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Spatiotemporal variability of typhoon impacts and relaxation intervals on Jaluit Atoll, Marshall Islands

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Appendix 1 Methods

Image processing and shoreline interpretation

Vertical aerial photographs and high resolution satellite imagery provided the basis for assessing both the impacts of the typhoon as well as the post-typhoon adjustment and recovery of the islands (Table DR1). Jaluit Atoll had a significant Japanese military presence during World War Two (WWII). As a result, high quality vertical aerial photographs are available from this time. An extensive aerial photograph survey of Jaluit was also conducted in 1976. We assumed that the 1945 photographs represented the pre-typhoon morphology of the islands. The 1976 photographs provided the first available post-typhoon imagery. Consequently, analyses of these images most likely to under-represented typhoon damage as they included 18 years of post-event change.

Two mosaics of modern, high-resolution, true-colour satellite images were provided pan-sharpened by the Natural Resource Conservation Service of the U.S. Department of Agriculture. Given the size of Jaluit Atoll and image quality issues (i.e. glare and cloud cover) the satellite images are a mosaic of scenes captured on different dates (Figure DR1). The 2006 mosaic was used as the source of ground control points for the aerial photographs and 2010 satellite image. A range of anthropogenic features (i.e. wharves), as well as natural features (i.e. coral heads, cemented beach rock) provided the source of ground control points.

All imagery was georeferenced using a 2nd order polynomial fit with Universal Transverse Mercator (UTM) Zone 59N providing the coordinate system. As with previous reef island change studies we adopted the edge of island vegetation as a shoreline proxy (Webb and Kench, 2010, Ford, 2013). The edge of vegetation was digitised as a line feature and converted to polygon features in ArcGIS 10.0.

Table DR1. Properties of imagery and positional uncertainty of edge of vegetation lines.

	Imagery Date			
	1945	1976	2006	2010
Type	B/W aerial	B/W aerial	Quickbird	WorldView2
Source	US National Archives	Alele Museum, Majuro	US Dept. of Agriculture	US Dept. of Agriculture
Date	7-January-1945	8-Jan-1976	Fig. DR1	Fig. DR1
Scale/Resolution	Unknown (0.8 m)	1:8000 (0.8 m)	0.6 m	0.5 m
Georeferencing (m)	0.49-2.15	0.56-2.11	0	1.34
Interpreter uncertainty (m)	1.81	1.75	1.27	1.27
Shoreline uncertainty (m)	2.04-2.92	2.00-2.86	1.40	1.91

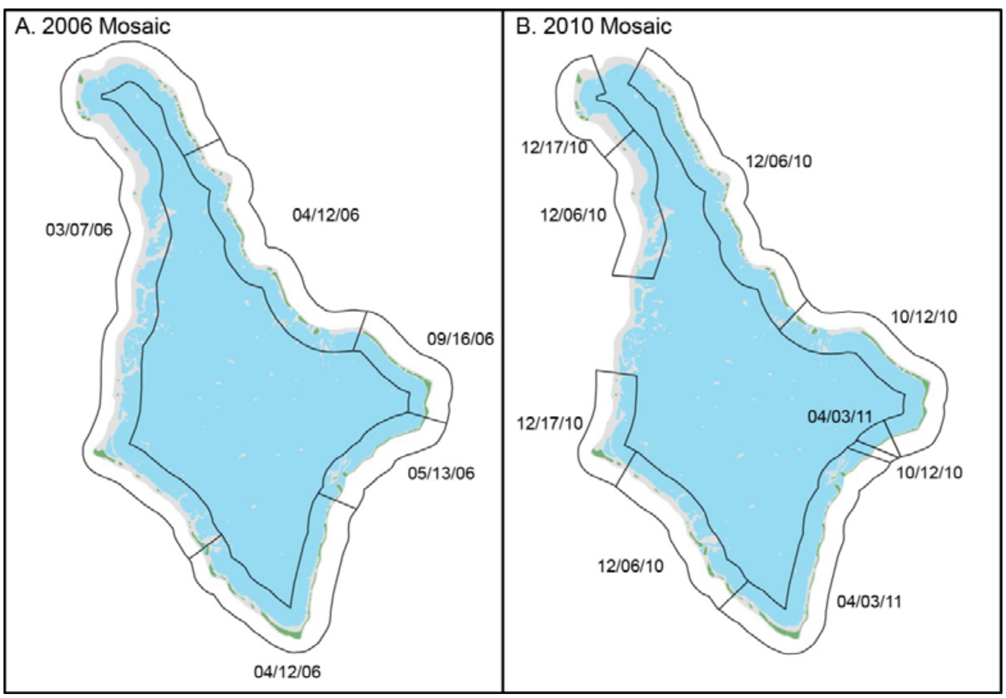


Figure DR1. Image acquisition dates for A) 2006 Quickbird satellite image mosaic and B) 2010 WorldView 2 mosaic.

Shoreline uncertainty

The positional error of a line is a fundamental issue in Geographic Information Science (GIS) and is subject to ongoing research (Tong et al., 2013). Within shoreline change studies the positional uncertainty of the shoreline has been assessed based on a number of sources of error associated with data collection and processing. Romine and Fletcher (2009) determine shoreline uncertainty as a function of up five potential sources of error when interpreting shorelines from aerial photographs (digitizing error, pixel error, seasonal error, rectification error and tidal error). Ford (2011) calculated the uncertainty of the edge island vegetation, using pixel size, rectification error and interpreter error. Romine and Fletcher (2009) assess interpreter error as the standard deviation of the difference between shorelines interpreted from the same imagery, by different trained operators. In order to assess interpreter error we follow Romine and Fletcher (2009), except repeat digitisation of an island shoreline is undertaken by a single operator. The positional uncertainty of island shorelines are summarised in Table DR1.

In order to calculate the uncertainty of island areas Kench et al. (2015) buffered island shorelines by the combined uncertainty of the pixel and interpreter error noting it was a conservative estimate. In order to estimate to the uncertainty of island areas we performed trials of repeat shoreline digitization of a number of islands. As a proportion of island area the uncertainty is greatest for increasing small and highly elliptical islands. Repeated digitising of 12 islands, primarily small elliptical islands, was undertaken to assess the range variation in digitised island areas compared to the island buffer. The standard deviation from samples of repeated digitisation of the same island ($n > 20$) is less than 1.5% even for small and elliptical islands on both 1945 aerial photographs and 2010 satellite imagery.

