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Wetland inventory, survey and assessment

DELINEATION OF INUNDATED AREA AND VEGETATION IN WETLANDS WITH SYNTHETIC APERTURE RADAR

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ABSTRACT

Hydrological, ecological, and biogeochemical studies of wetlands require measurements of extent and residence time of water and of vegetative cover and its phenology. Remote sensing with synthetic aperture radar (SAR) provides an alternative to difficult ground sampling of wetlands. SARs are active sensors operating in the microwave region, and offer a synoptic view of wetland inundation and vegetative structure, independent of cloud cover or solar illumination. Double-bounce reflections between trunks or stems and underlying water surfaces cause bright responses from flooded vegetation. The response varies with radar wavelength. We have accurately delineated floodplain inundation and vegetation in wetlands using multi-frequency SAR data. A decision tree model was used to formulate rules for a supervised classification into five categories: water, clearing, aquatic macrophyte, non-flooded forest, and flooded forest. SAR data for the Magela Creek region, northern Australia, were acquired with NASA's airborne SAR in September 1993 and with the Shuttle Imaging Radar-C instrument in April and October 1994. Video imagery was obtained concurrently from low-flying helicopter. We are in the initial stages of analysing these data, and present initial results as a further example of the application of SAR to the study of wetlands.

Keywords: synthetic aperture radar, microwave, remote sensing, SIR-C, AIRSAR, wetlands, floodplains, inundation, flooding.

1 Introduction

Wetlands play a critical role in maintaining and improving water quality, mitigating floods, recharging aquifers, and providing habitat for fish and wildlife. Deforestation in surrounding watersheds, and impoundments by dams, levees, and dykes, alter sediment loads and flooding regimes; channel, beach, or delta erosion, with accompanying degradation of water quality and ecosystem functioning, may result (Petts 1984). Wetland hydrology controls the source, amount, and spatial and temporal distribution of sediment and nutrient inputs, and influences distribution of flora and fauna. The ability of wetlands to maintain or improve water quality thus depends to a large extent on their hydrology (Johnston 1991). Mitsch and Gosselink (1986) state that 'Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes.'

Unfortunately, for many wetland systems our hydrologic understanding is limited to stream channels and immediately adjacent areas. Ground mapping of inundation is impractical for many wetlands due to difficulty of access. Channel gauge readings and local precipitation can be used to predict spatial distribution of flooding, but only for relatively small or simple systems. For rivers with complex floodplain topography, for inaccessible, extensive wetlands, and for regional studies in areas with a high density of small wetlands, remote sensing is the only practical method to obtain a synoptic view of wetland inundation. Colour infrared aerial photography, and visible and infrared satellite imagery such as from the Landsat thematic mapper, have been widely used for this purpose (Melack et al 1994). Because forest canopies, and in many cases aquatic macrophyte canopies, obscure underlying floodwaters, the use of visible or near-infrared remote sensing is severely constrained; these techniques are useful only for fairly open canopies and under cloud-free conditions.

Remote sensing with synthetic aperture radar (SAR) provides an alternative to ground measurement for detecting flooding beneath a vegetation canopy. SAR sensors can provide a synoptic view of inundation and of vegetation structure over large areas, unaffected by cloud cover or time of day. Although the ability of SAR to detect floodplain inundation has been known for over 20 years (Hess et al 1990), implementation of this ability has been limited by lack of consistent, readily available radar data.

Over the past four years, we have developed a technique for accurately classifying digital radar images into basic vegetative-hydrologic classes using SAR data obtained for the lower Altamaha River floodplain, Georgia, by the Jet Propulsion Laboratory's airborne imaging SAR (AIRSAR) (Hess & Melack 1994) and for the central Amazon as part of NASA's Shuttle Imaging Radar-C program (Way & Smith 1991, Hess et al in press). With the recent advent of commercial SAR satellites (Europe's ERS-1 (C-band, VV polarisation, launched 1991); ERS-2 launched April 1995; Canada's RADARSAT (C-band, HH polarisation, planned for launch in 1995); and Japan's JERS-1 (L-band, HH polarisation, launched 1992)), SAR monitoring of floodplain inundation has become feasible. However, there is little awareness of this technique on the part of researchers and managers outside the remote sensing community.

Our purpose here is two-fold: first we review basic SAR concepts and terminology including (1) the characteristics of SAR systems and (2) the mechanisms by which microwave energy is scattered by water, soil, and vegetation; second, we present an example of SAR-based classification of vegetation and flooding in wetlands of the southeastern United States and discuss its application to wetlands of northern Australia.

2.1 SAR system characteristics

Synthetic aperture radars are active sensors operating in the microwave region (roughly 1 mm to 1 m in wavelength), and may be mounted on aircraft, space shuttle, or satellite platforms. The radar antenna alternately transmits and receives short pulses oriented normal to the flight direction of the platform, imaging a continuous strip of terrain parallel to the flight track. The transmitted pulse travels to the surface, where it is reflected, scattered, and/or absorbed, depending on the surface characteristics; the intensity and timing of the energy scattered back toward the sensor (*backscattering*) are recorded. The location of features in the *range* (across-track) direction is determined by the time lag between transmitted and received pulses. In order to achieve good *azimuth* (along-track) resolution, *synthetic* aperture radars use Doppler frequency shifts resulting from the forward motion of the platform to 'synthesise' a narrow beam width. If an absolute calibration is performed on an image, the brightness of an object corresponds to its *radar cross-section*, σ (m^2), which is the area of a perfectly reflecting target that would yield a return equal to the power received by the radar. For distributed targets such as vegetation or soil, σ is divided by the illuminated ground area to yield the unitless *radar backscattering coefficient*, $\sigma°$. Because of the large dynamic range of SAR systems, $\sigma°$ is normally expressed in decibels ($\sigma°_{db} = 10 \log \sigma°$). The signal detected by SAR is the coherent sum of signals from randomly distributed scatterers within an image pixel. Random constructive and destructive interference in the addition of these signals causes variability in $\sigma°$ among pixels, even for homogenous targets. The resulting salt-and-pepper appearance, called *speckle*, poses problems in digital classification due to the high within-class variance of targets. Speckle is reduced during signal processing by multiple-look summing and can be further reduced during image processing by median or other filters.

Three radar system parameters affect the returns from a particular scene: incidence angle, wavelength, and polarisation. Because target scattering responses vary with all three parameters, multi-frequency, multi-polarisation, multi-incidence angle SAR datasets provide a rich source of information for image interpretation. Wavelength bands commonly used by SAR systems are shown in table 1. Note that the wavelengths, ranging from a few centimetres to a metre, are of the same order of magnitude as leaf widths, branch diameters, and trunk diameters for most vegetation canopies. Radars transmit and receive plane-polarised waveforms, oriented either horizontally or vertically. *Polarimetric* SARs record both amplitude and relative phase for all polarisation configurations of the transmitting and receiving antennas, and allow calculation of the *phase difference* between HH and VV polarisations, expressed in degrees.

Table 1a Microwave bands commonly used by radar

Band	Wavelength (cm)	Frequency (GHz)
X	2.4 - 3.8	12.5 - 8.0
C	3.8 - 7.5	8.0 - 4.0
S	7.5 - 15.0	4.0 - 2.0
L	15.0 - 30.0	2.0 - 1.0
P	30.0 - 100.0	1.0 - 0.3

Source: Sabins (1987)

Table 1b Radar polarisations

HH	Horizontal send, horizontal receive
VV	Vertical send, vertical receive
HV	Horizontal send, vertical receive

2.2 Microwave interaction with water, soil, and vegetation

Because SAR wavelengths are very long compared to atmospheric constituents, they are not significantly scattered or absorbed by the atmosphere as are visible and infrared wavelengths. The longer SAR wavelengths (L- and P-bands) are virtually unaffected by clouds or rain, while the shorter wavelengths can penetrate all but the densest clouds (C- and X-bands) and rain (C-band). Scattering from most earth surfaces usually involves a combination of surface scattering, where the medium encountered by the radar wave is homogeneous or nearly so (eg a water surface, and to a first approximation, a soil surface), and volume scattering, where the medium is inhomogeneous (eg a vegetation canopy). For surface scattering, the roughness of the surface determines the angular radiation pattern of the scattered wave, while the relative complex dielectric constant of the surface determines the strength of the scattered wave (Ulaby et al 1981). The smoother the surface relative to the radar wavelength, the greater the coherent specular component reflected away from the radar. The rougher the surface relative to the wavelength, the greater the diffuse component backscattered to the radar. The *dielectric constant* of a material is a measure of how absorptive or reflective it will be of an incident wave; for most natural surfaces, dielectric constant is a function of water content. Because of the high dielectric constant of liquid water, moist soils, for example, are more reflective than dry soils. In volume scattering, the density and dielectric constant of scatterers within the volume, such as leaves and branches within a forest canopy, determine the scattering strength, and the angular scattering pattern is a function of the boundary surface roughness, the average dielectric constant of the medium, and the sizes of the scattering objects in the volume (Ulaby et al 1981). Two smooth surfaces oriented perpendicular to one another, such as a paved surface and a building, constitute a *corner reflector*: the specular reflection from the first surface is directed back toward the radar by the second surface, causing a strong return. These *double bounce* returns are the mechanism for enhanced backscattering from flooded forest or marsh. Specular reflections from the smooth, highly reflective water surface are bounced back toward the radar by vertically oriented trunks, branches or stalks. In addition to increased magnitude, double-bounce returns show a distinctive HH-VV phase difference averaging 180°. Double-bounce reflections also occur in unflooded situations, but returns are much weaker because scattering off an unflooded soil surface has a much greater diffuse than specular component, and is less reflective because of its lower dielectric constant. Obviously, trunk-ground or canopy-ground double-bounce returns can occur only when the radar penetrates the canopy to reach the ground; extinction of the radar signal by absorption and scattering within the canopy volume can prevent this if the canopy layer is sufficiently dense or deep.

