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# Assessing fine beam RADARSAT-1 backscatter from a white mangrove (*Laguncularia racemosa* (Gaertner)) canopy

John M. Kovacs[1,*], Casey V. Vandenberg[2] and Francisco Flores-Verdugo[3]
*[1]Department of Geography, Nipissing University, North Bay, Ontario, P1B 8L7, Canada; [2]Department of Geography, University of Lethbridge, Lethbridge, Alberta, T1K 3M4, Canada; [3]Instituto del Ciencias del Mar y Limnología, UNAM, 82000 Mazatlán, Sinaloa, Mexico; *Author for correspondence (e-mail: johnmk@nipissingu.ca; phone: +705-474-3461; fax: +705-474-1947)*

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**Abstract**

To determine whether spaceborne Synthetic Aperture Radar (SAR), specifically fine beam RADARSAT-1 C-band, could be used to provide quantitative data on white mangrove (*Laguncularia racemosa* (Gaertner)) forests, backscatter coefficients ($\sigma°$) were examined in relation to structural parameter data collected from plots located in a mangrove forest of the Mexican Pacific. Significant coefficients of determination were recorded between the backscatter coefficients and the logarithms of both Leaf Area Index (LAI) and mean stem height at two incident angles for both the dry and wet seasons. The highest coefficients of determination for LAI ($r^2 = 0.60$) and mean stem height ($r^2 = 0.72$) were observed using the shallower ($\sim$40°) and steeper ($\sim$47°) incident angles, respectively. No significant relationships were recorded between the backscatter coefficients and either stem density, basal area or mean DBH. Given the results of this investigation, it is recommended that for cloud covered regions, fine beam RADARSAT-1 data could be used by resource managers when they require a quick method for surveying structural damage to mangroves resulting from both natural and anthropogenic causes.

## Introduction

Numerous studies have been conducted in the use of remotely sensed data from satellites for monitoring mangrove forests but few have examined the use of these data for estimating quantitative measures of these forested wetlands (Green et al. 1998). Consequently, there has been a recent interest (Jensen et al. 1991; Ramsey and Jensen 1996; Green et al. 1997; Kovacs et al. 2004a) in determining whether these sensors can be used as a method for extracting mangrove forest biophysical parameters such as Leaf Area Index (LAI). The results of these investigations do suggest that, in conjunction with field data, these satellite sensors can provide sufficiently accurate estimations of many of these structural parameters. For example, Kovacs et al. (2005) recently mapped estimated mangrove LAI at the species level using a combination of very high resolution IKONOS data and *in situ* LAI collected with a LAI-2000 Plant Canopy Analyzer.

Although the results of the aforementioned remote sensing studies on mangroves are quite promising, the sensors they have examined are limited to optical (passive) satellite platforms. In many tropical and subtropical regions persistent cloud cover is the norm and thus the availability of useful optical data of many mangrove regions is quite limited. One alternative to optical data is Synthetic Aperture Radar (SAR). Unhampered by cloud cover, SAR imagery can also provide unique information on the surface targets based on the interaction with the active energy and the geometry and dielectric constants of the ground features imaged (Ulaby et al. 1986). Moreover, due to characteristic interactions of SAR with persistently flooded forests and relatively flat terrain, mangroves are considered ideal forest canopies for SAR investigations (Hess et al. 1990). As with other forested wetlands, the backscatter from SAR is enhanced due to the smooth water below which enhances scattering mechanisms within the forest components (e.g. stems, branches). Although limited in number, recent studies (Mougin et al. 1999; Proisy et al. 2000; Proisy et al. 2002) of a mangrove forest in French Guiana have shown the utility of airborne SAR for estimating structural parameters of mangrove forest. Their results, based on 12 sample stands, revealed significant correlations between radar backscatter coefficients and numerous stand parameters (e.g. basal area, stem density) at various SAR frequencies and polarizations, including C-band HH polarization.

The purpose of this investigation is to determine whether C-band HH polarization data, captured from a satellite platform (*RADARSAT-1 fine beam*), can provide similar success in estimating structural parameter data of mangrove forest. In comparison to airborne SAR, spaceborne SAR data may be more applicable for mangrove monitoring systems as the data are available on a repetitive basis and cover much larger areas. Unlike the previous SAR studies, this investigation will also focus on potential differences associated with multiple incident angles and multitemporal data (i.e. seasonal acquisitions). Although using standard beam RADARSAT-1 and focusing on non-mangrove forested wetlands, the results of Townsend (2002) suggest that the accuracy of the estimation of the mangrove biophysical parameters are likely to vary according to these two variables.

