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ACOUSTIC REMOTE-SENSING OF REEF BENTHOS IN BROWARD COUNTY, FLORIDA (USA)*

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ABSTRACT

Benthic assemblages of variable density cover three progressively deeper ridges that parallel the Broward County, Florida, coast. An acoustic bottom classification survey using QTCView5 with a 50 kHz transducer showed different acoustic classes on the shallow reef-ridge and the two deeper reef-lines, which both showed the same acoustic signature. Ground-truthing showed that the differences in acoustic signature corresponded to different benthic assemblages: nearshore hardgrounds had low live cover and were dominated by algae covering substrate, the two deeper reef-ridges had the same acoustic signature and similar benthic assemblages (dominated by sponges and gorgonians). The QTCView5 was also able to differentiate between stable sands covered by a thin red algae turf and more mobile sand without turf cover. Acoustic remote-sensing methods can be used to differentiate benthic assemblages, as long as enough differences exist in the growth-form characteristics of the dominant species to provide for a different acoustic roughness.

1.0 INTRODUCTION

Benthic assemblages of typical Caribbean reef fauna cover, with variable density, three ridges that parallel the Broward County, Florida, coast at about 5-10m, 10-20m and 20-30m depth. Two of these ridges are drowned early Holocene *Acropora palmata* reefs of 5ky and 7ky uncorrected radiocarbon age respectively (Lighty *et al*. 1978). In response to changes in environmental factors (hydrodynamic exposure, ambient light, etc) the characteristics of these benthic assemblages change. For this reason, we wanted to produce habitat maps that accurately describe the spatial arrangement of these benthic assemblages.

Although a number of habitat classification methods employing the use of satellites and aerial photography have been described for coral reef habitat mapping (Mumby *et al*., 1997), these methods yielded generally unreliable results in an area such as Broward County where the water is generally very turbid year round. An alternative classification method was chosen using a single beam acoustic QTC View V bottom classification system (Quester Tangent Co, Sidney, B.C.). The QTC system uses the characteristics of a waveform reflected from the seafloor to generate its' habitat classifications based on the diversity of acoustic responses of different

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benthic assemblages. Benthic communities with different growth forms will influence the shape of a returning echo, i.e. a smooth bottom, or flat growth form will return a first echo with a smooth shape while a rough, complicated bottom, or branching growth form will return a more convoluted echo shape. Different echo shapes can then be digitized and statistically compared and clustered into geo-referenced groups along a trackline to provide a functional habitat classification (Collins et al. 1996). Figure 1. shows a summary flow-chart of the principles of acoustic habitat classification used in this study.

The QTC View series has been shown to be a suitable classification system in coral reef systems, if an appropriate amount of ground-truthing is also carried out (Hamilton *et al*., 1999). In order to achieve the level of ground-truthing necessary to describe the habitat types of Broward County, traditional ecological survey methods were employed and their data were statistically analyzed and compared with the acoustic habitat data in order to determine if distinct ecological benthic assemblages corresponded with the habitat classes produced by acoustic methods.