3.1 Mapping of vegetation and inundation in Georgia wetlands

Here we describe work carried out at the Altamaha River site using spaceborne and airborne SAR datasets (Hess 1993, Hess & Melack 1994, Hess et al 1994). The Shuttle Imaging Radar-B (SIR-B) was an L-band, HH SAR deployed aboard the Space Shuttle Challenger on an eight-day mission in October 1984 (Ford et al 1986). SIR-B data was obtained at incidence angles of 18°, 45°, and 58° over the lower Altamaha River floodplain. Previous studies of enhanced radar backscattering from flooded forests (reviewed by Hess et al 1990) had not included quantitative data on forest stand structure (making it difficult to extrapolate the results to other sites), had not considered cases where flooding is patchy rather than continuous, and had reached conflicting conclusions regarding the dependence of enhancement on incidence angle; these issues were therefore addressed using the multi-angle dataset (Hess 1993). Nine wetland forest stands were characterised by tree species, height, diameter at breast height (dbh), and density (stems per hectare); degree of flooding was estimated by ground surveying.

Using the multi-angle dataset, separability of five cover types was evaluated: flooded forest, partly flooded forest, pine forest (unflooded), marsh and water. These cover types were easily distinguished using a maximum likelihood classifier, with the exception of pine forest and marsh, whose multi-angle signatures overlapped significantly at LHH. The importance of incidence angle was supported by the finding that dry (pine) forest could be distinguished from flooded and partly flooded forest at 18° and 45° but not at 58°. For the wetland forest stands, densities (including trees with dbh ≥ 2.5 cm) ranged from 625 to 6944 stems per hectare; mean stand dbh range was 8 to 32 cm, and mean stand height ranged from 8 to 22 m. Kendall rank-correlation coefficient was used to test whether stem density and relative percent inundation were correlated with mean SIR-B brightness value. While no significant relationship was found for stem density, percent inundation was found to be strongly correlated with SIR-B returns ($K = 0.97, 1.00, 0.87$ for 18°, 45° and 58°). Thus the degree of inundation dominated the LHH backscattering, overriding the effect of forest structural variables such as stand density.

In order to realise the potential for operational mapping of inundation, robust digital classification methods are needed which do not require repeated optimisation by scene or date. Using multi-frequency polarimetric AIRSAR data for the Altamaha site, we have developed a classifier to distinguish five basic vegetative-hydrologic categories: woody flooded (flooded forest), woody non-flooded (upland forest), herbaceous flooded (marsh), herbaceous or bare non-flooded (clearcut, pasture, road), and open water (river, pond, ocean). To be widely applicable in both the space and time domains, a classifier should be as insensitive as possible to calibration error and to variability in radar returns caused by within-category differences in vegetation community structure, phenologic state, and dielectric constant. We are therefore using a rules-based approach (Wharton 1989) rather than a parametric classifier such as maximum likelihood, and are employing a tree-based model (Clark & Pregibon 1992) to develop classification rules. The tree model constructs a binary classification tree by recursively partitioning the training data into increasingly homogeneous subsets; decision nodes of the tree are the basis of the multi-stage, rules-based classifier.

The thirteen variables input to the tree model were the backscattering coefficient (σ°, in dB) at HH, VV, and HV polarisations for the three AIRSAR wavelengths (P-, L- and C-bands); the HH-VV phase difference (PD) at each band; and the incidence angle. Between 1650 and 2600 training pixels were used for each vegetative-hydrologic category. The classification tree produced by the model is simple (12 terminal nodes) and uses seven of the input variables: σ°_{PHH}, σ°_{CHV}, σ°_{LHH}, σ°_{CHH}, σ°_{PVV}, LPD, and incidence angle. Use of three bands, three polarisations, and phase difference by the classifier indicates that unique information is provided by the three wavelengths and polarisations. For the training data, pixels classified correctly by the tree ranged from 94% for swamp to 99% for open water; 97% of all training pixels were classified correctly. We are evaluating the robustness of this type of classifier both experimentally (comparing SAR data for multiple dates and regions) and theoretically (using a canopy backscatter model [Wang et al 1995]). Our modelling work is aimed toward predicting the sensitivity of the classifier to differences in vegetation structure and dielectric properties.

3.2 Application of SAR to wetlands of northern Australia

A rich variety of wetlands under the influence of a monsoonal climate occur across northern Australia (Finlayson et al 1988, Finlayson & Von Oertzen 1993). An especially well studied example is located on the floodplain of the Magela Creek, Northern Territory (Finlayson 1991, 1993, Finlayson et al 1990, 1993). SAR data for the region around the Magela Creek was acquired with NASA's airborne SAR in September 1993 and with the Shuttle Imaging Radar-C (SIR-C) instrument in April and October 1994. For each acquisition, video imagery was obtained concurrently from low-flying helicopter (Devonport et al 1994). Further ground surveys and overflights were made in March 1995. We are in the initial steps of analysing these data.

In figure 1 we present subscenes of SAR images of Magela Creek obtained from the Space Shuttle during the SIR-C mission on 16 April 1994, at the end of the wet season when there was considerable water on the floodplain. The image dimensions are about 42 x 18 km, the pixel size is 25 m, and the images are centred at approximately 12°26'S, 132°51'E. The two frequency-polarisation combinations shown (C-band, HH-polarisation at left; L-band, HH-polarisation at right) illustrate the ability of SAR to distinguish between herbaceous and woody vegetation, and to detect flooding under both types of vegetation. Areas that appear black or very dark at both wavelengths are mostly open water (w); little or no energy is scattered back to the radar antenna by the specular reflection from the smooth water surface. Bare fields near Mudginberri Station at the bottom of the scene also have very dark tones at both C- and L-bands: surface scattering is low due to low soil moisture, and little green vegetation is present. This contrasts with upland *Eucalyptus* woodland (u), which has a medium-grey tone at both wavelengths. C-band returns from these open woodlands can be attributed to double-bounce interactions between small and large branches, trunks, and the ground at C-band, and between large branches, trunks and the ground at L-band. Flooded aquatic macrophytes (a) and flooded *Melaleuca* woodland (m) appear much brighter than their non-flooded herbaceous and woody counterparts due to strong returns from double-bounce scattering between the smooth water surface and the vegetation. Flooded *Melaleuca* is bright at both C- and L-bands; aquatic macrophytes backscatter strongly at C-band but not at L-band.

Using training data based on the video survey and follow-up ground survey, we will use the decision-tree approach to classify the September 1993, April 1994, and October 1994 SAR scenes into the basic cover types discussed above, and compare extent of inundation and macrophyte communities for the three dates. Based on our initial analysis, these types will be easily separable. Further analysis will focus on understanding the returns from the flooded macrophyte areas, which range from medium grey to very bright at CHH, reflecting the structural diversity of the Magela macrophyte communities. Using the vegetation mapping units of Finlayson et al (1989), and moving from the lower (1) to the middle (2) and upper (3) portions of figure 1, the three aquatic macrophyte (a) sites represent 1) *Pseudoraphis spinescens* grassland mixed with scattered *Melaleuca*; 2) *Oryza meridionalis* and *Hymenachne acutigluma* grassland; and 3) *Eleocharis* sp. sedgeland and *Oryza meridionalis* grassland. Density and height variations within these communities, and variation in associated species within each community (including broad-leaved macrophytes such as *Nelumbo* and *Nymphaea*) make the macrophyte mosaic quite complex. Cross-polarised returns, particularly at C-band (CHV, not shown here) should be useful for distinguishing among these types since cross-polarised returns originate mainly from multiple scattering within vegetation canopies, revealing information about canopy structure. We also will analyse SAR data obtained from the Space Shuttle by the X-SAR instrument concurrently with SIR-C; we expect that the shorter X-band data will yield additional information for communities with low biomass or species with small leaf dimensions.