## Materials and methods

### *Study area*

The Agua Brava Lagoon is located along the Pacific Coast of Mexico within the State of Nayarit (Figure 1). This mangrove forest belongs to the much greater Teacapán–Agua Brava Lagoon–Estuarine System, which is considered one of the largest mangrove wetlands of the Pacific coast of the Americas (Flores-Verdugo et al. 1990). This system experiences sharp seasonal variation in precipitation, typical of the tropical sub-humid climatic zone, with distinct wet and dry seasons occurring in the months of June–October and November–May, respectively. Although considered a very important ecological reserve for numerous organisms (Flores-Verdugo et al. 1997) and an important local source of renewable products (Kovacs 1999), recent investigations (Flores-Verdugo et al. 1997; Kovacs 2000; Kovacs et al. 2001a, 2001b, 2004a, 2004b) have indicated that the system is experiencing considerable degradation, resulting primarily from anthropogenic causes. Consequently, a recent study of estimated mangrove LAI (Kovacs et al. 2005) has identified, based on state of degradation and species composition, four types of mangroves located within the Agua Brava Lagoon. These mangrove classes include dead white mangrove (*Laguncularia racemosa* (Gaertner)), poor condition white mangrove, healthy condition white mangrove and healthy red mangrove (*Rhizophora mangle* (L.)). The latter class, red mangrove, does not appear to be affected but is limited in distribution to the main edge of the Agua Brava Lagoon as well as along the numerous tidal channels that extend further inland.

### *Field data collection*

Fourteen circular plots (0.03 ha) were laid out in the Agua Brava Lagoon system during the month of May 2004. Within each plot, all trees of a DBH greater than or equal to 2.5 cm were measured and the central location recorded at a sub-meter accuracy using a differential post-processing GPS unit. The selection of the stands was chosen at random from homogeneous white mangrove areas that represented the three conditions that persist in

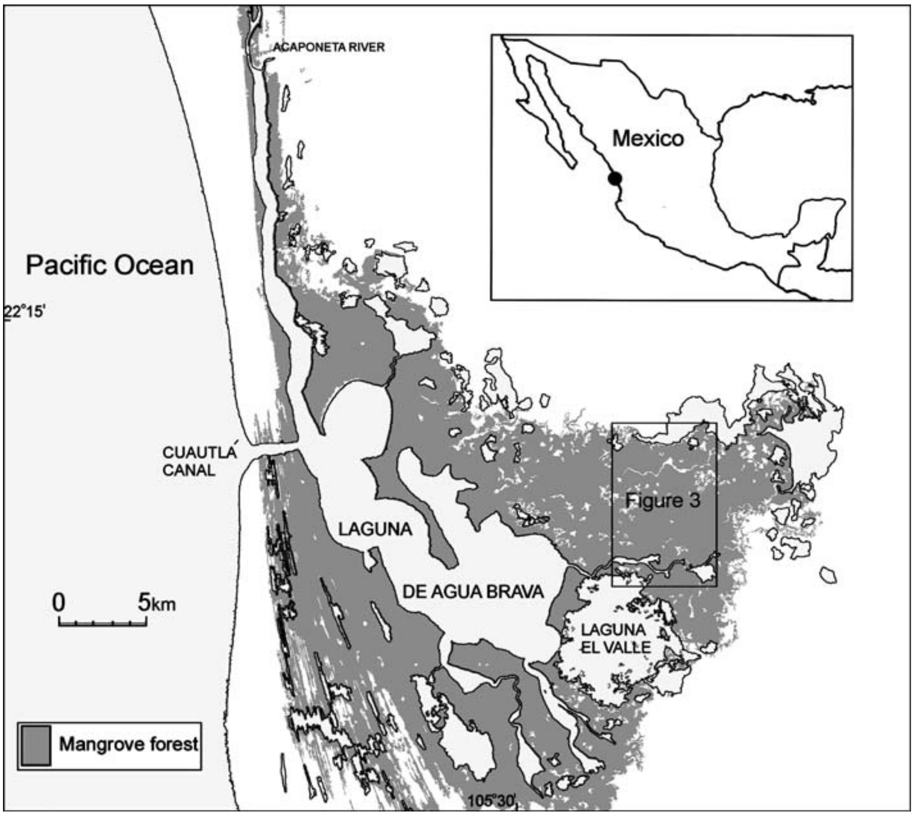


*Figure 1.* The Agua Brava Lagoon of the Mexican Pacific.

