifying and mapping every species in a remote sensing monitoring program is limited, particularly when considering small plants in the understory and ground layer (e.g. inch flora). Although species under canopies can, in certain conditions, be mapped when targeted with drones (Hernandez-Santin et al. 2019), the practicality of these methods is reduced when monitoring occurs over local and landscape scales (1–10 km^2), rather than at the individual plot level (<500 m^2). Since the protection of rare and uncommon species is often a widespread goal for restoration projects, this represents a serious limitation worth considering. Nevertheless, remote sensing is capable of detecting desired/undesired plants, and monitoring can be greatly improved when project objective and success criteria are well defined, and imagery is captured in conditions to maximize detection of target species.

By understanding the limitations of remote sensing approaches, including trade-offs for sensors and products, restoration ecologists can look to the next decade with a pragmatic but optimistic outlook for new monitoring opportunities. New choices for restoration stakeholders may be weighted more at the data product and service level, with less relevance given to the sensor(s) and the technical aspects used to capture the raw data. This user-focused approach rather than a producer approach can open the door to a new generation of restoration practitioners, requiring less technical background. However, the large combination of products, indicators, sensors, and methods highlighted in the paper suggests that choices for remote sensing approaches can be complex, and it is important that users have at least a base level understanding of the fundamentals of remote sensing and spatial analysis. This is particularly important given future movements to standardize indicators for EBVs through the CBD post-2020 biodiversity agenda. The user-focused approach will ultimately be defined by the restoration end goals and the level of precision required to adequately measure each sub-attribute.

Conclusion

Ecological restoration represents a broad continuum, with project objectives that range from full recovery of forest ecological structure and function, to novel ecosystems on post-mine rehabilitation. The SER ERW is uniquely placed to utilize remote sensing at the local, landscape and regional scale (1–100 km^2) and can be adapted as a monitoring framework to meet future monitoring challenges and tailored for specific project monitoring objectives. This paper demonstrated the feasibility of these measures and showed the strong potential of remote sensing to measure 11 of the 18 SER ERW sub-attributes by assessing a suite of indicators relevant to ecosystem restoration and specific project objectives. In the coming decade, we encourage restoration practitioners to utilize all the advantages of remote sensing for monitoring applications that are technologically feasible, physically practical, economically viable, and scientifically robust and repeatable. The most appropriate spatial and temporal technology should be considered dynamic, project specific and will undoubtably shift, along with technological advances and uptake.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Sub-attribute descriptions and examples relevant for restoration of terrestrial ecosystems.
Table S2. Combinations of remote sensing products/indicators and sensor/craft to measure each sub-attribute for a local to regional scale project used to create the alluvial chart.
Table S3. Combinations of remote sensing products/indicators and processing approaches to measure each sub-attribute for a local to regional scale project used to create the alluvial chart.

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