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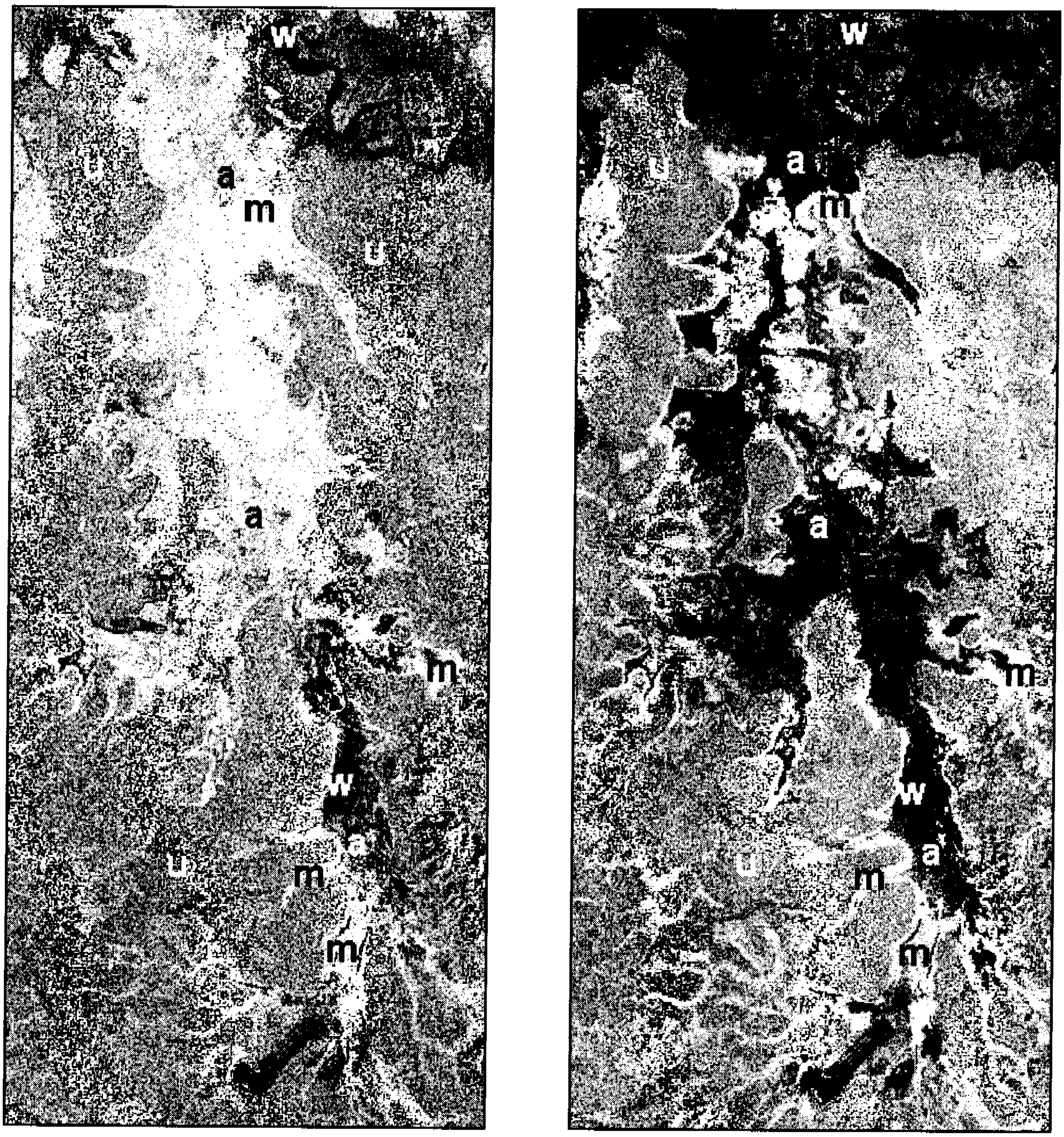

CHH LHH

Figure 1 Magela Creek SIR-C images, 16 April 1994, showing open water (w), aquatic macrophytes (a), upland woodland (u), flooded *Melaleuca* woodland (m)

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REMOTELY SENSED INDICATORS OF HABITAT HETEROGENEITY AND BIOLOGICAL DIVERSITY: A PRELIMINARY REPORT

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ABSTRACT

This paper presents the preliminary results of an investigation to examine the extent to which synthetic aperture radar (SAR) data collected during the Joint NASA/Australian AIRSAR deployment in September 1993 could be used to characterise the spatial attributes of habitats and their effect on biodiversity.

Bird population and census data and vegetation data were collected along a series of transects near Munmarlary, in Kakadu National Park. Radar backscatter response is correlated with measured vegetation structural features. Abundance response data for three bird species is then compared with selected vegetation structural features. Conclusions are drawn in respect to relative species abundance in heterogeneous landscapes and radar backscatter characterisation of habitat.

Keywords: synthetic aperture radar, AIRSAR, biological diversity

1 Introduction

The relationship between habitat area, spatial dynamics of the landscape, and species diversity is an important theme in population and conservation biology. Of particular interest is how populations of various species are affected by increasing habitat edges due to fragmentation. Over the last decade, assumptions regarding the effects of habitat edges on biodiversity have fluctuated wildly, from the belief that they have a positive effect to the belief that they have a clearly negative effect. This change in viewpoint has been brought about by an increasing recognition of the importance of geographic scale and a reinterpretation of natural history observations. In this preliminary report from an ongoing project we explore the use of remote sensing technology and geographic information systems to further our understanding of how species diversity and population density are affected by habitat heterogeneity and landscape composition. A primary feature of this study is the investigation of SAR for making more rigorous investigations of habitat structure by exploiting the interaction between radar backscatter and vegetation structure and biomass (Dobson et al 1992). A major emphasis will be on the use of SAR data to define relative structural types based on measures of structural consolidation using the vegetation surface area to volume ratio (SA/V). Past research has shown that SAR may be sensitive to this form of structural expression (Imhoff in press) which may affect biodiversity.

2 Site description and methods

In September 1993 P- L- and C-band SAR data were collected over a section of the South Alligator River in Kakadu National Park in the Australian Northern Territory (NT) as part of the Joint NASA/Australia AIRSAR Deployment. The SAR data were supplemented by Landsat TM imagery captured several days later. The area is tropical and is characterised by estuarine flood plains and freshwater billabongs with palaeosol (laterite) uplands and scattered sandstone ridges and outcrops. Elevation differences between the flood plains and the uplands are on the order of only a few metres. There are 16 monsoon rain forest floristic groups in patches on the uplands and low lying soils containing approximately 33 species of overstorey trees of Austral-Asian origin The area has a hot-wet hot-dry climate and 85–95% of the 1500 mm in mean annual precipitation occurs between December and March. In August-September 1994 field data consisting of vegetation structure and other habitat spatial information and census data on the distribution and density of all bird species within the test site were collected along transects orthogonal to a series of habitat edge gradients in the test area. The research described in this report focuses on a set of two primary habitat edges based on vegetation differences. The edges run roughly east-west in orientation spanning approximately 5 degrees in SAR range (52–57 degree incidence angle). The gradient changes in a north-south direction which is the azimuth direction of the radar. The area was selected because while the edges are distinct one edge is predominantly structural in nature while the other is floristic in nature. The structural edge will be identified henceforth as edge A and the floristic one as edge B.

2.1 Birds

Ten north-south trending transects were established at random locations orthogonal to the edge lines with a minimum separation of 100 m and a maximum separation of 200 m. Along each transect, census points were placed systematically at intervals of 100 m. The southernmost census point was established 200 m south of the edge between a wet *Melaleuca* forest and a dry *Melaleuca* woodland (edge A). Each of the ten transects spanned edge A and a second edge (edge B) between the dry *Melaleuca* woodland and open mixed *Eucalypt* woodland. Each transect was censused twice (between 1/2 hr and 3 hrs after sunrise) over ten consecutive days; once beginning at the northern end of the transect and once beginning at the southern end. Transects were selected arbitrarily each morning and specific pairings of transects were not repeated. At each census point, 5 minute stationary census were conducted. All birds seen or heard were recorded along with an estimate of their distance from the census point, up to a maximum of 50 m. Birds detected at distances greater than 50 m were not recorded (Reynolds et al 1980). For each species, abundance represented by the number of detections per point count, was plotted against the position of the point along the habitat gradient. Frequency of detection was tested against a uniform distribution (G-test) to identify significant changes in abundance at the two edges. In all cases a probability of $p<.05$ that the observed changes in abundance were due to chance alone was deemed sufficient to reject the null hypothesis that the detections were distributed randomly along the gradient.