this basin mangrove forest (Kovacs et al. 2005). Specifically, four of the plots were laid out in poor condition white mangrove stands and seven of the plots in healthy condition sites. The remaining three plots were laid out in dead tree stands. All fourteen plots were located in areas where the substrate is completely saturated or flooded. An average stem height, an average DBH and both stem density and basal area was determined for each location (Table 1). In addition, to confirm the homogeneity of the locations, average tree heights and quick estimates of basal areas, calculated using a forest prism (BAF2), were determined at a 20 m distance from the centre of the plot in all four cardinal directions. Using the technique described by Kovacs et al. (2004a), estimated LAI maps for the two seasons, dry and wet, were then derived from an April 2004 and an October 2004 IKONOS scene, respectively. As a result, using the estimated LAI maps, an average LAI value was then determined for each plot, for both the dry and wet seasons.

*Remote sensing data acquisition & processing*

Two fine beam mode RADARSAT-1 (C-band) scenes of the study area, representing two incident angles, were acquired for both the dry and wet seasons. Specifically, the two band positions chosen, SAR F2Near and SAR F5Far, represent incident angles of approximately 40° and 47°, respectively. At present RADARSAT-1 fine beam has the highest spatial resolution for a SAR based satellite platform with a spatial resolution of approximately 8 m and a pixel spacing of 6.25 m. Meteorological records from an adjacent town were used to determine if any precipitation events occurred prior to or during the SAR acquisitions. For each scene, radar backscatter coefficients ($\sigma°$) were then recorded, in decibels, by using the original brightness values, the georeference segments, the orbital segments and arrays provided. All four of the scenes were then co-registered to a geometrically corrected 2004 IKONOS scene. Using the sub-meter GPS data collected, a series of

*Table 1.* Biophysical parameter data for the *Laguncularia racemosa* dominated plots.

| Plot # | Vegetated condition | Stem density (stems/ha) total (L.r/R.m.) | Basal area ($m^2$/ha) total (L.r/R.m.) | Mean DBH (cm) | Mean stem height (m) | LAI dry season | LAI wet season |
|---|---|---|---|---|---|---|---|
| 1 | dead | 3633 | 9.2 | 5.5 | 0.5 | 0.20 | 0.01 |
| 2 | | 4367 | 13.5 | 6.1 | 0.5 | 0.10 | 0.31 |
| 3 | | 4533 | 17.5 | 6.7 | 1.2 | 0.01 | 0.01 |
| 4 | poor | 4633 | 15.6 | 6.1 | 3.7 | 1.10 | 1.41 |
| 5 | | 5133 | 24.6 | 7.1 | 3.5 | 1.16 | 1.28 |
| 6 | | 7067 | 19.9 | 5.3 | 2.6 | 0.87 | 1.81 |
| 7 | | 2902 | 4.7 | 4.2 | 3.0 | 1.10 | 1.63 |
| 8 | healthy | 6833 | 24.3 | 6.1 | 2.5 | 2.00 | 3.36 |
| 9 | | 5133 | 19.5 | 6.2 | 3.0 | 2.57 | 3.95 |
| 10 | | 9767 | 29.5 | 5.7 | 5.5 | 2.02 | 3.44 |
| 11 | | 3712 (3666/46) | 16.0 (15.93/0.02) | 6.5 | 4.5 | 2.27 | 3.66 |
| 12 | | 3237 (3116/121) | 11.2 (10.93/0.29) | 6.0 | 7.0 | 2.78 | 4.12 |
| 13 | | 4282 (4068/214) | 11.1 (10.88/0.22) | 5.3 | 3.5 | 2.57 | 4.10 |
| 14 | | 4988 (4926/62) | 8.6 (8.54/0.05) | 4.2 | 4.5 | 2.38 | 4.06 |

L.r. = *Laguncularia racemosa* and R.m. = *Rhizophora mangle*.

masks, to approximate the area of sampling, were then created for each plot. Consequently, a mean backscatter coefficient, in decibels, was then derived from the pixels located under the masks. The masks were slightly larger than the actual plot areas but given the homogeneity of the areas, determined from the IKONOS maps and prism sweeps, this was deemed appropriate. The size of the masks was selected to reduce radiometric resolution errors originating from speckle for the homogeneous targets (Ulaby et al. 1986). Finally, simple linear regression techniques were employed to examine whether the radar backscatter coefficients could be used to predict any of the biophysical parameters.