No consistent record of island names exists for all islands in the atoll. As a result, we adopted a numbering system for the islands which are numbered consecutively clockwise around the atoll rim starting in the north (Figure DR2). Islands along the eastern rim, south of 59a tend to be narrow, often less than 40 m wide, and were highly fragmented in 1976. Due to the small, fragmented nature of these islands it is difficult to directly map the change of individual islands. As a result, in order to compare land area change the islands were grouped into a series of islands units. Islands units contain all island fragments along a certain length of atoll rim. Divisions of the rim were made at locations with existing gaps in the shorelines either at passages between islands or at areas obscured by cloud cover in aerial photographs. We refer to whole islands and island units as islands. We focused on the analysis of 87 islands for which imagery from all four time periods allows the digitization of a complete shoreline necessary for the calculation of island area (Figure DR3).

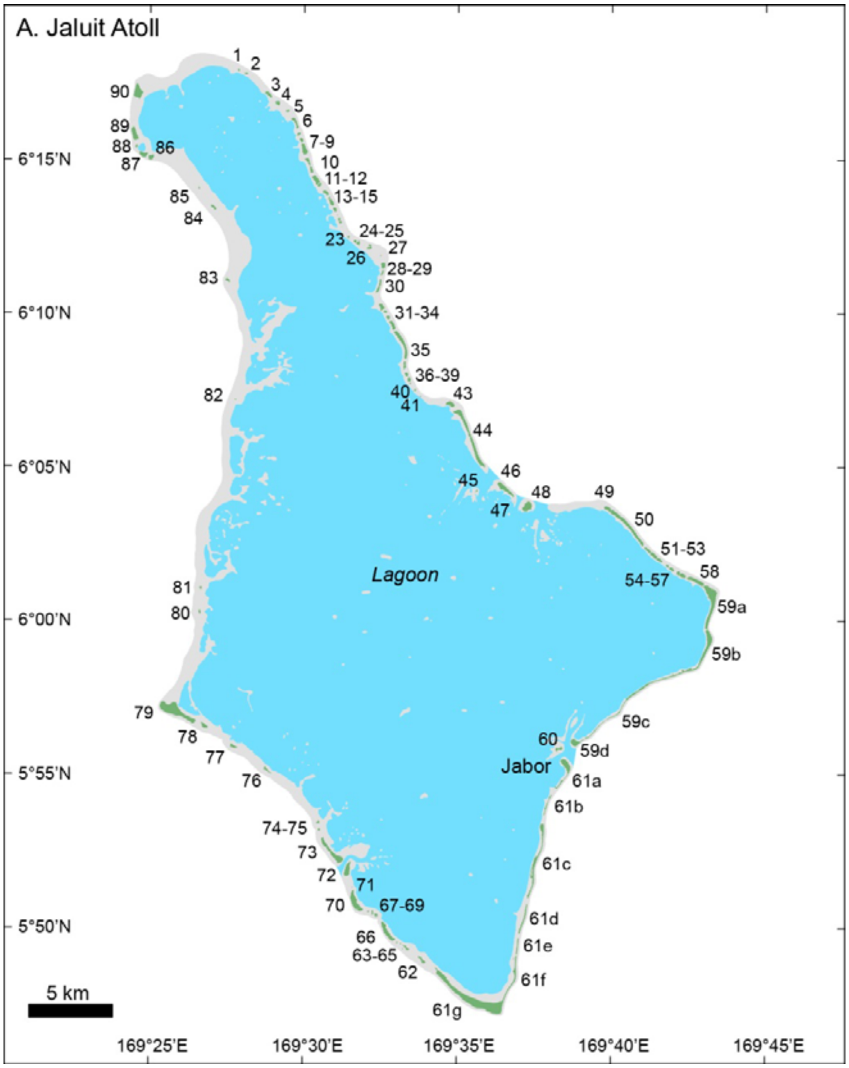


Figure DR2. Numbering scheme adopted for islands on Jaluit Atoll.