2.2 Vegetation

Vegetation data were collected along seven of the bird survey lines using the point-center-quarter (PCQ) method. Point data were taken at 33 m intervals and included: species identification, stem diameter (dbh), height, height to live crown, crown dimensions in x and y and stem density. In all more than 200 points on the ground were surveyed compiling measurements for over 1000 individual trees. Measurements for crown components such as branch length, number of branches, and leaf area are being made using photographic methods including hemispherical canopy photography. The PCQ data were divided into nine 100 metre wide geographic zones parallel to edges A and B for statistical analysis. Each zone contains a minimum of 21 PCQ points from which statistics were generated. Results are given for floristic composition and vegetation structure including: mean stem density, dbh height, biomass, and vegetation surface area to volume ratio SA/V.

2.3 SAR analysis

The SAR analysis is in the correlative phase. The MacsigmaO program written by JPL was used to derive backscatter statistics for the 9 vegetation edge zones. Radar backscatter is reported as $\cdot^{\circ}$ in dB (m^2/m^2) and is compared to the vegetation (bole) surface area to bole volume ratio (SA/V) and bole biomass.

3 Results and discussion

SAR and Vegetation Structure:

The SAR data used in this study successfully identified a series of edaphic driven structural changes across a floristically homogeneous stand of vegetation. Such a change was evident at edge A where a *Malaleuca cajuputi* woodland changed in structure from a tall, closed canopy (zones 1-3) to a more densely stocked formation of smaller individuals (zones 4-6). All of the structural parameters except stem density changed significantly across edge A ($p<0.01$, T-test). The SAR data also detected another structural/floristic edge at zone 5 where the *M. cajuputi* changes to a more dense smaller statured stand containing a mixture of *M. cajuputi* and *M. viridiflora*. The bole SA/V changed dramatically in zone 5. All three SAR bands were capable of clearly identifying these changes yet these changes *were not* as readily discernible on the Landsat TM image. Because the stands in zones 1-6 are nearly monospecifc substantial changes in the canopy opening were required before the ground contribution could alter the otherwise identical TM spectral reflectance from the canopy. Edge B represents the opposite situation from edge A. At edge B there is an abrupt and complete floristic change but the structural differences are more subtle. Only crown volume was significantly different ($p< .01$ T-test). In the case of edge B, bole biomass does change significantly but this is due to the higher bulk density of Eucalypts and not to a bole volume difference. The best correlations were achieved between the C-HV, L-VV, P-VV and C-VV, L-VV, P-VV backscatter and bole biomass and SA/V respectively (figure 1).

3.1 Birds and vegetation structure

During the census 1449 positive identifications were made representing 58 species. Here we represent data for three avian species that illustrate the range of responses observed across the habitat gradient. The Lemon-Bellied Flycatcher (*Microeca flavigaster*) responded primarily to floristics (figure 2a). It was associated with habitats dominated by both *Melaleuca* species and abundance did not change significantly at the structural edge (edge A). At edge B where vegetation structure did not change dramatically but where *Melaleuca*-dominated woodland was replaced by mixed Eucalypt woodland, the species declined significantly. The Brown Honeyeater (*Lichmera indistincta*) followed a different pattern. It occurred abundantly throughout the study site (figure 2b) and its density did not change markedly in the different vegetation communities. Its significant increase at edge B and a smaller increase at zone 5, indicates that this species may be responding to some structural aspects of its habitat. Some significant structural shifts did occur at zone 5 (SA/V) and edge B (crown volume). The Yellow Oriole (*Oriolus flavocintus*) seems to be strongly associated with wet *Melaleuca* forests (figure 2c). Within this habitat it occurred with greater frequency at the edge. This species appears to be responding strongly to both floristic and structural elements generating a more complex edge-associated response.

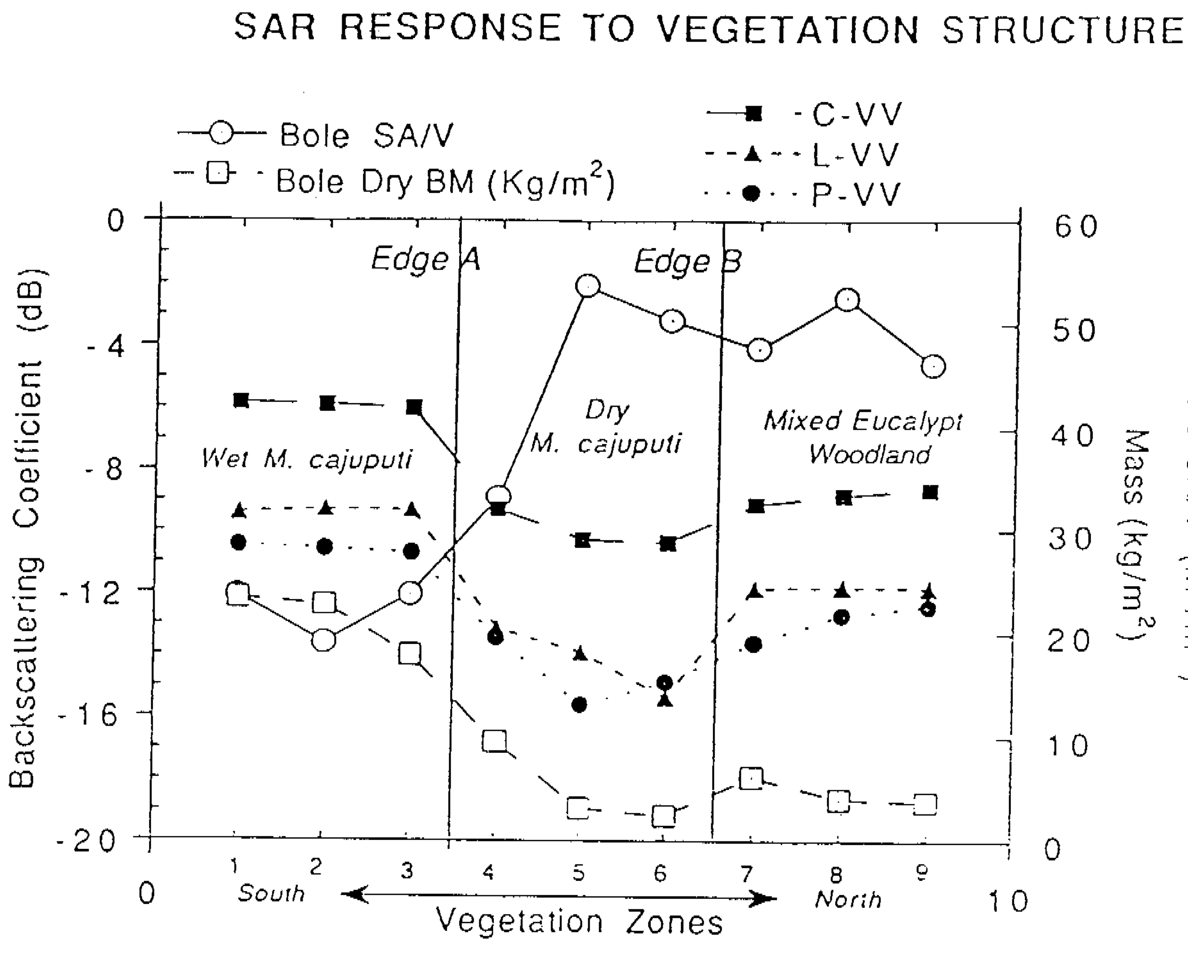


Figure 1 SAR response to vegetation structure and biomass along the habitat gradient. As biomass decreases across the gradient SA/V increases and SAR backscatter decreases. All changes in structural parameters except stem density were significant across edge A, as was AV/V at zone 5 ($p<.01$, T-test). Few structural changes were statistically significant across edge B. Bole volume differences across edge B are not significant, but biomass changes are more evident due to bulk density differences between the *Melaleuca* and the *Eucalypts*