## Results and discussion

Based on the linear coefficients of determination between the logarithm of the stand parameters and the mean RADARSAT-1 backscattering coefficient (Table 2), only two parameters, LAI and mean stem height, were identified as having a significant relationship ($p < 0.01$) for both incident angles and for both seasons. Specifically, lower mean backscatter coefficients were recorded from white mangrove plots having lower LAI and lower mean stem heights (Figure 2). It must be noted that although both of these parameters were identified separately as statistically significant they are interrelated with one another and thus should not be expected to respond separately or uniquely in relation to the total backscatter observed from each plot. Specifically, according to Table 1, LAI and mean stem height are highly correlated. However, given the characteristic properties of the radar wavelength selected (C-band), it is postulated that LAI plays the dominant role in the contribution of the observed backscatter. Specifically, it is commonly agreed (Leckie and Ranson 1998) that the primary contributor to backscatter

*Table 2.* Linear coefficients of determination ($r^2$) between the logarithm of structural parameters of white mangrove plots ($n$ = 14) and RADARSAT-1 fine beam backscattering coefficients (*dB*) at two incident angles (F2N = 40°; F5F = 47°). Boldface numbers represent significant relationships at $p < 0.01$.

| Parameter | Dry season | | Wet season | |
|---|---|---|---|---|
| | F2N | F5F | F2N | F5F |
| LAI | **0.60** | **0.56** | **0.48** | **0.45** |
| Mean stem height (m) | **0.68** | **0.55** | **0.61** | **0.72** |
| Stem density (stem/ha) | 0.04 | 0.16 | 0.10 | 0.05 |
| Basal area ($m^2$/ha) | 0.01 | 0.06 | 0.14 | 0.00 |
| Mean DBH (cm) | 0.06 | 0.02 | 0.01 | 0.13 |

