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Letters

Satellites miss environmental priorities

Scott R. Loarie, Lucas N. Joppa and Stuart L. Pimm

Nicholas School of the Environment and Earth Sciences, Duke University, Box 90328 Durham, NC 27708, USA

Sixteen years ago, Pimm [1] caricatured most ecological studies as covering a few hectares, spanning a few years and involving a handful of species. Although satellite imagery for visualizing and monitoring terrestrial ecosystems began earlier, only the past decade has provided inexpensive, global remote sensing – and desktop computer software for its analysis [2]. Comparisons of ecological patterns and changes over decades on huge spatial scales are now routine. Everyone can visualize current study sites (and select future ones) on GoogleEarth (http://earth.google.com/), increasingly with a spatial resolution that shows individual tree canopies. We worry that this revolutionary change in ecology's cosmos might be ephemeral.

Ecologists require sensors that differ in temporal, spectral and spatial resolutions. Detecting landscape change requires sequences of images. Quantitative identification of ecological communities relies on spectral data. High spatial resolution helps to resolve fine-scale features, calibrate courser data and coordinate field studies. There are sensors to monitor tropical rainfall, fires and clouds and specialized sensors, such as Lidar and Radar. Space prevents discussion of the fates of all of these. However, Landsat's TM (later ETM+) sensor, EOS-MODIS (Box 1), and recent high spatial resolution sensors are the workhorses of the environmental community. They exemplify the utility of [3–5], and the problems threatening, remote environmental monitoring.

From 1972 to 2003, Landsat provided uninterrupted global images, with a resolution of 15–60 m, every 16 days or so. NASA built and launched these satellites but has no mandate to support and distribute their products after initial development. Nothing replaced Landsat7 after technical problems compromised it in 2003. Landsat5 has far outlived its expected lifetime. While the United States Geological Survey continues to archive images of the USA, Landsat5 deletes images from most of the rest of the world before they reach the ground. NASA launched the first Moderate Resolution Imaging Spectroradiometer (MODIS) sensor in 1999. It has lower spatial resolution but makes near daily revisits and boasts more spectral bands. Midway through their expected 15-year life spans, MODIS sensors have been most successful but, similarly to Landsat, might not be supported in the long term.

The growing fleet of commercial high spatial resolution satellites exemplifies the trend to delegate satellite administration to the private sector. Five with <5 m resolution were in orbit by 2004 –QuickBird, IKONOS, Spot5, Orbview3 and EROS A1. Unlike courser-scale satellites that image continually, these only respond to specific requests. Until recently, the price of archived imagery – ~$1250 for a minimum of 50 km^2 – was prohibitive. Now, GoogleEarth provides ready access to the archived QuickBird imagery of Digital Globe. In 2007, GeoEye formed a foundation to distribute archived IKONOS and OrbView3 imagery to humanitarian and environmental researchers. Meanwhile, NASA continues to purchase and distribute commercial images through their Science Data Purchase project.

Of course, other, better-funded clients originally commissioned these images. Environmental scientists have little influence over which part of the Earth these clients select. The private sector has no incentives to represent environmental priorities, especially the most biologically diverse parts of the globe [6], the global network of protected areas [7] and ecosystems that might rapidly influence (carbon in the Amazon [8]) or respond (ice in the Arctic [9]) to climate change.

Digital Globe and GeoEye report every location captured by IKONOS, OrbView3 and QuickBird (Figure 1a). Currently, at least one image covers 56% of the land surface (Figure 1b, unbroken line). These satellites should sample the entire globe by 2012. If they minimized overlap, they would have completely sampled the land surface of the earth by 2003 and would now be nearing their third completion (Figure 1b, dashed line).

The World Wildlife Fund for Nature [10] publishes ecoregions that delineate the major ecosystems of the planet – tundra, grasslands or moist tropical forests, for example. Moist tropical forests and the poles have particularly poor satellite coverage – only 31% of the surface (see Supplementary Material online). These ecosystems are often cloudy [11], of course, but that makes frequent and well-coordinated coverage even more necessary. Protected areas are similarly under-represented. Boundaries from the World Database on Protected Areas (http://sea.unep-wcmc.org/wdbpa/) reveal that there are 20% fewer images inside protected areas than we would expect from their corresponding area. High-resolution sensors cannot offer global coverage but subsidies that coordinate imaging rather than mine archives could greatly increase representation of environmental priorities.