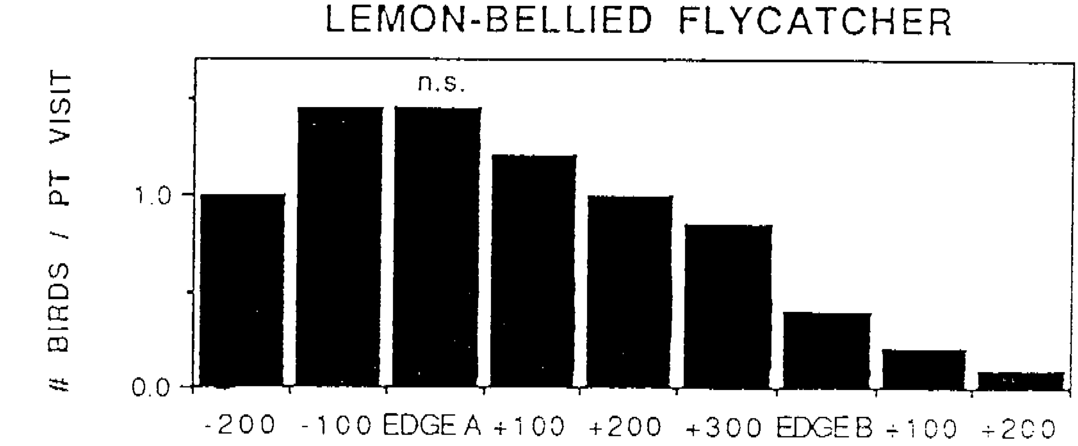
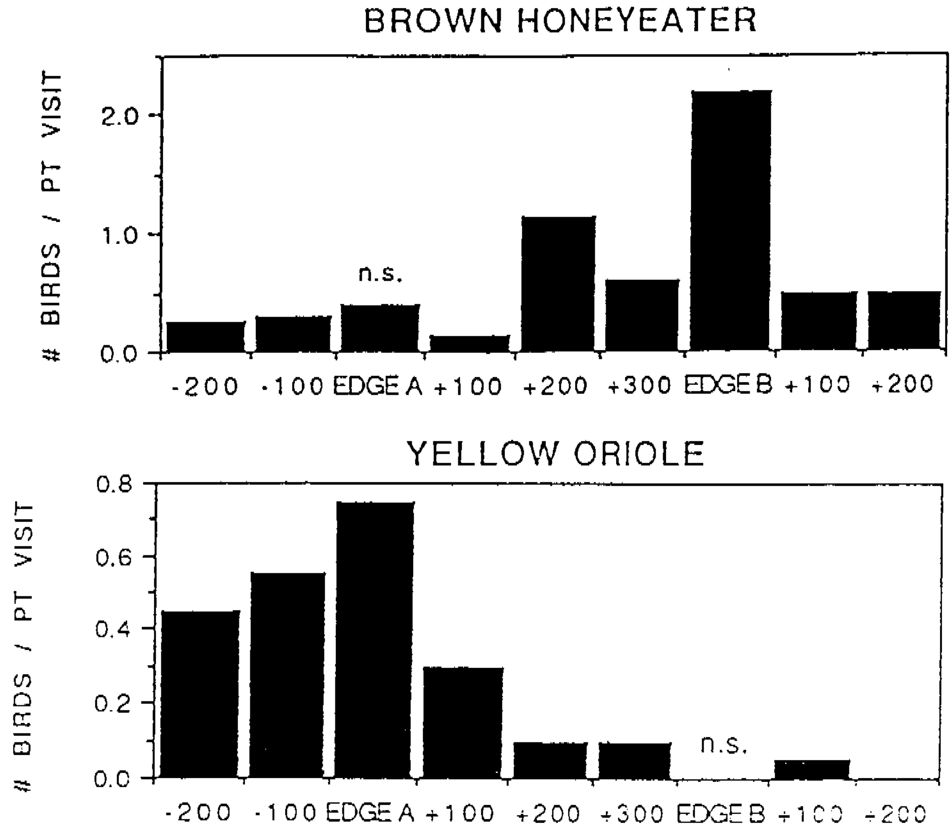


Figure 2a Abundance response to vegetation for the lemon-bellied flycatcher (*Microeca flavigaster*) which responded primarily to floristics. Change is significant (* = p≤ .05) at edge B but not at edge A (n.s.). Histogram blocks correspond to vegetation zones 1-0 as shown in Figure 1



Figures 2b and 2c Top: Abundance response to vegetation for the brown honeyeater (*Lichmera indistincta*). Abundances for this species did not change markedly in the different vegetation communities. Change is significant at edge B (* = p≤ .05) but not at edge A (n.s.). Bottom: Abundance response for the yellow oriole (*Oriolus flavocintus*) is strongly associated with wet *Melaleuca* forests. Change is significant (* = p≤ .05) for edge A but not edge B (n.s.). Histogram blocks correspond to vegetation zones 1-9 as shown in figure 1

4 Conclusion

Results from this study indicate that bird species are individualistic in their responses to habitat heterogeneity and that edges are potentially powerful factors in determining the abundance of bird species in a heterogeneous landscape. Through the integration of SAR and TM data with field data we were able to isolate trends in floristic and structural components of bird habitats. We found that different bird species responded differently to these structural factors and that SAR data are capable of identifying some of those structural factors. The combination of SAR, multispectral, and species-level ecological data may provide the foundation for a new generation of modelling tools designed to make predictions of relative species abundances in heterogeneous landscapes based on spatial patterns in the distribution of habitat types.

Acknowledgements

The authors would like to thank Dr Arthur Johnston, Director of the Environmental Research Institute of the Supervising Scientist and his staff for the logistical support provided during the field campaign in September 1994. Also, to Kym Brennan and Marvilyn Palaganas who assisted with vegetation sampling at Munmarlary.

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SMART INFORMATION SYSTEMS - CURRENT EVOLUTIONARY TRENDS FOR WETLANDS DATABASE CREATIONISTS

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ABSTRACT

Currently available microcomputer technology makes it possible to develop comprehensive information systems to assist with tidal wetlands management. Over the last three years, the Australian Marine Conservation Society (formerly Australian Littoral Society), working with the Queensland Department of Environment and Heritage, has prepared an extensive information system for Queensland's tidal wetlands. The development of the system is described. Data, both stored and generated by the system, can now be used for coastal management planning, wetland site resource assessments, environmental impact assessments, and determining research priorities for tidal wetlands management. Evolution of today's wetland information systems into expert systems may provide a crucial management tool for achieving both the preservation of biodiversity and ecologically sustainable use of the world's tidal wetlands in the future.

Keywords: information systems, tidal wetlands, coastal management planning, resource assessments, environmental impact assessments, research priorities.

1 Introduction

For over a decade, the development of a comprehensive database of wetlands resources frequently has been cited as an important tool for wetlands managers, both within Australia and other countries (eg Saenger et al 1983, Hamilton & Snedaker 1984, McComb & Lake 1988, Aksornkoae 1993). However, only for the last few years has the computer hardware and software been available to make this a practical tool that could be developed with the resources available to most wetlands management agencies.

The various Australian states developed their basic understanding of the extent and values of their wetlands during the 1970s and 80s (McComb & Lake 1988). It has been a widely shared goal to develop both a more detailed understanding, and more sophisticated systems for collating and retrieving wetlands knowledge in ways that serve the needs of wetlands managers. However, progress has varied from state to state.

Stanton (1975) carried out the first detailed survey of the extent of wetlands in Queensland. In all, 142 major wetland aggregations were identified that were believed to represent about 90% of the total natural wetland area in the state. An assessment by Arthington & Hegerl (1988) found that 91 reserves protected all or portions of only 39 of Stanton's 142 major Queensland wetland aggregations. By 1991 this had expanded to 109 reserves covering 50 of the 142 wetlands.

2 Methods

At the beginning of 1992 the Queensland Department of Environment & Heritage commissioned the Australian Littoral Society to develop a text-based information system that would identify the locations and summarise current knowledge of Queensland's tidal wetlands. This was to include all tidal marshes, mangrove forests, and intertidal seagrass beds, as well as the associated intertidal mudflats and sandflats, that could be identified from recent aerial photographs. Intertidal was defined as the area between Highest Astronomical Tide and Lowest Astronomical Tide. Data on the sub-tidal channels within the wetland boundaries were to be included, as were data on sub-tidal seagrass beds immediately adjacent to the tidal wetland.

In addition to summarising knowledge of the major wetland habitats within each Queensland tidal wetland, the database was to include a summary of the human use and the condition and conservation status of each wetland. To the maximum extent that current taxonomic knowledge permitted, it was to collate data on the individual plant and animal species within each wetland habitat and to be able to link this to an overview of the distribution and conservation status of each species. Finally, the ecological, social and cultural benefits of each tidal wetland were to be evaluated using agreed criteria and a list of 'important' Queensland wetlands generated for use in the state Coastal Protection Strategy.

The developmental phase of this project was carried out with the involvement of an interdepartmental working group of wetlands managers based along the Queensland coast. A series of workshops were held to evolve an information structure that would satisfy the needs of the primary users. These were Queensland Government officers involved in coastal management planning, day-to-day wetlands management, impact assessment, and monitoring activities. Researchers and special interest groups were seen as secondary users.