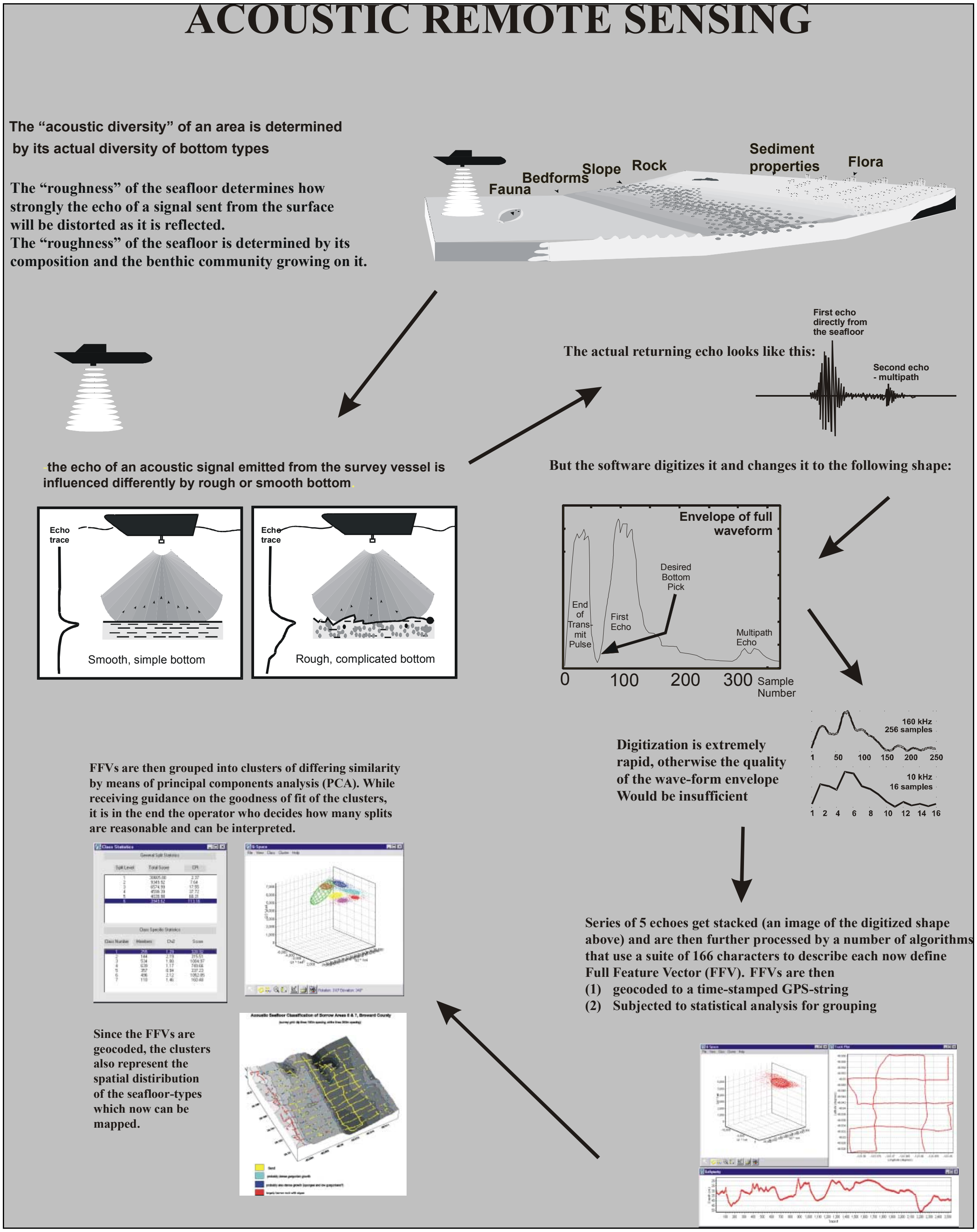
2.0 METHODS

2.1 ACOUSTIC DATA COLLECTION AND PROCESSING

An acoustic bottom classification survey was conducted for an area of 1.7 square Km off Pompano Beach, FL, using a QTCView 5 system based on a single-beam 50 kHz transducer (Suzuki ES-2025). The 50kHz transducer was mounted through the hull of a research vessel and connected to an on-board data-capturing and a data-processing computer. HYDAS (Quester Tangent Corporation, Sidney, Canada), a high-speed hydrographic survey data acquisition software was used to determine sample grids, grid spacing and to provide guidance to the helmsman. Sample grids were arranged along-strike for all three offshore reef structures (parallel to the coast) on a 25-m grid spacing. For quality-control purposes, a series of tie lines were run perpendicular to the coast-parallel sample grid. The data-points at intercepting survey-lines had to provide the same classification, otherwise the data set would be considered faulty and discarded. Vessel speed for the survey varied between 7 and 9 knots.

During the survey operation a continuous stream of NMEA encoded, WAAS augmented GPS data were time-stamped and collected in separate files from the independently time-stamped raw-acoustic data. Both time-stamping procedures were synchronized using the CPU clock of the same on-board computer. After the surveys, raw acoustic data were transformed into full feature vectors (FFV's) and then merged with the time-stamped geo-referencing data, resulting in one processed, geo-referenced signal per second. These processed signals were then stored in separate files for later statistical analysis.

Signal quality control consisted of checking for correct time-stamps, correct depths (all signals were displayed on a bathymetry plot, with outliers being removed by the operator) and correct signal strengths. All signals that did not pass the appropriate level of quality were discarded.