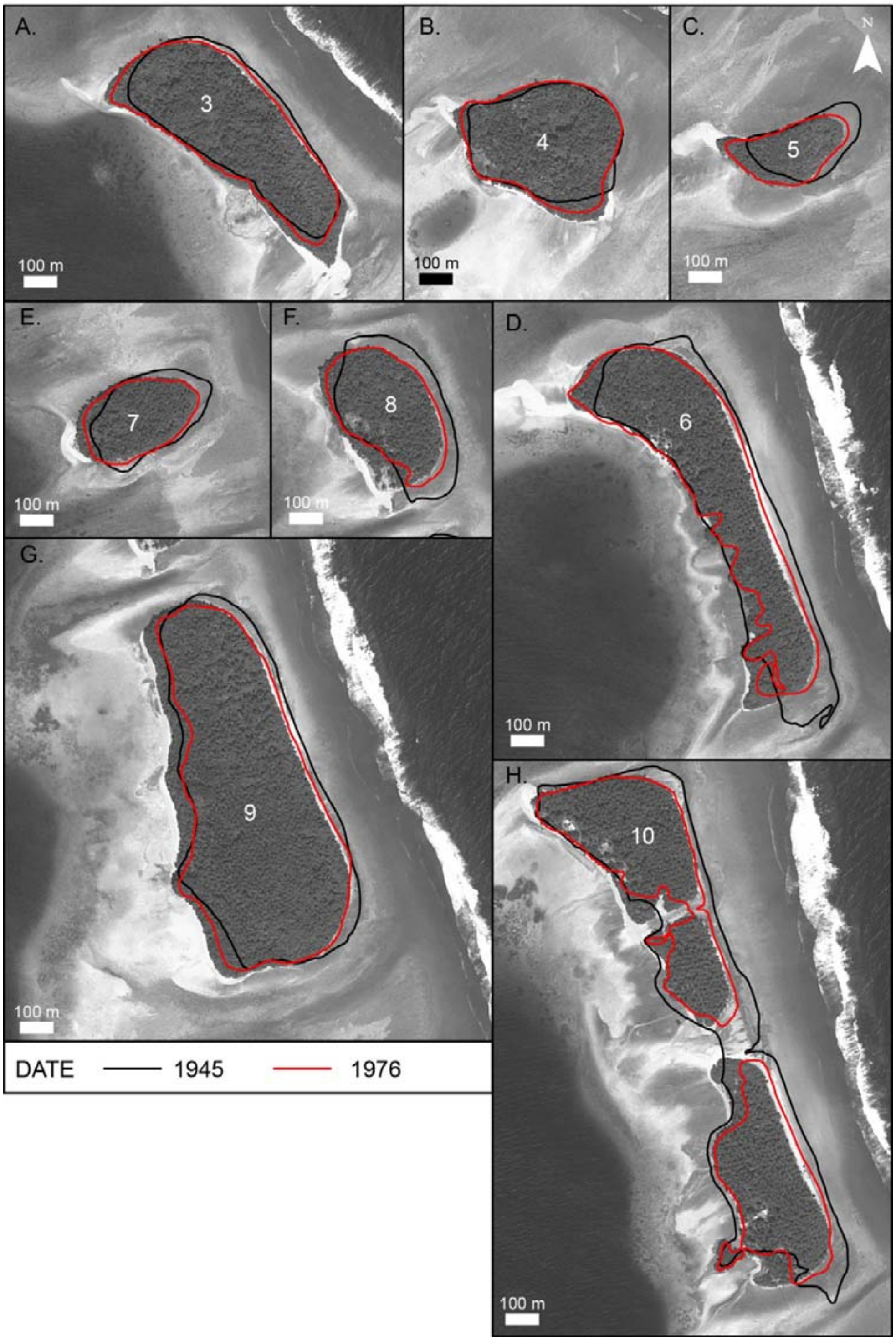


Figure DR3. Interpreted shorelines from Jaluit Atoll overlaid 2010 satellite imagery. See Figure DR2 for island locations and Table DR2 for island areas. Includes material © 2015 DigitalGlobe, Inc. All rights reserved.

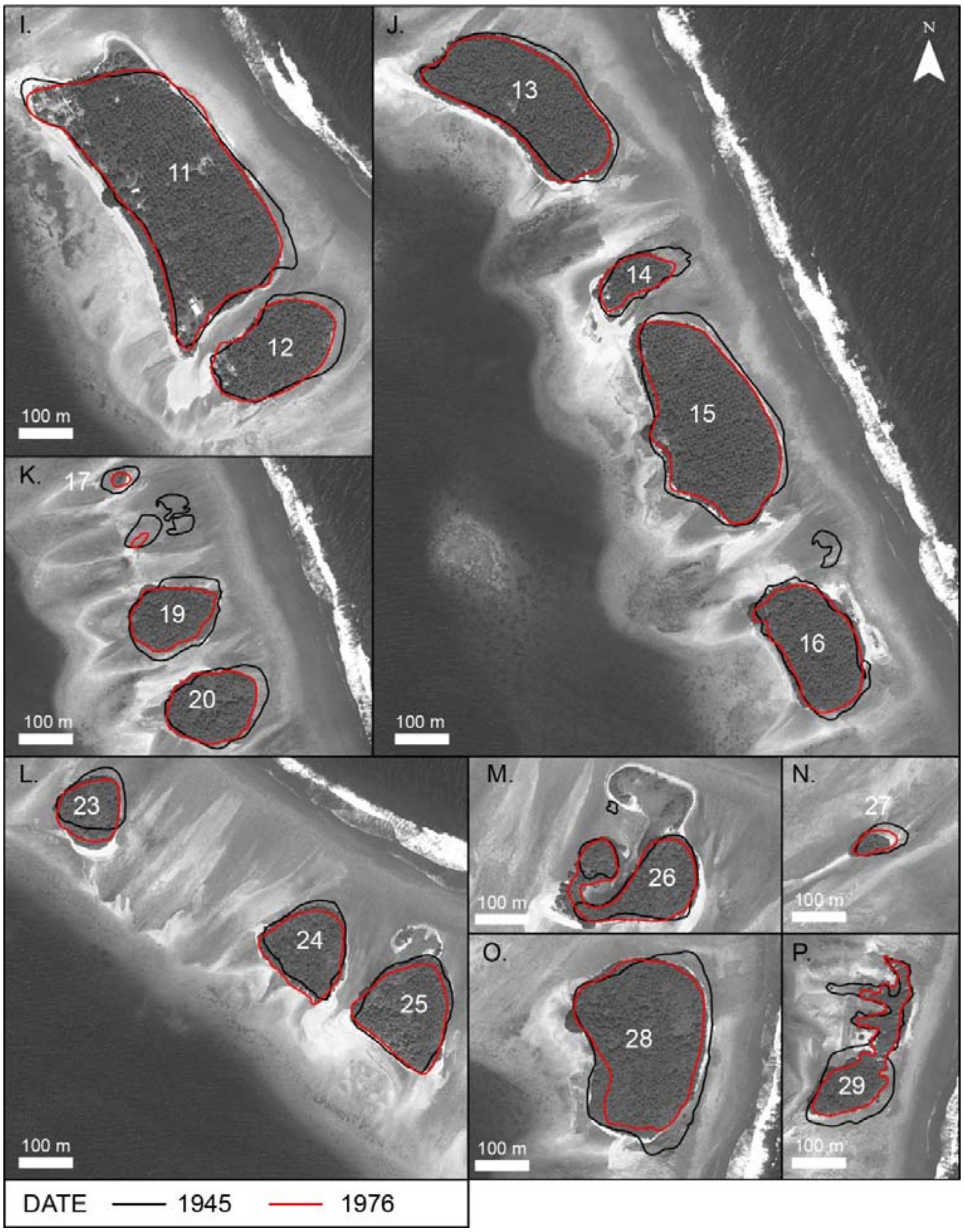
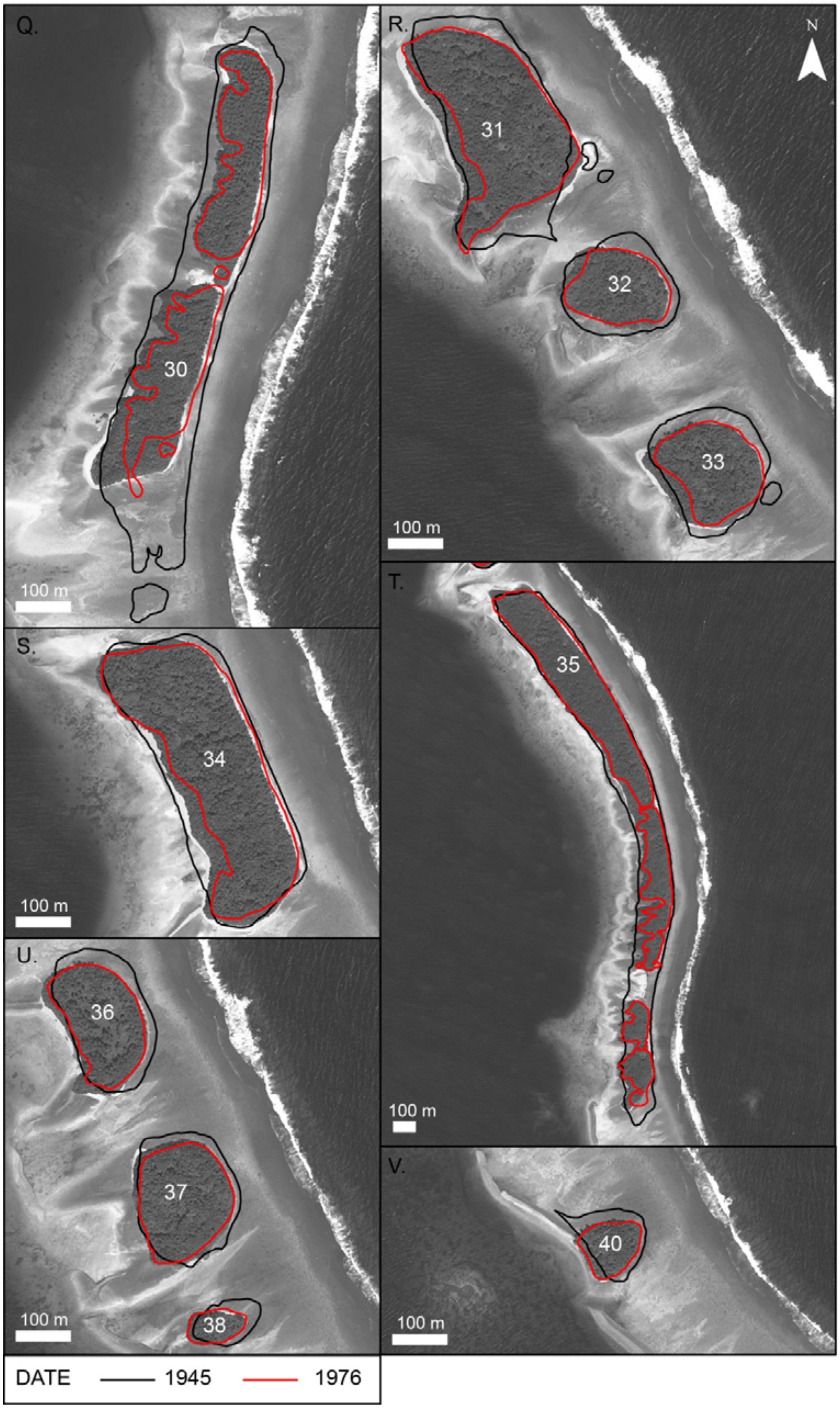