In developing an information system on a specific ecosystem, it is essential that the system designer should have a detailed knowledge of the ecology of that system.

Our team was fortunate that we also had a programmer who had some understanding of natural systems that was based on field experience, and consequently, understood what we were trying to achieve.

The commitment of about two person-years of development time was necessary to produce the structure that Queensland tidal wetlands managers were seeking. This task would have been much more difficult if we had not had an experienced development team thoroughly familiar with the software.

The next phase of the project involved identification of wetland sites and defining their boundaries from recent aerial photographs. Maps were produced and digitised for each wetland. The aerial photographs also helped identify the types of vegetation present within each wetland and the gross impacts of human activities both on the wetland, and on the adjacent catchment. The literature was then searched for all relevant data on each wetland.

Since the information system needs to accurately summarise the literature, data entry, like the mapping, is a slow, and hence, expensive process. It has taken a further two years to compile the available data on 409 Queensland tidal wetlands and 198 plant and 673 animal species found within these wetlands. Currently the system contains about 12 megabytes of text data. It is estimated that there are over 800 tidal wetlands along the east coast of Queensland and at least twice as many species as are currently documented in the system.

However, for the sections of the coast that have been completed, the goal of providing 'instant information at your fingertips' does seem to have been achieved.

We can rapidly access and collate data and print out reports on what is known about a wetland or species, or groups of wetlands or species. The evaluation criteria built into the system also provide assessments of the known local, regional, national and international conservation values of each wetland.

It was clear that collating what was known about these wetlands also would highlight what was not known and that this would make it easy to target field surveys at filling crucial gaps in knowledge. Consequently some of the screens in the information system were designed to facilitate easy entry of field data from proformas already in use to survey specific wetlands taxa or habitats. This has proved very successful as it has provided voluntary community groups with wetlands expertise both the opportunity and incentive to assist in gathering information that will help conserve wetlands that they value. The Queensland Wader Study Group, for example, has provided field data on over 600 wader/shorebird surveys of south-east Queensland tidal wetlands.

3 Software

The Queensland Tidal Wetlands Information System has been developed using Advanced Revelation Version 2.1 software. This is a powerful MS-DOS relational database package that contains many features that are advantageous in a natural resource management information system. These include stability, capability to incorporate maps, graphics and photographs, and variable length field architecture to accommodate the storage of substantial quantities of descriptive text with minimal use of disk space. In addition, it also supports the usual database capabilities for handling numerical data and formulas.

Since the data are accessed from menus, the system is easy to use. However, its sheer size and scope are such that users need to undertake a two-day training course to become familiar with the extent of information that is available.

A Microsoft Windows version of Advanced Revelation called Open Insight (Version 2.5) is now available. This offers superior user-friendliness, OLE support, and the capability to incorporate Windows help systems and tutorials. We have not yet converted to this software as, at this stage, we prefer to focus our development time on adding more data, rather than improving ease of use.

4 Evolving 'Smarter' Systems

The very rapid development of computer software has provided this generation of scientists and natural resource managers with new tools for recording, collating, analysing and displaying natural resources data. Over the next decade, the software is likely to continue to become even more powerful, but easier to use. Hopefully, we will see a 'seamless' merging of high-end relational database technology and GIS technology in an integrated package.

However, what is currently available is adequate to provide rapid access to large amounts of information. This should result in better local and regional planning, more accurate and relevant environmental impact assessments, more successful nature conservation efforts by management agencies, and also assist with determining new research priorities for habitat and species management.

The problem for today's natural resource managers is that they may not have had sufficient professional opportunities to develop personal understanding of systems like wetlands that would allow them to make effective use of a wetland information system. With the Tidal Wetlands Information System, we have attempted to provide an explanation of what each information category in the database means. The system also collates various types of management information with only a few keystrokes. It might be considered a 'smart' information system, but it only has limited capacity for answering the more obvious questions.

This falls well short of the 'expert systems' that have been developed for the medical profession in which a medical practitioner can enter a patient's health symptoms and receive guidance that identifies the most probable health problem and suggests appropriate treatments.

While defining very specific ecosystem parameters is likely to prove more complex than the human body, it is not a problem of inadequate software technology or programming expertise. We are still constrained by the very serious inadequacies in our knowledge of ecosystems.

If we want to develop expert information systems that can help managers make better use of scientific data, it will be up to the scientific community to undertake quite detailed and focused studies on specific habitats, on the plant and animal species within those habitats, on the interactions between species, and on the interactions between the habitats and species and various human activities.

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FRAMEWORK FOR BIOGEOGRAPHIC INVENTORY, ASSESSMENT, PLANNING AND MANAGEMENT OF WETLAND SYSTEMS - THE QUEENSLAND APPROACH

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ABSTRACT

Problems of broad scale loss and degradation of Queensland's wetland resources are being addressed as part of the Queensland Wetland Inventory Program. A two fold strategy is providing a uniform body of information for assessment of wetland resources, and enables this information to be presented in a readily accessible form.

A hierarchical biogeographic framework is used to integrate an ecologically based classification of wetlands and deep water habitats with a biophysical classification of land surfaces. This has created a robust framework for systematic regional scale inventory and assessment of wetland resources, and a strategic basis for regional conservation planning and management of wetlands.

Digital processing of satellite imagery is used to map wetlands within the biophysical framework. GIS techniques integrate the digital image mapping with wetland survey and other spatially related natural resource, cadastral, and cultural information. The resultant wetland information system enables assessment at any scale from state wide through regional to individual cadastral parcels. Rapid field survey techniques have been developed to meet shortcomings in existing data.

The system meets the needs of planners by integrating wetland resource information with cadastre and other spatially related information. It meets the needs of managers by placing wetlands within the overall context of landscape, addressing their management as functional components within this. Information can be effectively communicated in graphical and visual hardcopy formats, and made available for interactive viewing on personal computers running 'user friendly' windows software.

It is suggested that research should now be directed at understanding patterns and processes of natural and man induced changes within the different wetland systems, as the basis for developing effective methods for monitoring wetland environments. The hierarchical framework enables this to be undertaken at any scale appropriate to the resources available.

Keywords: wetland assessment, wetland inventory, wetland classification, biogeographic regions, resource planning, resource management, wetland monitoring, geographic information systems, remote sensing.

1 Introduction

Queensland's wetland resources are notable for their richness, diversity, and extent (Arthington & Hegerl 1988, Blackman et al 1993), but as elsewhere, wetlands are subject to a formidable and increasing array of threats (McComb & Lake 1988). Significant degradation and loss of wetlands is occurring, particularly in areas where development is most extensive, ie coastal regions (Blackman & Brooke 1994).

These problems are being addressed as part of the Queensland Wetland Inventory Program using a two fold strategy that provides a uniform body of information for assessment of wetland resources, and presents the information in a readily accessible form that meets the needs of planners and managers.

The purpose of this paper is to describe the strategic framework within which biogeographic inventory, assessment, planning and management of wetlands and deep water habitats are being addressed. The operational approach and an overview of the wetland information system are presented. The application of the framework is outlined and some observations made concerning direction of future work.

2 The framework

A biogeographic model comprising a hierarchy of land surface and wetland elements (figure 1) provides the conceptual basis for the program. The model depicts wetlands as being functional units of land surface and provides a hierarchical framework for integrating an ecologically based classification of wetlands and deep water habitats with a biophysical classification of land surfaces (Blackman et al 1992).

2.1 Biogeographic classification

At the uppermost level of the model climate, geology, geomorphology, landform, soil and vegetation criteria are used to define 13 biogeographic regions for terrestrial Queensland (Stanton & Morgan 1977).

Six of these have coastal boundaries with the marine environment, and for the purposes of the program intertidal lands are included with the terrestrial regions with which they are contiguous. Marine biogeographic regions have still to be formally defined (Stevens 1994).

Within biogeographic regions finer divisions of the above criteria are used to identify functionally distinct provinces (Morgan & Terry 1990), which contain suites of landsystems (Christian & Stewart 1968) united by function or origin. The provinces are further subdivided into land types containing suites of similar land units grouped across related landsystems. Biogeographic regions are expressed at nominal scales of 1:500 000 and larger, provinces at 1:250 000 and land types at 1:100 000 and lower.

2.2 Wetland classification

Wetlands are integrated with the biophysical classification as wetland landtypes in an ecologically based hierarchical framework (Blackman et al 1992) progressing from system and subsystem at the most general levels, to class and subclass below. Modifiers for water regime, water chemistry, and soils are applied to classes and subclasses. Special modifiers describe wetlands and deepwater habitats that have been either created or modified by man. Dominance types named for the dominant plant or animal forms of the habitat are at the lowest level. Systems/subsystems/classes can be expressed at nominal scales of 1:100 000, class/subclass at 1:50 000, subclass/dominance types at 1:25 000, and dominance types at 1:10 000 and lower.

