Wang *et al.* found more illustrative evidence that nucleated dwarf galaxies transform into ultra-compact dwarf galaxies using observations of the Virgo galaxy cluster obtained with ground-based telescopes. In their images, the authors identified several galaxies that clearly fill the gap between ultra-compact dwarf galaxies and regular, as-yet-undisturbed dwarf galaxies hosting nuclear star clusters (Fig. 1). They found examples of dwarf galaxies with overly massive nuclei, which suggests that they have already started to lose their stellar envelope through tidal (gravitational) interactions with more massive galaxies in the cluster. The authors also catalogued ultra-compact dwarfs that still have stellar envelopes around their compact cores. In a few cases, these galaxies even showed extended tidal tails — a clear sign that they have undergone interactions with other galaxies.

Wang and colleagues' analysis suggests that Virgo comprises a continuous spectrum of objects, ranging from nucleated dwarfs to ultra-compact dwarfs that have been fully stripped of their stellar envelope. Their findings illustrate that the long-held distinction between ultra-compact dwarfs and nucleated galaxies disappears — or at least blurs — when deeper data reveal previously invisible structures.

Nonetheless, the spatial resolution of ground-based data is limited, so the authors' analysis was restricted to higher-mass ultra-compact dwarfs, and the possibility that these galaxies came from nucleated dwarfs was already clear from simulations[8]. The European Space Agency's Euclid space telescope that launched in July and NASA's upcoming Nancy Grace Roman Space Telescope will push such analyses to lower-mass ultra-compact dwarfs, which is a class that probably comprises objects with a mixture of origins, including star clusters and remnant nuclei.

Developing techniques to identify nuclei-type ultra-compact dwarfs will no doubt reveal the evolution of these objects. But these tools might also prove useful for reconstructing the formation of galaxies. Although simulations imply that massive galaxies assemble a considerable fraction of their mass by merging with smaller dwarf galaxies[9], pinpointing the properties or even the number of minor merger events is extremely challenging. Ultra-compact dwarfs that stem from nucleated galaxies are the surviving remnants of long-gone dwarf galaxies and might open a window to observational studies of how galaxies assemble.

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Conservation biology

The scale of rubber deforestation assessed

Carlos Souza Jr

Understanding the extent of deforestation associated with agriculturally harvested crops has implications for conservation efforts. A method to assess satellite data offers an accurate way to estimate rubber deforestation. **See p.340**

High-resolution satellite data are being used to quantify deforestation directly at global[1] and regional scales[2]. However, mapping the agricultural commodity drivers of deforestation is challenging — soya plants[3] and palm oil trees[4] are rare examples of success. Rubber plantations have proved more difficult to monitor. Global growth in demand for rubber has put high biodiversity and carbon-rich forests, mainly in southeast Asia, under pressure from deforestation. On page 340, Wang *et al.*[5] report that previous attempts to estimate the extent of deforestation associated with rubber plantations in southeast Asia are based on non-spatially explicit uncertain models that provide estimates varying by more than fivefold. Wang and colleagues implemented an innovative approach, using a massive volume of satellite data, cloud computing and image-processing algorithms to detect rubber deforestation in southeast Asia, thereby increasing the accuracy of such mapping.

Satellite imagery can be used to distinguish targets on Earth's surface by combining analysis of spectral, textural and temporal characteristics, known as signatures. Separating rubber-tree plantations (Fig. 1) from forests is challenging because they both have similar signatures in satellite data. Wang and colleagues had another problem to overcome. In their study area, rubber deforestation generally occurs in small patches of five hectares in smallholder lands, making them difficult to map.

The authors' algorithm requires two major steps. First, they used Sentinel-2 satellite imagery (with individual pixels that correspond to 10-metre-sided squares) across southeast Asia for 2021 to characterize what is termed the phenological spectral signature — representing how rubber trees are captured by satellite measurements when they shed leaves and when new leaves come out. Identifying the annual time window of this phenological pattern for rubber trees, which can be tracked by the spectral bands that Sentinel-2 data record, enabled the authors to distinguish rubber-tree plantations from evergreen and deciduous forests, other monoculture forests, and forest regeneration after land abandonment (secondary forest regrowth).

Another challenge was to overcome cloud blocking of ground observations, because Sentinel-2 captures spectral bands that do not penetrate clouds. The authors improved ground observations using a multi-year imagery composite for 2021 to remove clouds and shadows.

The second step was to train, calibrate and test a machine-learning algorithm, called Random Forest, with more than 3,800 reference ground samples. The result was a rubber-tree plantation map for southeast Asia for 2021.

A goal of Wang and colleagues' work was to estimate the number of rubber-tree plantations directly associated with deforestation. For this, the authors used Landsat imagery time series (with pixels that correspond to 30-m-sided squares and data providing historical coverage) to estimate the deforestation date for rubber plantations mapped in 2021. These were then grouped into two time-frame categories: 1993–2000 and 2001–16. Wang *et al.* used a time-series algorithm named LandTrendr[6] that detects 'breaking points' (changes from tree cover to tree removal) in a pixel's spectral history. The authors also used the normalized band ratio (NBR) spectral index to capture abrupt changes from

JONATHAN KLEIN/AFP VIA GETTY

Figure 1 | Harvesting rubber sap on a plantation.

tree-cover classes to bare or burnt ground. The authors selected only the first breaking point signal in the time series after 1990 to avoid double counting deforestation associated with plantation rotations in cleared forests.

Wang and colleagues' map shows 14.2 million hectares of rubber-tree plantations in 2021. The authors say that their estimate is conservative, on the basis of the reference ground data used to assess the accuracy of the map. The overall classification accuracy was 95%, but this was lower in areas where rubber phenology is less predictable under short seasonality, and where there is more notable variation in climatic conditions.

The authors estimate that direct conversion of forest to rubber-tree plantation accounted for 4.1 million hectares between 1993 and 2016, and that more than one million hectares of biodiversity-rich forests were lost owing to rubber deforestation in 2021. Given the rising demand for rubber for tyre production, forest loss associated with this agricultural commodity might increase, as Wang and colleagues suggest.

This detection algorithm for rubber deforestation might help the rubber industry to review its claims of eco-friendly tyre production. European Union deforestation regulations (see go.nature.com/4972txo) were introduced in 2023 to ensure that products, including rubber, do not contribute to deforestation. Wang and colleagues' study sheds light on how to monitor rubber-related deforestation. This is a crucial step to support the implementation of legislation and voluntary market commitments, as well as companies' environmental, social and governance policies linked to the rubber supply chain.

Given that the demand for rubber will probably grow, there is an opportunity to provide an incentive for rubber-tree plantations to be established in previously deforested areas, changing the commodity's negative associations (carbon emissions and biodiversity loss) to positive ones (carbon sequestering, and increased landscape connectivity and biodiversity). For that to happen, Wang *et al.* urge careful regulation with spatially explicit monitoring of deforestation. Consumers should also be informed that most rubber products are associated with deforestation, and be educated on why a market for goods with more-transparent supply-chain traceability is needed.

Wang and colleagues' groundbreaking work is anchored in the use of open Earth Observation data, planetary-scale cloud computing and open-source image-processing algorithms. Increasingly, geo-information is being generated to guide conservation policies and the sustainable use of natural resources. Satellite-monitoring information needs to be used effectively to drive a revolution in the traceability of agricultural commodities so that it has a positive effect on the environment and improves social well-being. Governments, agricultural supply-chain partners and consumers can play their part, guided by science and technological advancements, as demonstrated by Wang and colleagues.

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