Figure DR3. Continued.



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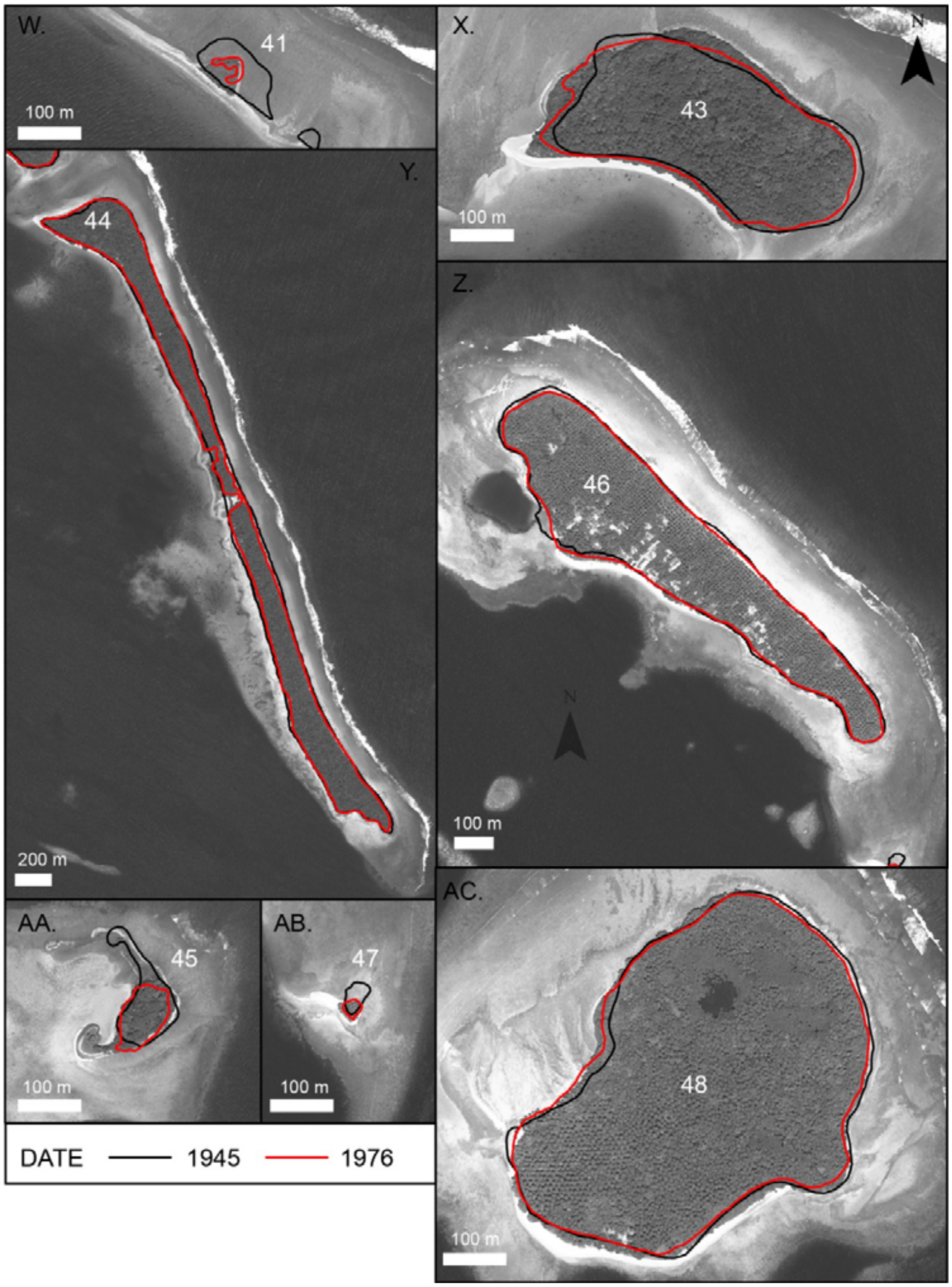