ACOUSTIC REMOTE SENSING

The “acoustic diversity” of an area is determined by its actual diversity of bottom types

The “roughness” of the seafloor determines how strongly the echo of a signal sent from the surface will be distorted as it is reflected.
The “roughness” of the seafloor is determined by its composition and the benthic community growing on it.

the echo of an acoustic signal emitted from the survey vessel is influenced differently by rough or smooth bottom

The actual returning echo looks like this:

But the software digitizes it and changes it to the following shape:

Digitization is extremely rapid, otherwise the quality of the wave-form envelope Would be insufficient

Series of 5 echoes get stacked (an image of the digitized shape above) and are then further processed by a number of algorithms that use a suite of 166 characters to describe each now define Full Feature Vector (FFV). FFVs are then
(1) geocoded to a time-stamped GPS-string
(2) Subjected to statistical analysis for grouping

FFVs are then grouped into clusters of differing similarity by means of principal components analysis (PCA). While receiving guidance on the goodness of fit of the clusters, it is in the end the operator who decides how many splits are reasonable and can be interpreted.

Since the FFVs are geocoded, the clusters also represent the spatial distribution of the seafloor-types which now can be mapped.

Figure 1: Flow chart depicting the principles of acoustic habitat classification using the QTC View System (after Collins *et al*. 1996).

After data collection, processing of raw acoustic signals into signal envelopes, FFV's and time stamping, the data were submitted to Principal Components Analysis (PCA) in order to obtain clusters of similar acoustic returns that could then be correlated to similarly obtained clusters of *in situ* ecological data (ground-truthing data). Seven iterations of clustering of the entire dataset were used before ideal cluster size was chosen. Ideal cluster size was considered such that allowed unequivocal identification of individual FFV's (i.e. the actual sampled area, the size of which is determined by the acoustic footprint of the sonar beam).

2.2 GROUND-TRUTHING AND ECOLOGICAL SURVEY METHODS

Ground-truthing of the acoustic data set was achieved by SCUBA divers using traditional transect methods, collecting *in situ* community data. Six point-intercept transects (Ohlhorst et al. 1988) of 50 meters length with 1m point spacing were taken per dive site. Sites were chosen on the basis of the ideal cluster split obtained from the acoustic data set, with at least one array of transects taken from each of the three reef ridges. Transects were arranged in the following pattern: 2 transects laid adjacent to each other with 5 meter spacing, 2 parallel transects spaced 5 meters from the original set, and 2 more parallel transects spaced 5 meters from the previous transects. For each sample site, 105 linear meters of reef were evaluated. Several reasons suggested measuring three parallel series of transects rather than stretching all transects along the exact interface of different habitat types: (1) irregular reef edges made exact transect placement at the exact edge difficult, many points fell in the sand and would tend to underestimate true cover or community structure, (2) the ecological edge of benthic communities frequently stretches over an ecotone several meters wide. The width of this zone varies with the mobility of the adjacent sand and needed to be taken into account.

Weighted tapes, 50m long and marked at meter intervals were used for each transect. At every meter marking, whatever was immediately underneath the meter mark was recorded. This could either be bare substratum, sand or any type of sessile benthic organism. The organisms were, when possible, identified to species. If unequivocal identification under water was not possible, a generic name was applied (i.e. "red algae turf", "erect yellow sponge").

Ecological data were then ordered into a presence/absence species matrix and analyzed for similarity of benthic assemblages using a non-metric multi-dimensional scaling (MDS) ordination (Kruskal and Wish, 1978). Additional calculations were made to determine percent cover and species dominance in each area as well. This data was then compared with the acoustic data to assess the accuracy of the acoustic habitat classifications. It should be noted that while PCA was the ordination method of choice for the FFV's, the different data structure of ecological data – non-normality and prevalence of zero-counts – suggested ordination by MDS.

3.0 RESULTS

Acoustic data showed different acoustic classes between the shallow, nearshore reef-ridge, and the two deeper reef-ridges, which both returned the same acoustic signature. Rubble beds inshore of the third, deepest reef-line showed a "mixed" acoustic signature. The QTC View 5 system was also able to differentiate between deeper, more stable sands covered by a thin red algae turf and shallow, more mobile sand with no algal cover. Figure 2 shows the survey area and resultant habitat classification derived from the acoustic data.

