DOI: 10.24425/academiaPAS.2022.144675

Paweł Strzeliński, ME, PhD
works in the Department of Forest Management at the Faculty of Forestry and Wood Technology, Poznań University of Life Sciences. In his research he harnesses advanced geomatics technologies, particularly ground-based and airborne laser scanning and satellite and aerial imagery.
pawel.strzelinski@up.poznan.pl

The Forest in Infrared

High-resolution images of forest areas taken by drone or satellite, further integrated with airborne and terrestrial laser scanning data, can provide early warning of damage – even of individual trees afflicted by pests.

Paweł Strzeliński

Faculty of Forestry and Wood Technology, Poznań University of Life Sciences

Science fiction fans the world over will instantly recognize the words: "Space: the Final Frontier...". The fictional world reflects humanity's eternal curiosity, wanting to see and know more. Technological developments in the mid-twentieth century led humankind to conquer space. Very quickly, it became apparent that from Earth orbit one can see not only more, but also better. The demand for data from space grew rapidly.

After more than 60 years of experience with satellites, we can now make use of images supplied by civilian satellites with sensors able to record images of the Earth's surface with a pixel dimension (so-called spatial resolution) of just 10 cm for grayscale, or 40 cm for near-infrared.

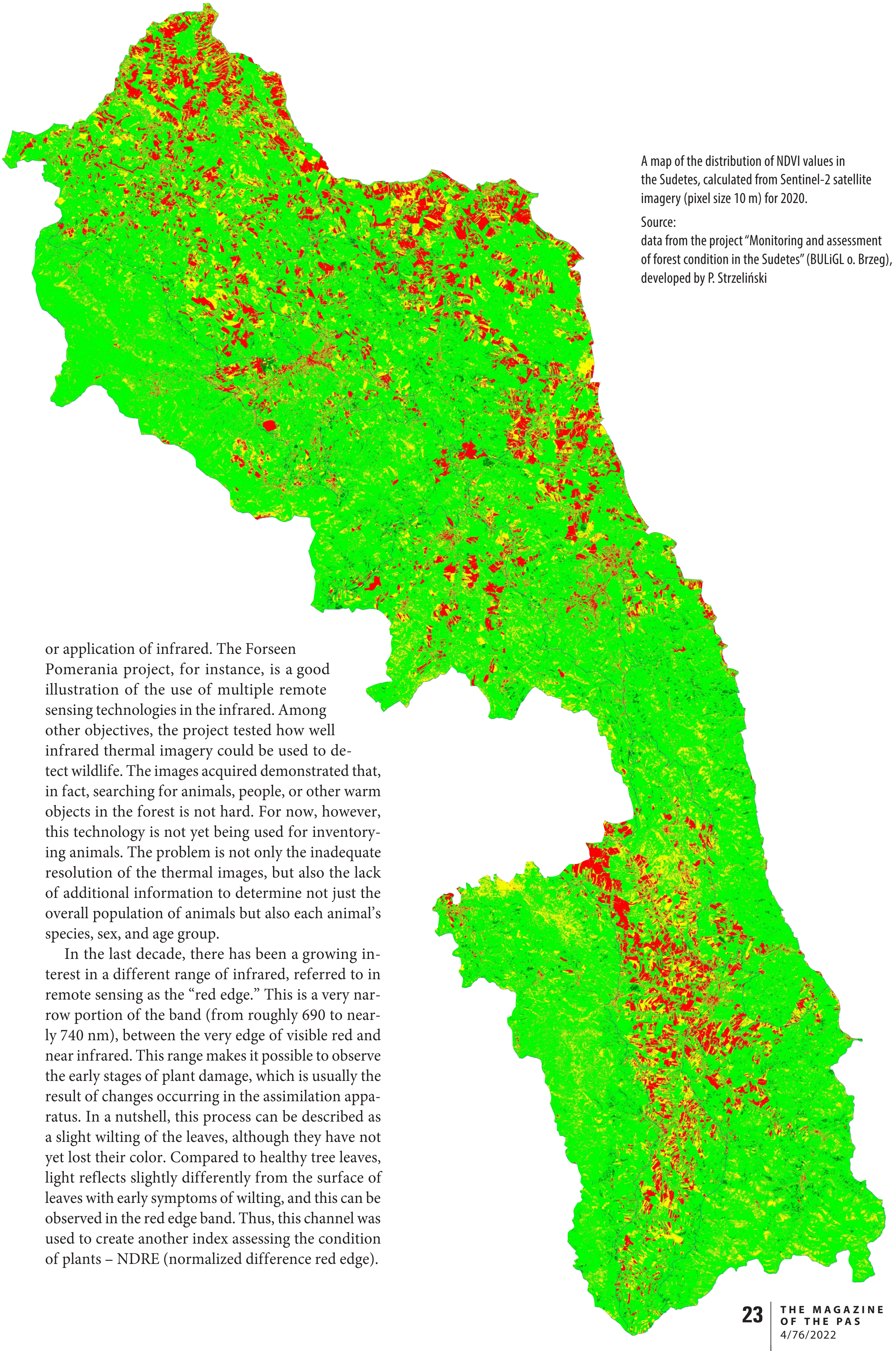
Of course, this quite high achievable spatial resolution is not the only benefit of using satellites. Often, of much greater importance is the recordable spectral range, described in terms of electromagnetic wavelengths. The human eye perceives reality in so-called natural colors, which correspond to the spectral range between 400 and 700 nm. However, much more interesting information about the natural environment can be obtained by analyzing images taken in the infrared band (above 700 nm).