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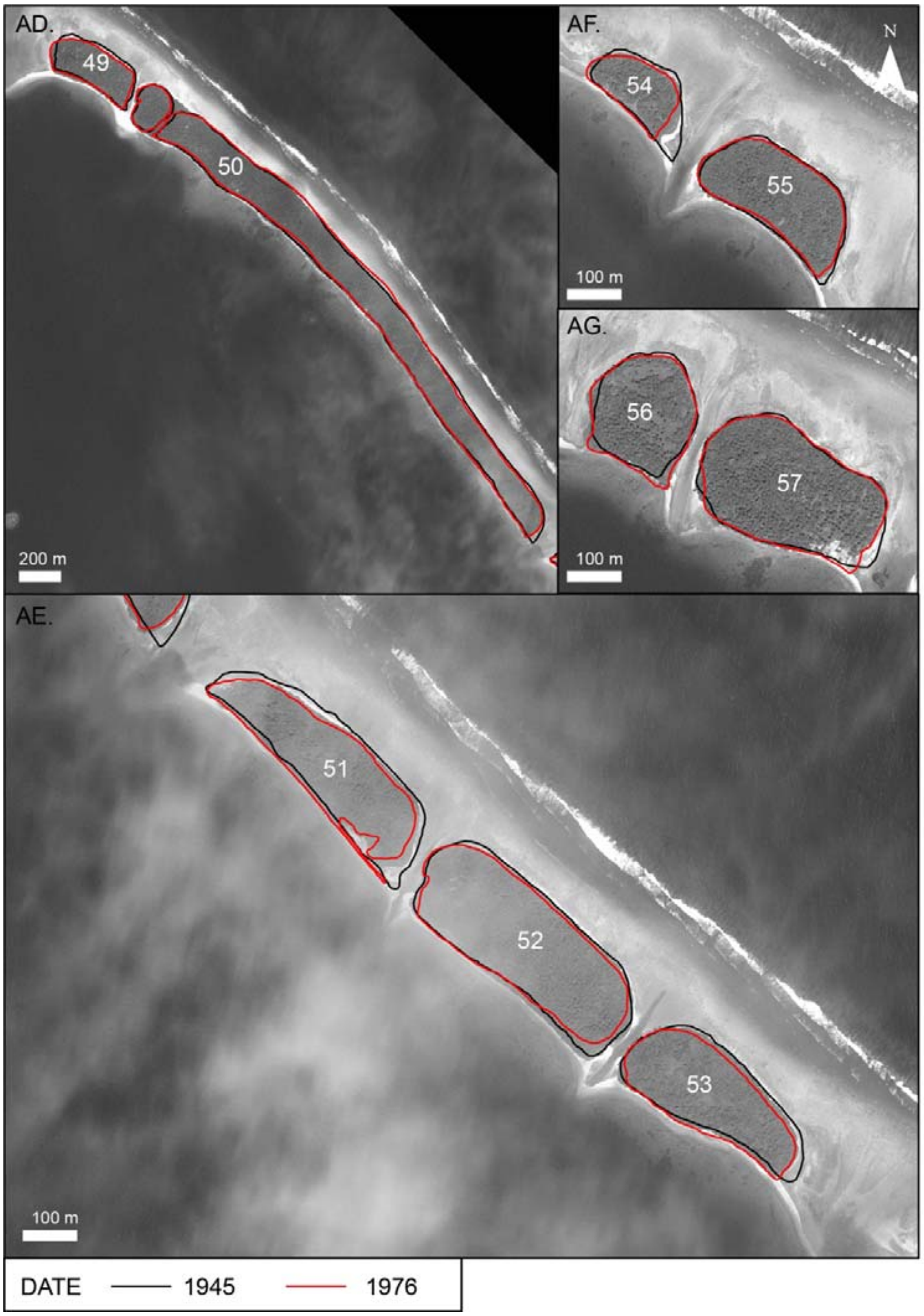

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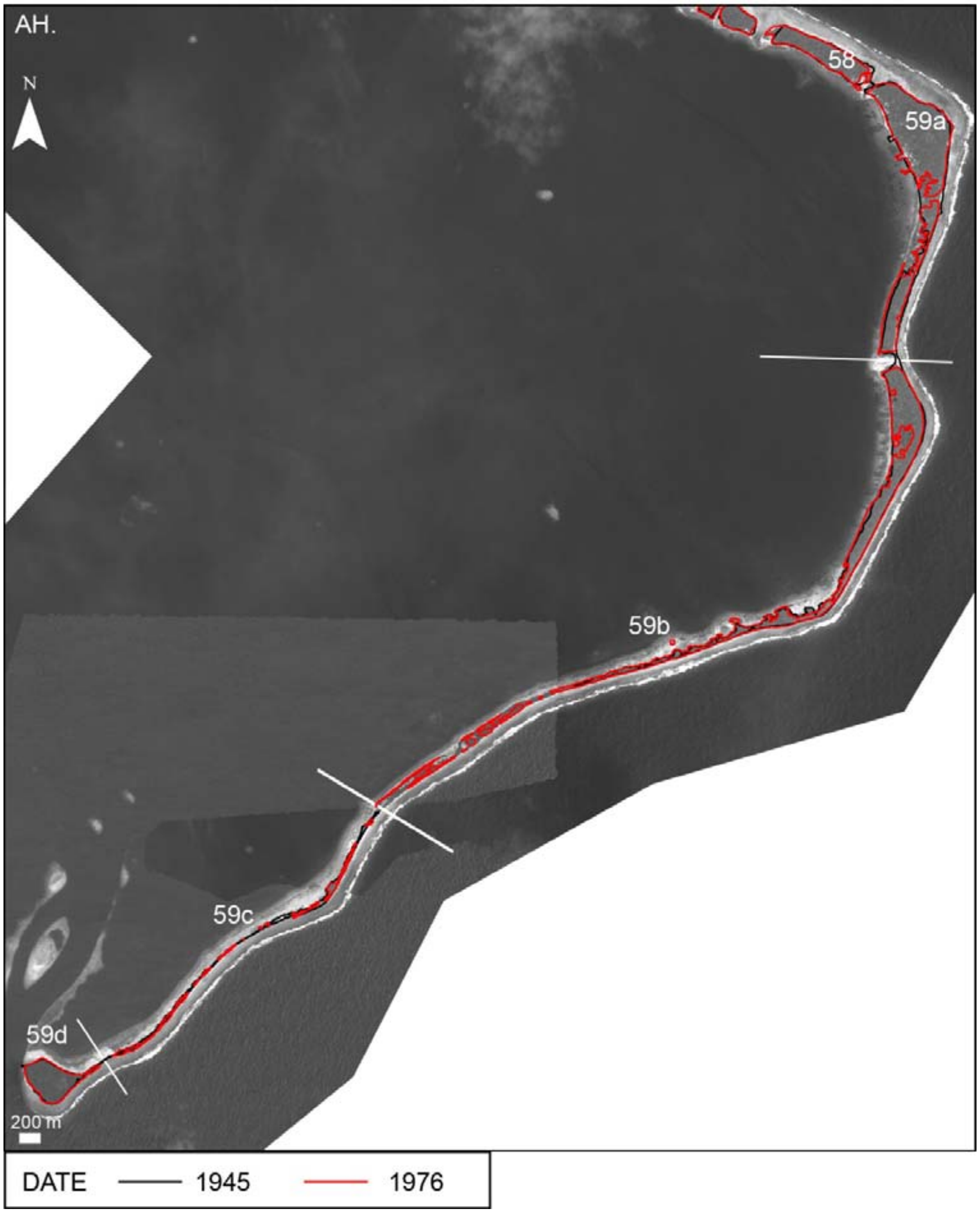