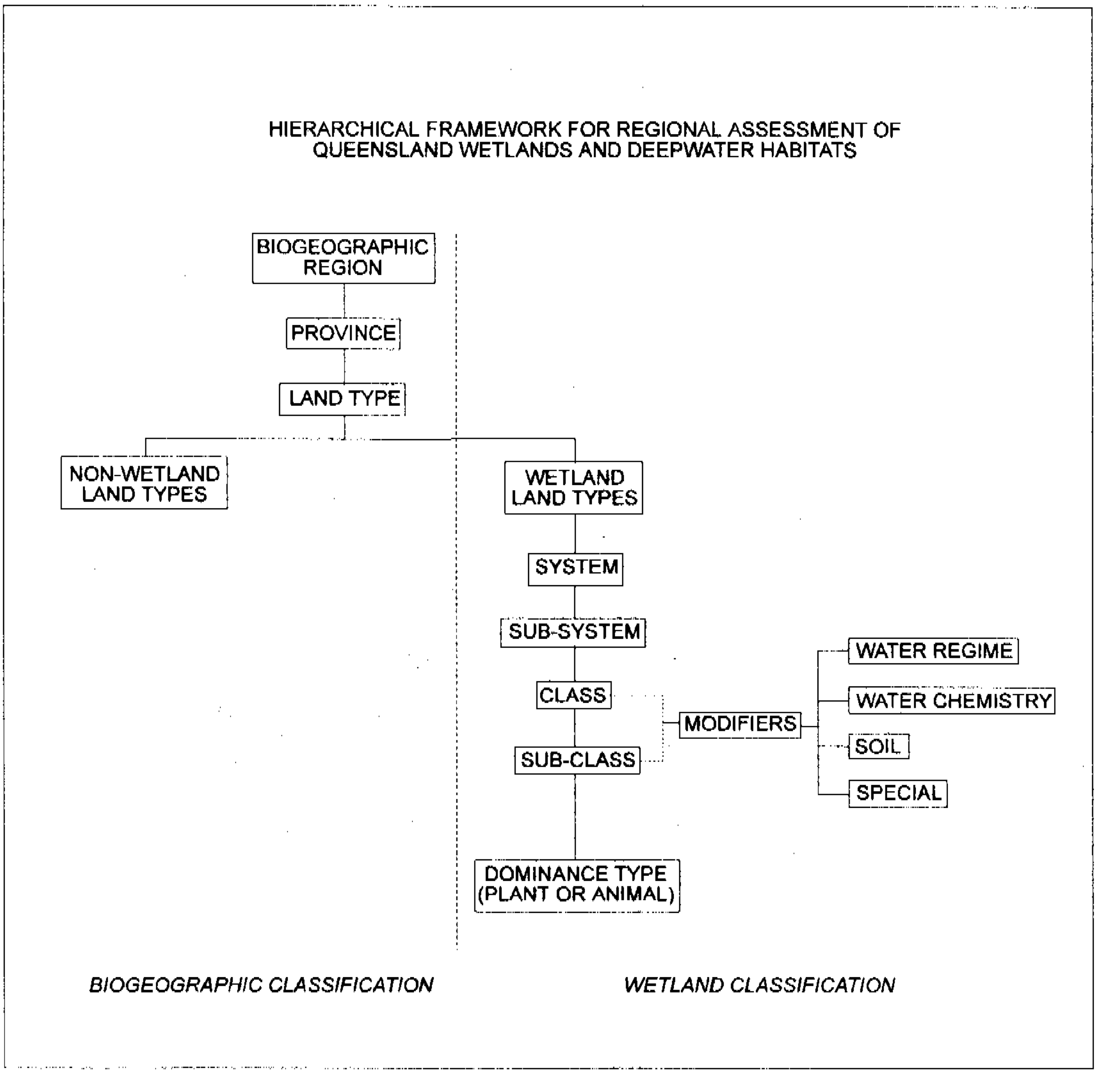

Figure 1 Biogeographic model showing the hierarchical framework integrating a biophysical classification of land surfaces with an ecological classification of wetlands and deep water habitats

3 Inventory and the wetland information system

The biogeographic model has created a robust operational framework for systematic regional scale inventory and assessment of wetland systems. The operational procedures used in establishing the biophysical structure, designing and undertaking field survey, and developing the wetland information system are detailed below and schematically illustrated in figure 2.

3.1 Identification and delineation of biogeographic boundaries

The biogeographic regions identified for Queensland (Stanton & Morgan 1977) are revised in the light of current information. Province boundaries are initially identified using available natural resource information, associated mapping, and hard copy satellite images. At the same time land types are identified and characterised by landform, soil and vegetation.

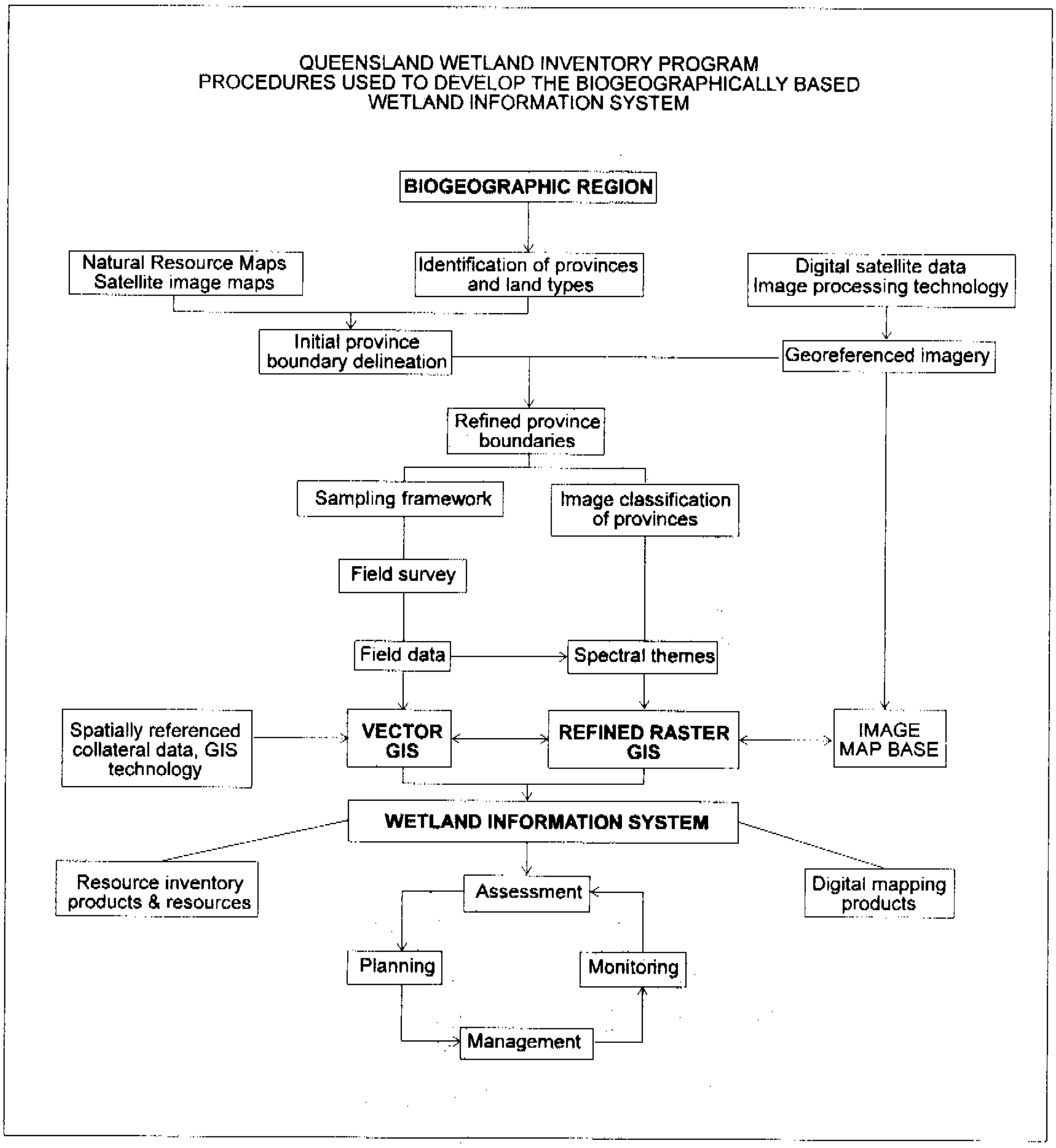

Figure 2 Procedures used to develop the biogeographically based wetland information system

Province boundaries are transferred to 1:250 000 scale geological maps, the latter being the only consistent thematic natural resource mapping for the whole of Queensland. Many of the province boundaries align well with geological boundaries. The transferred boundaries are labelled and digitised to create an initial GIS vector coverage for the entire biogeographic region. These boundaries are projected over an enhanced, spatially accurate digital image (see below) and edited to the image base. In most instances land types are readily identified on the satellite image but are not mapped at this stage.