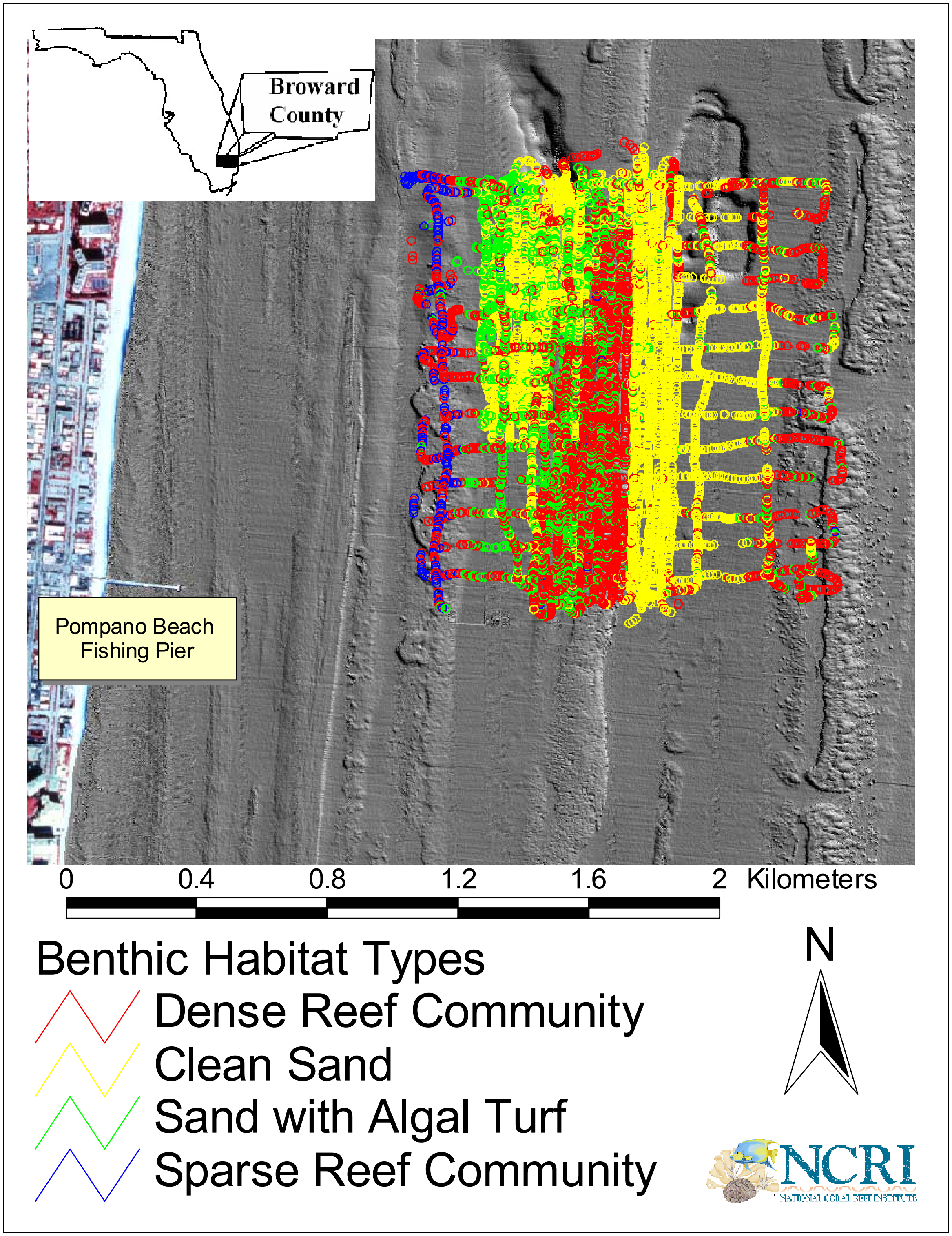


Figure 2: Acoustic habitat classification overlaid onto sun-shaded LADS bathymetry data.

Ground-truthing data showed that the differences in acoustic signature corresponded to different benthic assemblages: the nearshore reef-ridge had low live cover (10%) and were dominated by algae and hydrozoa, the two deeper reef-ridges both had intermediate live cover (25-50%), and were dominated by tall sponges and gorgonians. Subtle differences in species composition did exist between the two deepest reef-ridges, but since growth-form characteristics, and thus acoustic surface roughness characteristics were the same in both areas, no acoustic split was achieved. Figure 3 shows the benthic community composition, and representative photographs for each of the three reef-ridges.