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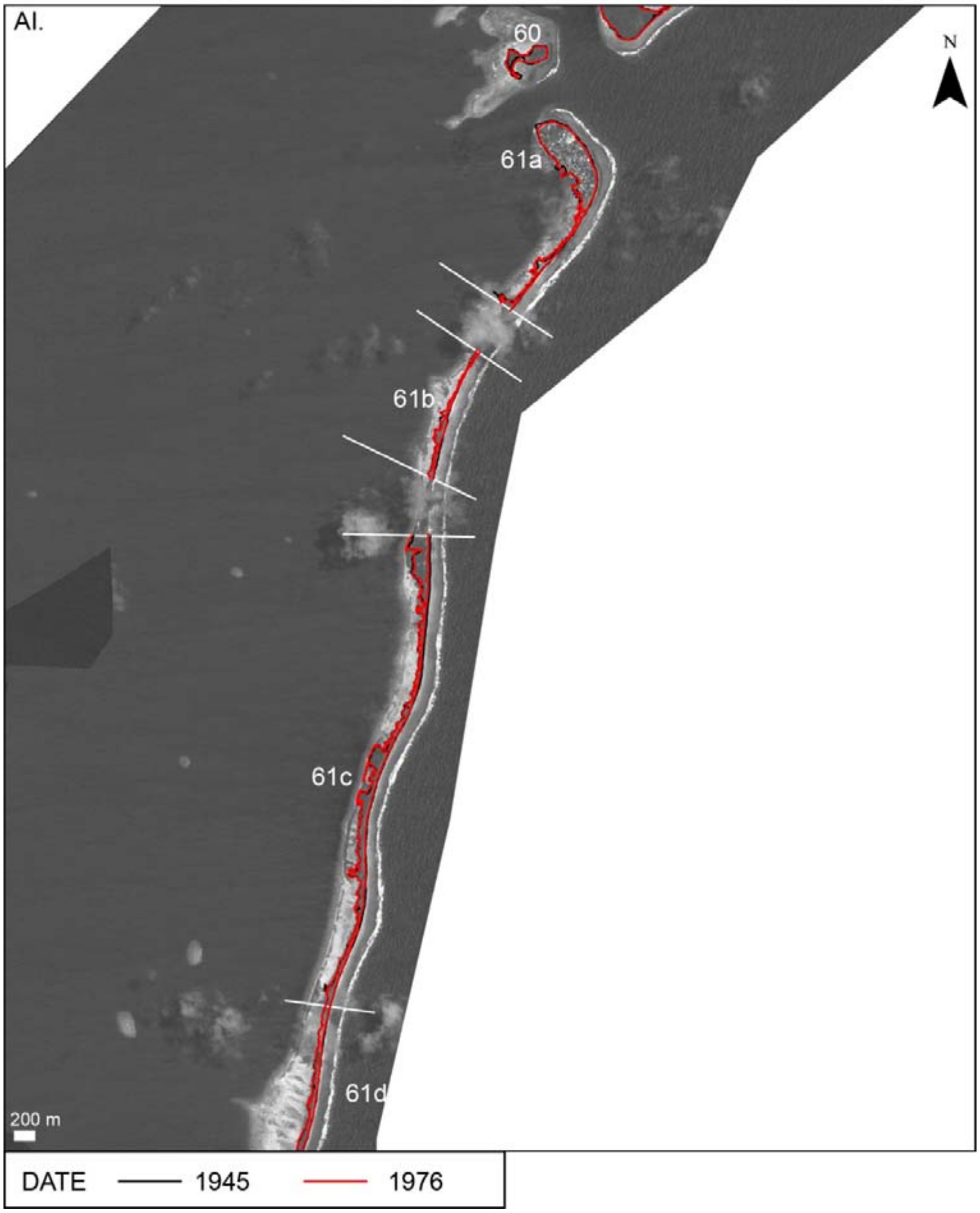

