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Spectrographic imaging

## A bird's-eye view of the health of coral reefs

Almost three-quarters of the world's coral reefs are thought to be deteriorating as a consequence of environmental stress. Until now, it has been possible to evaluate reef health only by field survey, which is labour-intensive and time-consuming. Here we map live coral cover from the air by remote imaging, a technique that will enable the state of shallow reefs to be monitored swiftly and over large areas.

It is predicted that coral reefs will suffer mounting stress associated with a global increase in atmospheric carbon dioxide over the coming decades<sup>1,2</sup> and from local disturbances such as overfishing<sup>3</sup> and disease<sup>4</sup>. The most obvious effect of such stress is a decline in living coral cover, so a temporal change in cover is a good indicator of the state of health of a coral reef. However, the measurement of coral cover by field survey<sup>5</sup> is impractical on the scale of hundreds to thousands of square kilometres.

Measurements of the reflected light spectra of reef biota and substrata indicate that the dominant groups can be distinguished *in situ*<sup>6–10</sup>, but until now it has not been clear whether such spectral differences can be detected remotely from the air or from space. We acquired high-spatial-resolution (1 m × 1 m), multispectral images from the air of two reefs in the lagoon of Rangiroa Atoll, French Polynesia, by using a compact spectrographic imager. We carried out this imaging in November 1998 because coral populations had suffered significant mortality after the extreme El Niño/Southern Oscillation that occurred in the austral summer of 1997–98 (ref. 11). At the same

time, we carried out detailed *in situ* surveys of coral populations on each reef.

The first reef was dominated by large live and dead colonies of *Porites*, the remotely sensed spectra of which were readily distinguishable on the basis of their first spectral derivatives (rate of change of reflectance versus wavelength<sup>12</sup>) in the wavelength region 506–565 nm, as expected from *in situ* measurements<sup>8</sup>.

The habitat of the second reef was highly heterogeneous and we used the imager to estimate the percentage cover of all substrata in ten plots of 25 m<sup>2</sup> each. Although within-plot estimates of the cover of dead *Pocillopora* coral, coralline red algae and sand varied by as much as 25–29%, estimates of live coral never differed from field data by more than 10% (Table 1). At a whole-reef (interplot) scale, estimates of the mean cover of all major benthic categories differed by less than 8%, and the cover of both live and dead coral was estimated to within 3%. There were no significant differences in estimates of mean habitat cover at the 95% confidence level (paired *t*-tests).

The video surveying methods currently used by scientific divers on the Great Barrier Reef are estimated to have a 95% probability of detecting a 10% change in live coral cover from one year to the next<sup>13</sup>. Power analysis of our data indicates that 22 plots of 25 m<sup>2</sup> each would need to be surveyed by remote sensing, compared with 20 equivalent-sized plots by video camera, to achieve the same level of statistical resolution on the reefs surveyed (that is, similar sample sizes for field and remote methods). However, spectrographic images can be acquired over areas that are many times larger than those that can be surveyed underwater.

We anticipate that the application of multispectral remote sensing will signifi-

cantly improve estimates of coral cover and changes in coral cover over time. It took us 1 hour to acquire images over 92,500 m<sup>2</sup> of reef, which represents 3,700 plots of 25 m<sup>2</sup> each, compared with 3 days to survey 10 such plots underwater. Moreover, remote images are acquired as numerical data, which can be rapidly processed electronically, reducing the time needed to generate estimates of surface cover.

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**Table 1** Estimates of substrate cover for live and dead reefs

	Cover (%)		Mean disparity (%)	Maximum disparity (%)	Minimal detectable disparity of means (%)
	Field survey	Imagery			
Live <i>Porites</i>	11.5 (2.7)	8.8 (2.9)	–2.7	–9	5.6
Recently dead <i>Porites</i>	7.8 (1.6)	6.8 (3.1)	–1.0	18.9	10.6
Dead <i>Pocillopora</i>	32.5 (8.3)	37.2 (12.6)	4.7	28.9	17.3
Red coralline algae	21.9 (2.4)	15.2 (4.8)	6.6	–25.7	14.3
Sand	18.9 (6.0)	26.8 (9.1)	7.9	27.2	12.1
<i>Halimeda</i>	3.9 (1.6)	5.1 (2.1)	1.2	–9.7	8.3

Field and remote estimates of substrate cover are shown for comparison (standard errors shown in parentheses). Results of pairwise *t*-test comparisons for each habitat were non-significant ( $P < 0.05$ ). Minimal detectable difference represents the smallest disparity in mean cover between field and image estimates that would result in a significant *t*-test with 90% power. These values provide a worst-case scenario for the accuracy of remote sensing to predict mean habitat cover: actual disparities were considerably lower. Compact airborne spectrographic imager (CASI) data (10 bands) were corrected for depth variation (1–7 m) using image-derived attenuation coefficients. Substrata were predicted from unsupervised classification of spectral data and were categorized using independent field data. Each plot was identified on CASI images by triangulation to white plastic markers (4 m<sup>2</sup>) and mapped *in situ* with a resolution of 0.01 m<sup>2</sup>.

Immune recognition

## A new receptor for β-glucans

The carbohydrate polymers known as β-1,3-D-glucans exert potent effects on the immune system — stimulating antitumour and antimicrobial activity, for example — by binding to receptors on macrophages and other white blood cells and activating them. Although β-glucans are known to bind to receptors, such as complement receptor 3 (ref. 1), there is evidence that another β-glucan receptor is present on macrophages. Here we identify this unknown receptor as dectin-1 (ref. 2), a finding that provides new insights into the innate immune recognition of β-glucans.

We screened a RAW264.7 complementary DNA retroviral expression library using the β-glucan-rich particle zymosan<sup>3</sup>