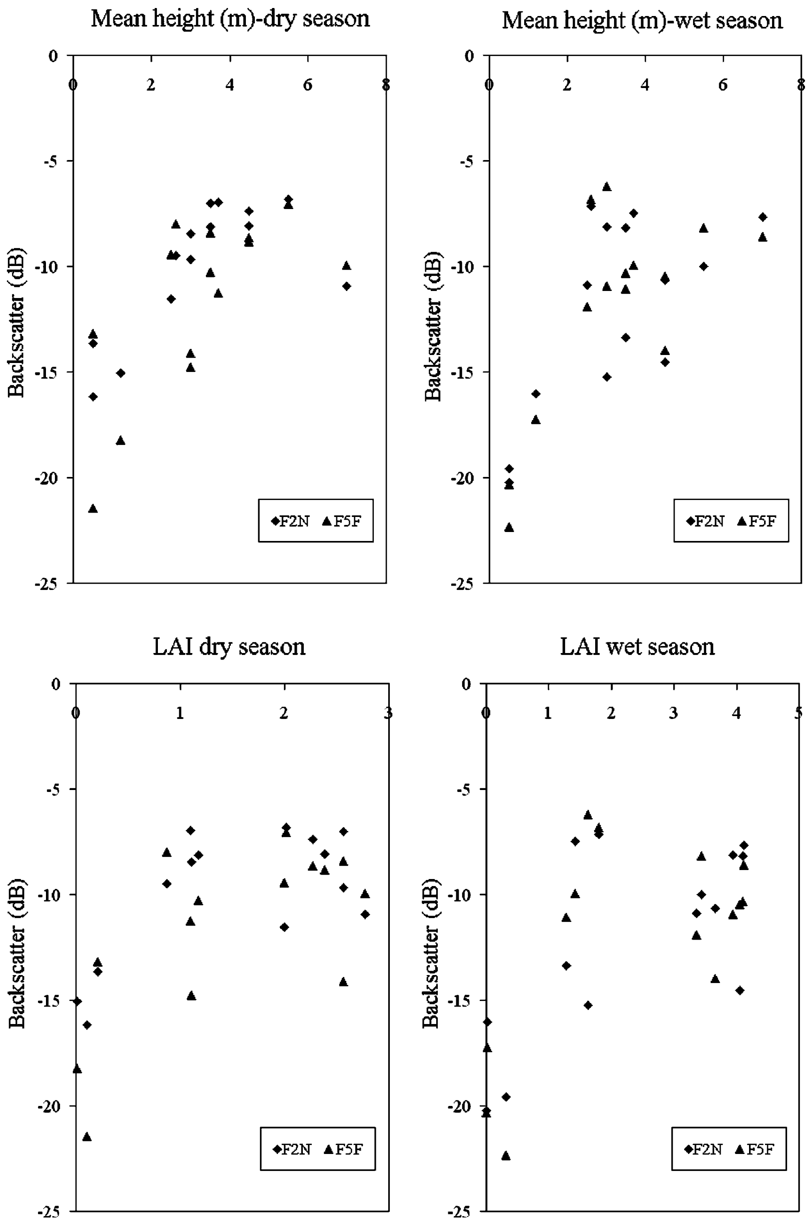


*Figure 2.* Fine beam RADARSAT-1 backscattering coefficients, at two incident angles (F2N = 40°; F5F = 47°), vs. Leaf Area Index (LAI) and mean stem height for 14 white mangrove plots located in a mangrove forest of the Mexican Pacific.

from forest canopies in the shorter wavelengths (e.g. K, X, C) is from the interactions with the leaves and smaller canopy elements (i.e. volume scattering). Consequently, little or no backscatter should be expected from dead mangrove areas (Figure 3) which contain few, if any, leaves (i.e. LAI $\sim$ 0), especially with the flooded regime of the mangroves which limits ground reflectance contributions. In contrast, the interactions of SAR with trunks and main branches are considered the main contributors of forest stand backscatter for the longer SAR wavelengths (e.g. L and P). As a result, for such SAR wavelengths, the backscatter coefficients from the dead areas, where trunks remain, should be significant. This would be especially true in these flooded forests where the

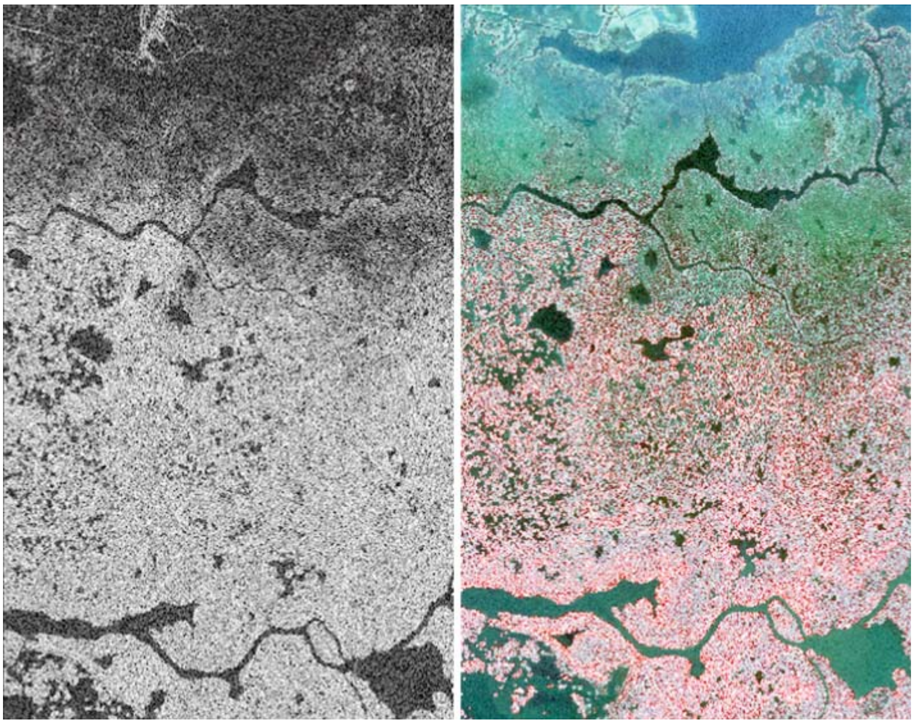

*Figure 3.* Comparison of RADARSAT-1 F5F backscatter from a white mangrove forest with an enhanced optical IKONOS data false colour composite (4, 3, 2). Note the large expanse of dead mangroves in the top portions of the images. Refer to Figure 1 for geographic position.

double-bounce effect would result from the interactions between the standing water and the trunks which act as dihedral corner reflectors.