The first environmental satellite whose images began to be widely used in environmental analysis was Landsat 1, launched into orbit on 23 July 1972. Thanks to observations obtained from this satellite, one of today's best-known vegetation indices – the normalized difference vegetation index (NDVI) – was created. Today, this indicator is very widely used, and because it only requires information from two color channels – red (R) and near infrared (NIR) – it is also very simple to calculate.

Over time, newer versions of the Landsat satellite were placed in orbit. The spatial and temporal resolution of environmental satellites has also increased. In 2014, the first satellite of the Sentinel constellation was launched; its successive versions provide images with a resolution of 10 to 60 meters at five-day intervals. They are recorded in 13 channels, including in infrared light. Most importantly, these images are available free of charge! This means they are also used for analyzing NDVI and many other environmental indicators.

On the edge

The infrared band of electromagnetic radiation covers a very wide range. It includes the thermal infrared, which is extremely useful in detecting heat sources. In forestry, this can be applied, for example, in forest-fire monitoring. But this is not the only advantage



A map of the distribution of NDVI values in the Sudetes, calculated from Sentinel-2 satellite imagery (pixel size 10 m) for 2020.

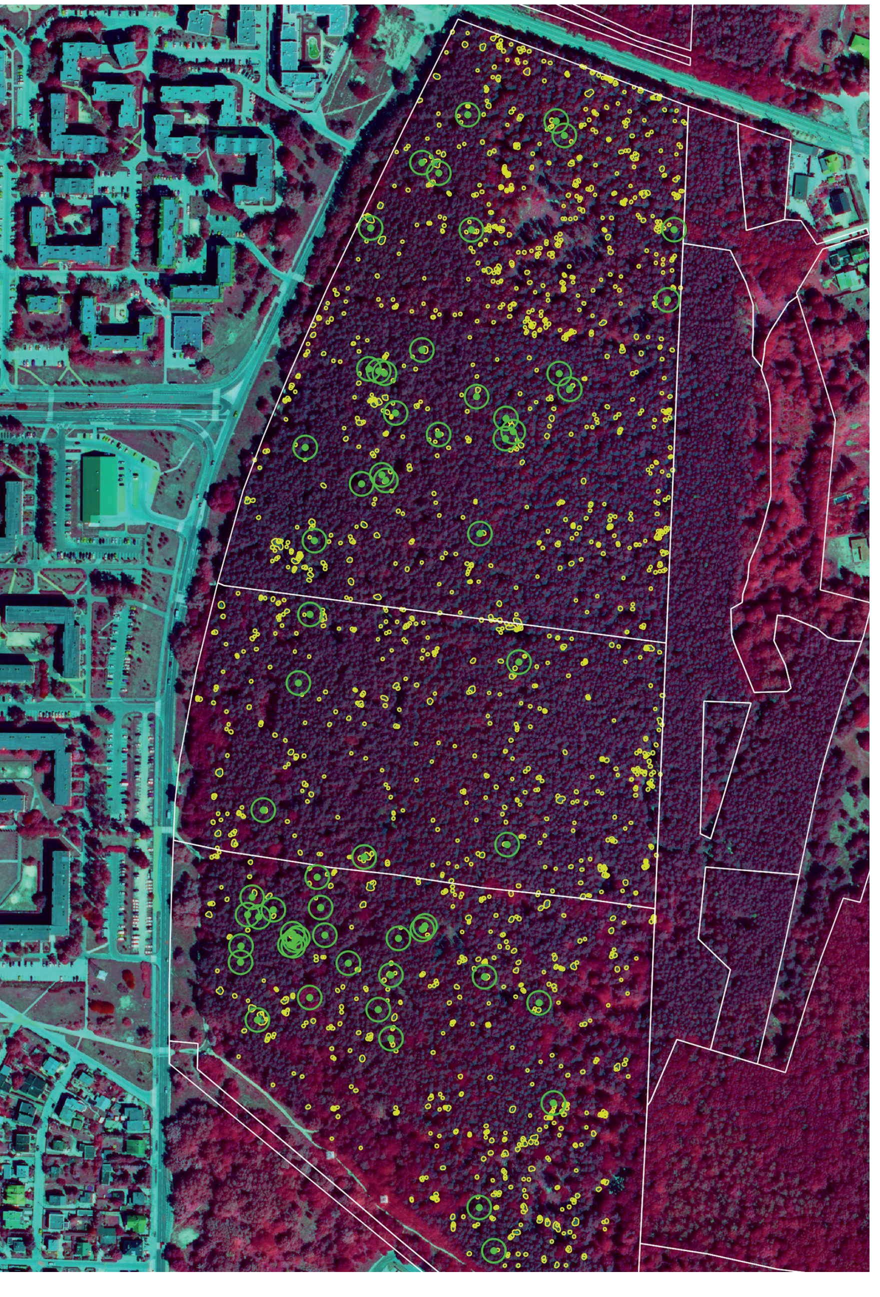
Source:
data from the project "Monitoring and assessment of forest condition in the Sudetes" (BULiGL o. Brzeg), developed by P. Strzeliński

or application of infrared. The Forseen Pomerania project, for instance, is a good illustration of the use of multiple remote sensing technologies in the infrared. Among other objectives, the project tested how well infrared thermal imagery could be used to detect wildlife. The images acquired demonstrated that, in fact, searching for animals, people, or other warm objects in the forest is not hard. For now, however, this technology is not yet being used for inventorying animals. The problem is not only the inadequate resolution of the thermal images, but also the lack of additional information to determine not just the overall population of animals but also each animal's species, sex, and age group.