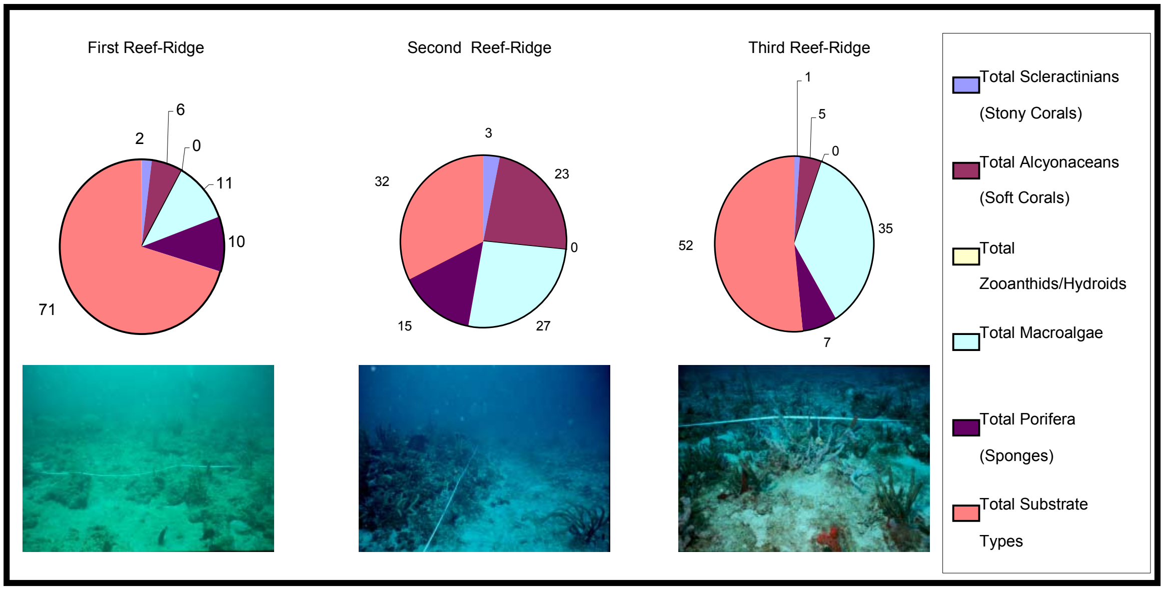


Figure 3: Benthic community composition derived from *in situ* data and representative photographs of each reef-ridge community (Photographs: S. Thornton)

4.0 DISCUSSION

Based on the comparison of acoustic habitat classification data to ground-truthing data, acoustic methods seem to be appropriate for our particular study area where turbidity prevents accurate classification using aerial photographs or satellite imagery. Acoustic and *in situ* data agreed well when a small number of habitat classes were chosen during the iterative process of principle component analysis. In this study, a maximum of seven acoustic splits (resulting in seven unique habitat types) were performed, however it was found that only four splits (resulting in four unique habitat types) gave the best representation of the actual spatial distribution of habitat types when compared with the *in situ* data. The habitat classification data also becomes much more meaningful when loaded into a GIS and combined with high-resolution bathymetry data such as LADS or LIDAR.

Since the growth forms characteristics of dominant species, and therefore, acoustic roughness were the same for the second and third reef-ridge communities, no acoustic split was shown between the two communities, even though subtle differences in species composition were found. This held true through all seven iterative splits of acoustic data. This indicates that at present, our acoustic habitat classification yields good results for broad-scale spatial patterns, but may not be able to detect subtle, small-scale differences in community structure or habitat type. This seems logical considering that fauna with similar growth forms, regardless of species or function within the ecosystem, will return similar acoustic roughness values. Future study hopes to provide a finer level of resolution within the acoustic data set, using not only acoustic roughness data from the first echo return, but also using acoustic hardness information contained within the second echo return.

We therefore conclude that acoustic remote-sensing methods can be used to differentiate benthic assemblages, as long as enough differences exist in the growth-form characteristics of the dominant species to provide for a different acoustic roughness.

5.0 ACKNOWLEDGEMENTS

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