Although LAI and the corresponding backscatter coefficients were deemed significant, the data plotted in Figure 2 indicate that the discrepancy between no leaf content (i.e. LAI $\sim$ 0) and some leaf content (i.e. low LAI) is more apparent than between low LAI and high LAI for the RADARSAT-1 data. This circumstance could explain the lower coefficients of determination recorded for the wet season data, when the range of the LAI increased dramatically. The limited ability to discern LAI values for the healthier mangroves may be due to saturation of the SAR signal occurring much earlier than that which might be expected from longer SAR wavelengths (Dwivedi et al. 1999). Specifically, shorter wavelengths are known to be constrained in their ability to penetrate closed forest canopies.

Unlike the previous work of others using airborne SAR (Mougin et al. 1999; Proisy et al. 2000; Proisy et al. 2002), the results of this study do not indicate significant relationships between SAR backscatter coefficients and other mangrove structural parameters. For example, in these studies, in addition to biomass, coefficients as high as 0.90 and 0.88 were recorded for basal area and mean DBH in relation to AIRSAR C-HH backscatter. The much higher spatial resolution of their SAR platform and, possibly, the greater range of the parameters recorded in their study plots may explain the discrepancy. For example, in this study, although the LAI varied considerably among the sample plots, this was not the case for the basal areas and stem densities (Table 1).

Enhanced backscatter from flooded areas is angle dependent and thus an important consideration for mangrove areas. However, with regards to the examination of two incident angles, the results of this study indicate that the use of the shallower incident angle (40°) only slightly improves the relationship between LAI and the corresponding backscatter coefficients. At the fine beam mode, RADARSAT-1 data selection is restricted to an incident angle range of approximately 38°–47°. At the standard beam mode, the range of incident angles available does improve

(24°–47°) but at the expense of a lower spatial resolution (25 m).

With regard to seasonality of the data, the coefficients of determination for LAI and SAR backscatter coefficients were greater for the dry season. LAI values for the plots did, however, vary quite dramatically as a result of the phenological changes associated with the white mangroves of this study area. In this investigation no precipitation events were recorded three days prior to or during the acquisition of the wet season imagery. Consequently, it was not possible to determine whether surface moisture, which increases the dielectric constant of the leaves, would have altered the relationship between LAI and the backscatter coefficients.

## Conclusion

The results of this investigation suggest that spaceborne SAR, specifically fine beam RADARSAT-1, can be used to some extent for extracting biophysical parameter data from mangrove forests. Specifically, in this investigation it was possible to discern dead white mangrove stands from healthy ones due to a significant relationship between LAI and corresponding RADARSAT-1 fine beam backscatter coefficients. The results also indicate that a steeper incident angle and the acquisition of SAR in the dry season may improve this relationship. Although the coefficients of determination were not as high as those determined by others using airborne SAR, the results of this study would suggest that RADARSAT-1 could be used as an alternative method for monitoring mangrove forests, particularly for regular surveys of mangrove damage incurred by major disturbances (e.g. hurricanes, pollution). The use of spaceborne SAR imagery can provide resource managers with quick synoptic assessments of large areas of mangrove at a known schedule and for regions where persistent cloud cover is the norm.

Based on the results of this investigation, it is recommended that further studies with RADARSAT-1 data be conducted for other white mangrove areas, particularly those with structural parameters that vary considerable from this study area. Moreover, it is suggested that investigations of these data for other mangrove species be considered. Given the outcome of this study, it is anticipated that with the planned launch of RADARSAT-2 the extraction of mangrove biophysical parameter data from spaceborne SAR will improve significantly. The launch of RADARSAT-2 will ensure the continuity of all existing RADARSAT-1 beam modes, which would allow for long term change detection studies. Moreover, RADARSAT-2 will provide new capabilities for improving mangrove forest structural parameter extraction including the addition of an ultra fine beam mode (3 m resolution) and quad-polarization.

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