In the last decade, there has been a growing interest in a different range of infrared, referred to in remote sensing as the "red edge." This is a very narrow portion of the band (from roughly 690 to nearly 740 nm), between the very edge of visible red and near infrared. This range makes it possible to observe the early stages of plant damage, which is usually the result of changes occurring in the assimilation apparatus. In a nutshell, this process can be described as a slight wilting of the leaves, although they have not yet lost their color. Compared to healthy tree leaves, light reflects slightly differently from the surface of leaves with early symptoms of wilting, and this can be observed in the red edge band. Thus, this channel was used to create another index assessing the condition of plants – NDRE (normalized difference red edge).

Using red edge, it was possible to distinguish the crowns of individual large trees, i.e. those whose crown area as seen by the satellite eye as a small number of pixels of a color that distinguished them from neighboring plants. Detection of such trees in early stages of an outbreak makes it possible to take the necessary measures to stop it. These can include spraying with appropriate chemicals or removing single, diseased individuals that are the source from which the next generation of bark beetles will hatch. These issues arise very frequently in the context of the Beskid and Sudeten spruce tree stands.

One of the research projects in which satellite images are used is the "Monitoring and assessment of forest condition in the Sudetes" program, which has been implemented since 2020 on behalf of the State Forests by the Bureau of Forest Management and Geodesy, Brzeg Branch. The goal of this project, in addition to monitoring the health of the Sudeten forests, was to define the degree of stability and likelihood of future dieback. Threat analyses in this project are carried out using images from the aforementioned satellites – Landsat 8 (for NDVI) and Sentinel-2 (NDVI and NDRE) – and verified by a ground-based network of monitoring surfaces, as a reference.