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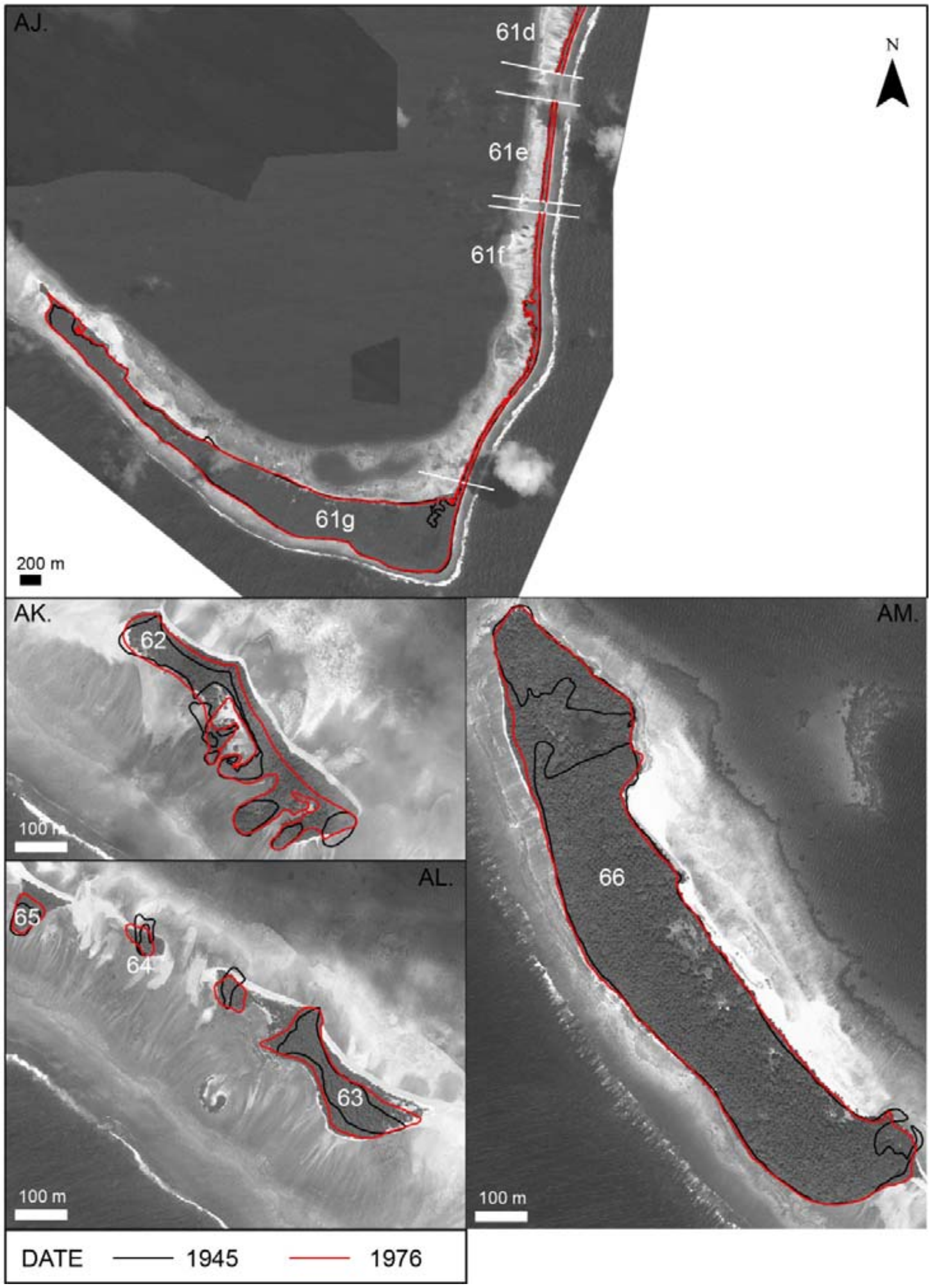

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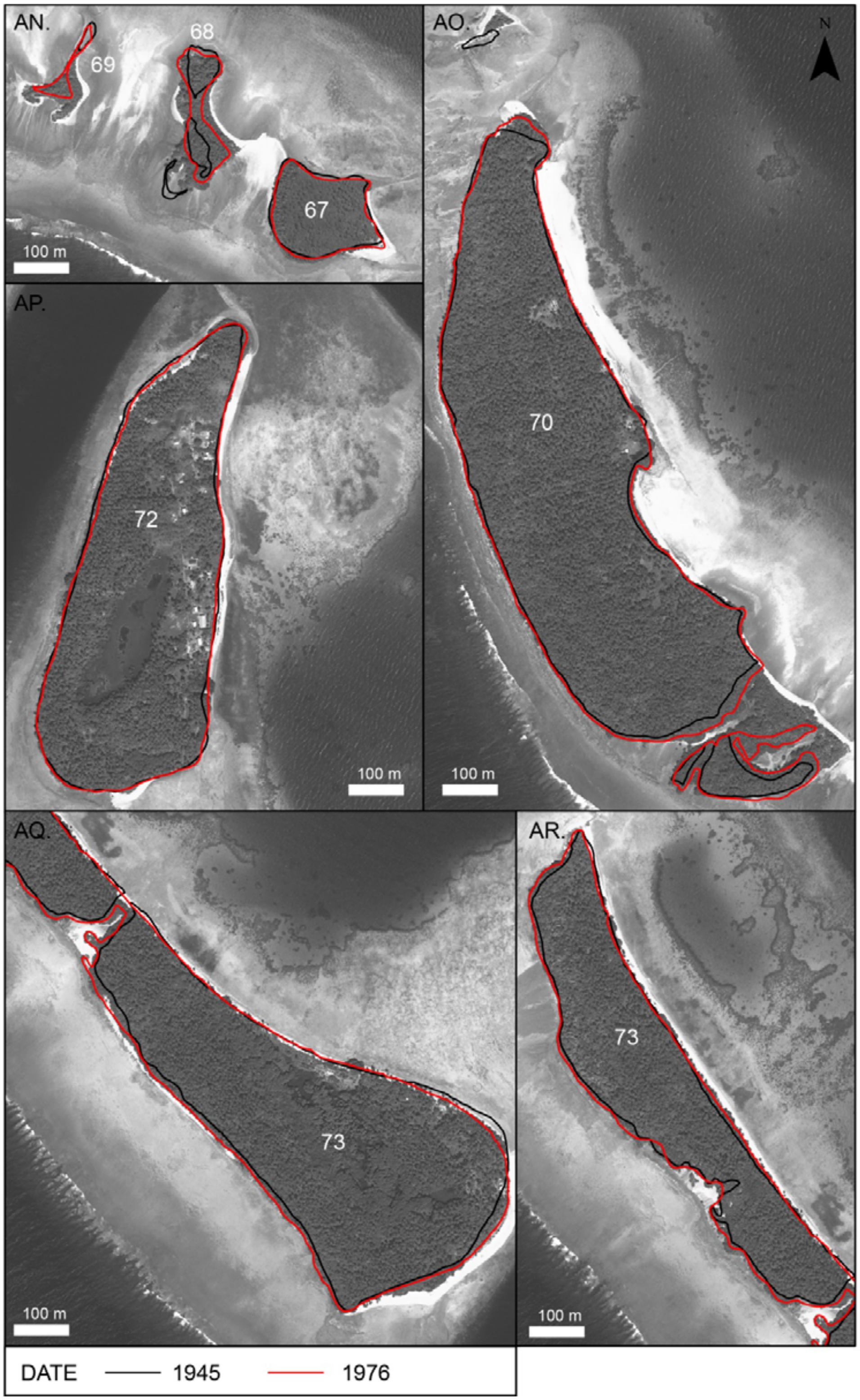