Simply, Landsat no longer provides global coverage, leaving the environmental community blind to the ongoing changes in land-use patterns across key ecosystems. Commercial coverages under-represent environmental priorities. These facts are part of a much larger crisis across all US earth-observing initiatives [12], including satellites that monitor hurricanes, such as the aging QuikSCAT. Environmental sciences are indebted to innovators such as

Corresponding author: Pimm, S.L. (stuartpimm@aol.com).
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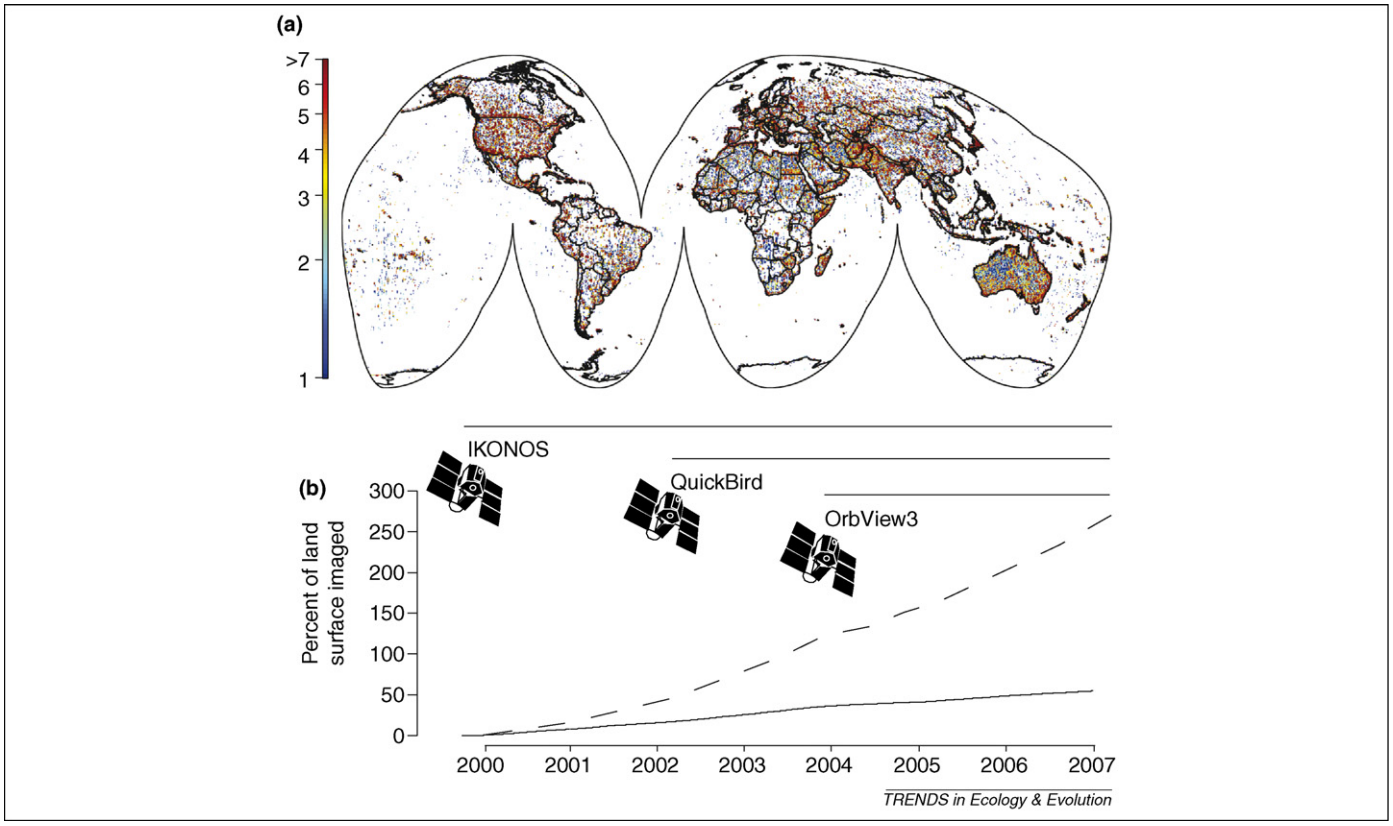

Figure 1. The distribution of high-resolution images. **(a)** Colors indicate the number of overlapping images (scale at the left of the map). **(b)** The percentage of land surface imaged (unbroken line) and the amount possible if the same images overlapped minimally (broken line). Arrows indicate the history of a satellite.

Box 1. List of acronyms

EOS-MODIS: Earth Observing System Moderate Resolution Imaging Spectrometer
EROS-A1: Earth Resources Observation Satellite A1
Landsat TM: Landsat Thematic Mapper
Landsat ETM+: Landsat Enhanced Thematic Mapper
Lidar: Light Detection and Ranging
QuickSCAT: Quick Scatterometer
Radar: Radio Detection and Ranging
Spot5: Satellite Pour l'Observation de la Terre 5

GoogleEarth, GeoEye and other private satellite companies for rapidly increasing the availability of images. Finding innovative solutions for the long-term support, coordination and distribution of earth-observing products requires government leadership. Space exploration must not replace earth observation. We, the environmental community, must be more vigorous in urging this leadership.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tree.2007.08.018.

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