Detection of dead and dying trees in municipal forests of the City of Poznań. Yellow dots indicate dying and dead trees identified by NDRE index analysis.
Source: 2017 CIR orthophotomap, resources of the City of Poznań Forest Department, compiled by. Ł. Polakowski

Drones over the city

Rather than using satellites, of course, we can instead come down to the level where aircraft or drones operate. Such flights require appropriate procedures and weather conditions, but this absolutely does not disqualify the use of such aircraft for research purposes. On the contrary: the ability to achieve sub-centimeter resolution of multispectral images and the integration of these data with laser scanning (3D modeling) has, on the one hand, opened up new avenues of research and, on the other, enabled more rapid and accurate decision-making. This principle was the basis for the creation and implementation of a spatial information system for the municipal forests of the city of Poznań. One of the phases of this project, initiated in 2017, included the launch of nature monitoring in the urban forests. The health of tree stands was assessed using orthophoto maps from aerial photographs (recorded in the RGB and CIR channels) and advanced algorithms that automatically search for dead and dying trees on these images. This first required the creation of appropriate patterns – called photogrammic keys – which are based on field surveys showing the precise location of model trees, representing different species, age, and habitat conditions, and above all – their classes of crown defoliation. Identifying the selected model trees on the orthophoto maps allowed us to pin down the color characteristics of the pixels comprising their crowns. And from there we were only one step away from creating algorithms that automatically searched throughout the analyzed area for crowns exhibiting similar characteristics.

The forest in infrared

A much more extensive project utilizing aerial technologies was the study entitled "Research and development work on prototype technology for a multisensory aerial diagnostic station, enabling large-scale inventorization and parameterization of plants," carried out by GISPRO in cooperation with scientists from the University of Life Sciences in Poznań, the Adam Mickiewicz University in Poznań, and the Poznań Universi-

Comparison of aerial photos taken in natural color (A) and color infrared (B). The ellipse shows the location exhibiting the greatest contrast between the crowns of the three tree species.

Source: http://195.216.117.150/sip/nmap/mapa/1/default (accessed on 12.04.2019), compiled by P. Strzeliński

ty of Technology. This study used an airborne sensor system recording RGB, CIR, and red edge images in combination with airborne laser scanning (ALS) data for vegetation parametrics. Seemingly nothing new or out of the ordinary – but the aerial data was also supplemented with the analyses of Landsat 8 and Sentinel-2 satellite images. The ground reference, in turn, was a network of surfaces precisely measured and scanned with terrestrial laser scanning (TLS) technology. And all at the highest possible resolution.

This project focused on lowland forests, and specifically on the Notecka Primeval Forest, where pine stands dominate. As with mountain spruce, pine stands in the lowlands are plagued by insect outbreaks. Particularly troublesome for the Notecka Forest was the Pine beauty (*Panolis flammea*) moth outbreak, which in 1922–1924 led to the destruction of more than 60,000 hectares of forests. The GISPRO project has demonstrated that integrating several modern technologies together makes it possible to effectively inventory the health of a forest, both when focusing on individual trees and covering entire stands. Thus, another system (hardware, software and analytical methods) has been developed to enable efficient monitoring of forest ecosystems.

We could conclude with a vision of the near future, in which autonomous drones scan forested spaces, instantly diagnosing pest factors, and precision nanobots then restore balance in the ecosystem. But… is this really just a vision for the future? ■

Further reading:

Hellwig F.M., Stelmaszczuk-Górska M.A., Dubois C., Wolsza M., Truckenbrodt S.C., Sagichewski H., Chmara S., Bannehr L., Lausch A., Schmullius C., Mapping European Spruce Bark Beetle Infestation at Its Early Phase Using Gyrocopter-Mounted Hyperspectral Data and Field Measurements, *Remote Sensing* 2021, vol. 13, https://doi.org/10.3390/rs13224659

Hawryło P., Bednarz B., Wężyk P., Szostak M., Estimating defoliation of Scots pine stands using machine learning methods and vegetation indices of Sentinel-2, *European Journal of Remote Sensing* 2018, vol. 51:1, https://doi.org/10.1080/22797254.2017.1417745

Schröder J. (ed.), *Szacowanie biomasy leśnej za pomocą teledetekcji i modelowania – Wyniki projektu zrealizowanego w ramach współpracy polsko-niemieckiej "Forseen Pomerania"* [Estimating forest biomass using remote sensing and modeling – Results of the project carried out within the framework of the Polish-German "Forseen Pomerania" cooperation], 2014.