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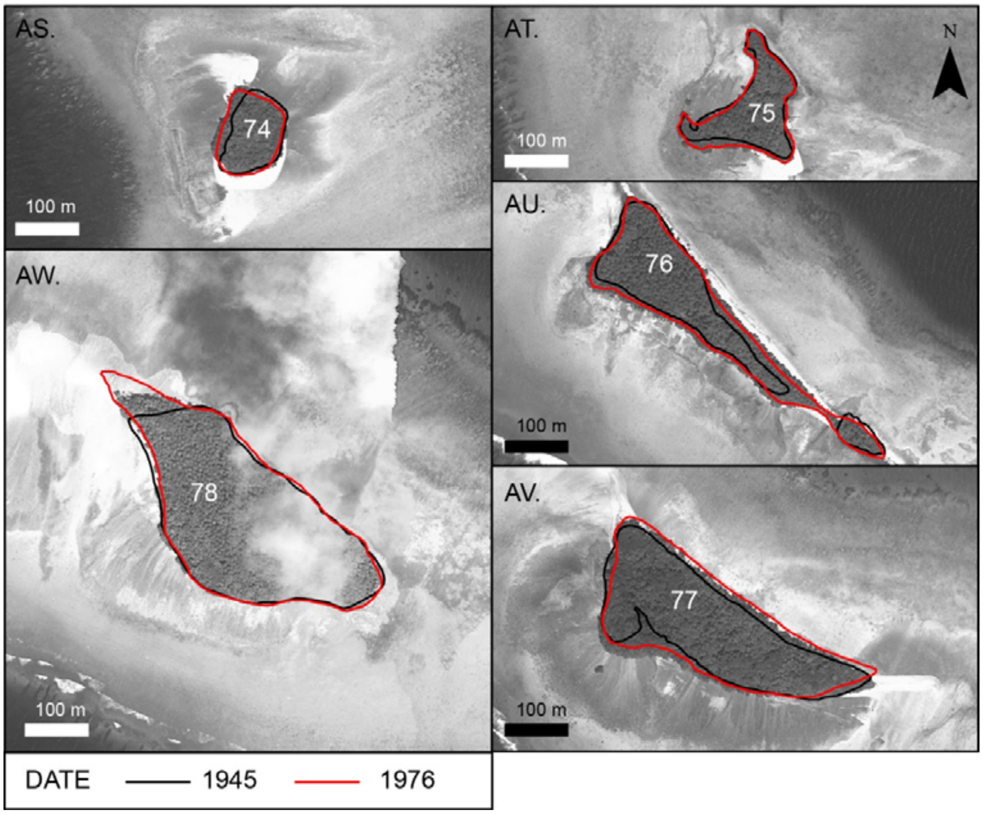

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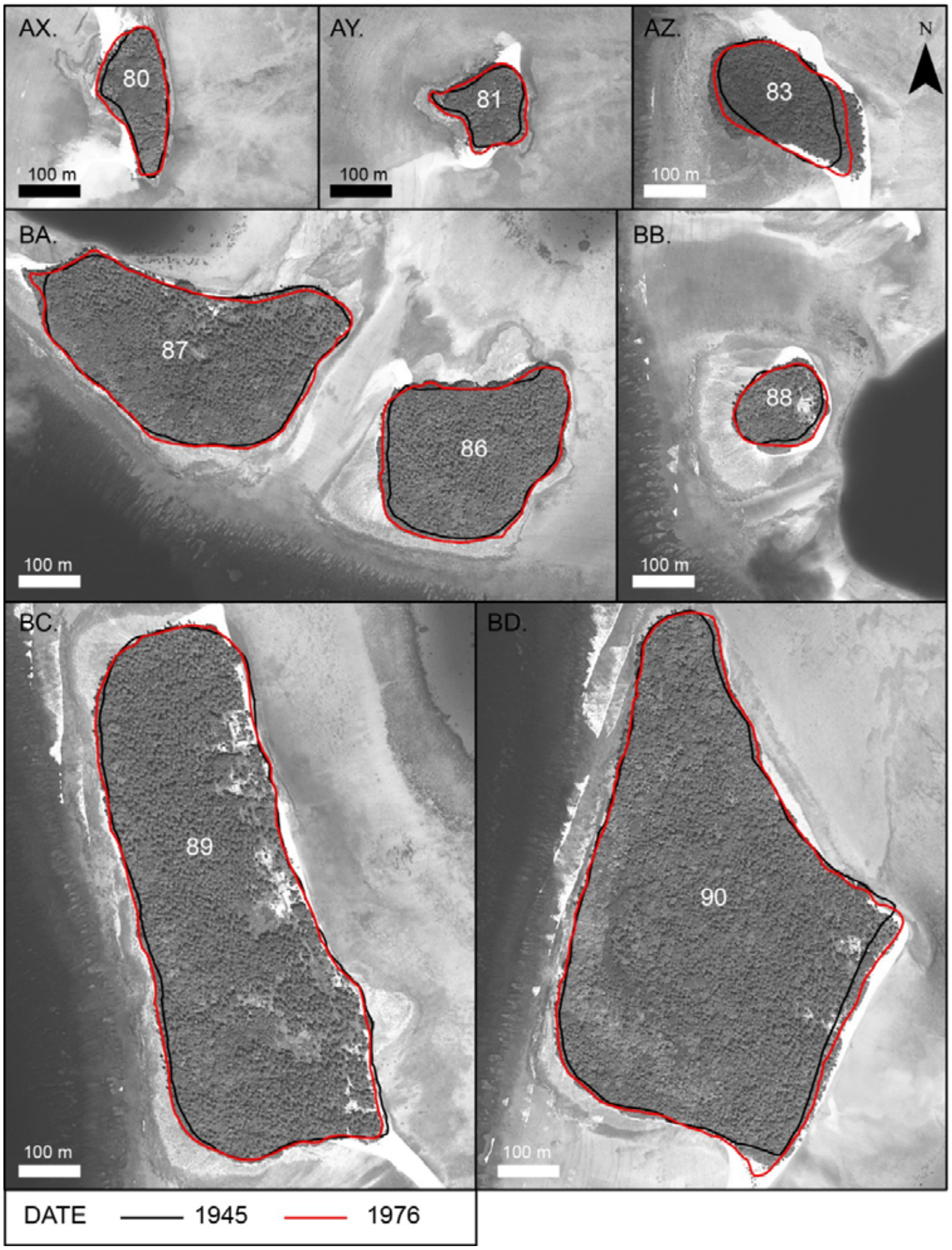

Figure DR3. Continued.

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