3.2 Field survey and collation of data

The survey strategy is dictated by scale and existing information, both of which vary considerably throughout the State. To date a two stage survey strategy has been adopted. The first stage provides a reconnaissance level of gradient orientated information from a large number of sites over the full extent of the region. The second stage provides more detailed information from a representative sub-sample of the above. The provinces and land types provide the framework for stratification of the region and the allocation of sample sites, with sampling intensity dependent on the size and environmental variation within each province. Replicates of all wetland land types are sampled, with sites chosen subjectively because the logistics and cost of implementing a statistically proper sampling procedure over such vast areas is prohibitive. Individual sites are selected using hard copy satellite image maps and aerial photography in association with 1:250 000 and 1:100 000 scale topographic maps. The sample sites are marked on 1:250 000 scale topographic maps and the geographical coordinates of each recorded. Each site is coded, named and along with a brief reference description entered into a data base.

In some regions the information for the first stage is available in the form of collateral data from detailed land system, vegetation and soil studies. Field survey can then be confined to the second stage where detailed information is required from only a relatively few sites. At the other end of the scale some regions are vast mostly inaccessible areas, with little prior information on their wetland systems and field survey has to be much more extensive, as in the Gulf Plains. Ideally, field survey of wetland systems should be undertaken in the post wet season. However at that time the country is virtually inaccessible to ground vehicles and aerial survey methods are required. The first stage of the Gulf Plains survey was carried out by fixed wing aircraft to assess some 700 sites over the 246 500 km^2 area involved. Sampling sites were located using a real time global positioning system (GPS). Low level (100–200 ft) transects through sites were used to obtain systematic descriptions of landform, vegetation, and wetland type and condition. Each site was photographed to complement the descriptions and counts were made of any water birds observed. All observations were linked to positions recorded on the GPS. The second stage was carried out using helicopter and four wheel drive vehicle to gain ground access to a sub-sample of the above aerial survey sites. Data from these sites, including vegetation, soil and water specimens, photographs, and precise location, are recorded on pro-forma described in Blackman et al (1992) to provide information for classification and assessment of each site. Data from field surveys are collated and entered into a data base. In addition, relevant ancillary data such as literature references are stored in the same manner.

3.3 GIS integration of data with remote sensing and digital mapping

In parallel with the collection and collation of field and ancillary data, digital data sets are also prepared from satellite imagery and from hard copy maps. The process of creating digital data sets falls into two areas: image processing and development of raster GIS, and development of vector GIS.

Image processing and development of raster GIS:

Satellite image processing technology is well suited to regional scale natural resource mapping and monitoring. In depth analysis of satellite data can also produce detailed information for smaller areas. Image processing is used in the program in two ways: firstly, to produce a spatially accurate and appropriately enhanced map base for purposes ranging from delineation of natural boundaries (as above) to generation of mapsheet tiles at various scales (Blackman & Goulevitch 1992); and secondly, to create and refine raster GIS layers for the wetland information system by classification and recoding of the original satellite data. A range of image processing techniques are used to analyse both Multi Spectral Scanner (MSS) and

Thematic Mapper (TM) imagery. All output from image processing can be integrated with the wetland information system.

The biogeographic model provides a basis for using natural boundaries to organise satellite imagery for optimal analysis over large regions. The vectorised province boundaries are used to digitally cut the satellite scenes into the component provinces of the region. The imagery for provinces spanning satellite scenes are mosaiced so that each province is dealt with in a coherent fashion, rather than being analysed in a piecemeal way on a scene by scene basis.

Spectral classification of a province is used to delineate component land cover for the province. Testing of a number of techniques has shown that an unsupervised classification approach is appropriate for the large data sets being dealt with in the program. The classes generated are then interpreted over the imagery and grouped into spectral themes describing the main land cover for the area. These themes are the primary input to creating subsequent raster GIS layers for the wetland information system.

Ground truth data from the field survey are used to interpret the spectral groups, and to recode them to align with elements of the wetland classification. Attribute data are attached to each group, containing information such as land type, water regime, vegetation etc. Coding allows further manipulation of the raster GIS to generate customised maps. The raster GIS is more than a computerised mapping tool, however, as the wetland information system not only allows raster modelling of the data but its integration with data from other sources such as vector coverages and field survey databases.

Development of vector GIS:
A vector GIS is the most efficient means of extracting data for the wetland information system from existing maps. The strength of a vector GIS is its ability to incorporate large amounts of ancillary data through the use of attribute tables for each point, line and polygon stored in the coverage. In addition, it is possible to link to other databases which may contain useful information. In this way all existing information about a particular feature or locality can be spatially related and used within the information system.

3.4 Wetland information system

The wetland information system enables a comprehensive body of information to be integrated as spatially referenced wetland and collateral data; vector and raster GIS coverages; and digital satellite image maps (figure 2). Because data have been collected in a structured format, they can be utilised in a variety of ways. Information can be effectively communicated in graphical and visual formats. Digital and hardcopy output can be customised, and GIS modelling techniques can be applied to the data for specific purposes.

The system meets the needs of planners by integrating wetland resource information with cadastre and other spatially related information. Each data set is an asset in its own right, but the ability to combine and manipulate data from many sources greatly enhances their value. Data are analysed to generate information which can be used to assess options and scenarios for planning and decision making. The system meets the needs of land managers by placing wetlands within the context of the overall landscape. This promotes management strategies and techniques which appreciate this and address their management accordingly.

Access is facilitated by 'user friendly' windows software running on personal computers. This obviates the need for end users to have highly developed GIS or other computer skills and allows manipulation of data with no more than a computer mouse. Information can be accessed at state, regional and local scales. The data set can be compiled and viewed in many different ways depending on the particular needs of the user, and customised maps and reports designed to suit end users needs.

4 Application of the model

The model provides a rigorous basis not only for wetland assessment, planning and management, but for environmental management in general. The use of biogeographic regions for this purpose is outlined in Morgan & Terry (1990). Its application to delineation of a coastal zone for Queensland is described by Blackman et al (1993).

The hierarchical framework means that any scale of assessment from regional analysis to studies of individual land parcels can be accommodated, depending on particular needs and resources. Its structure enables data needs to be identified. The capacity to quickly place wetland environments into an overall context means that rapid field survey of selected sites (Blackman et al 1992) can be effective. Data can therefore be collected and stored in a piecemeal but structured way, with the model providing the framework within which this data can be extrapolated. It thus provides a predictive framework for cause and effect and enables efficient use of existing information, however limited that may be.

Scale related assessments, such as analysing deficiencies in a conservation reserve network, assessing threatening processes and environmental impacts of developments, or determining a suitable management response and monitoring program, are all readily accommodated. The classification has the capacity to precisely record the ecological character of a site at any one of a number of levels. Pro-forma for the detailed recording of reference sites are described by Blackman et al (1992). Its application to monitoring has been demonstrated for the Townsville Town Common (Blackman & Brooke 1994).

5 Conclusions

The most pressing problem for wetland conservation is to redress the continuing loss and degradation of wetlands, mostly as the result of localised and often unrelated land use decisions associated with rural, urban, and industrial developments, and accompanying land management practices. The Queensland Wetland Inventory Program has addressed this problem strategically. A robust framework for assessment, planning and management of wetland resources has established a uniform basis for dealing with wetland planning and management issues at state, regional or local scales. Information requirements are supported through regional scale inventory of wetlands, with information made available through an accessible information system.

One important strength of the framework is the capacity to place information in a structured context irrespective of it being derived from dedicated regional survey, which is preferable, or from opportunistic piecemeal recording at disjunct locations. The framework has proved to be particularly effective in using piecemeal information collected to assist short term management objectives. However the application of the framework in this respect should not overshadow the importance of undertaking dedicated regional surveys as the major source of wetland information.

Completion of regional inventories and the associated information system is a major priority for the Queensland program because of the strategic importance of having state wide uniform information. This is an effective basis for regional assessment, for planning to secure the status of important areas, and for focussing management prescriptions for these.

A priority for research is to develop effective monitoring of wetland systems, particularly on conservation reserves. Blackman & Brooke (1994) demonstrated the utility of the wetland classification in recognising changes in a wetland over time, and the hierarchical framework of the model allows this to be expressed at various scales. However there is a need for better understanding of patterns and processes of change within different wetland systems in response to natural and man induced alterations to their environments.

It is suggested that research should be directed towards this, as a basis for developing effective methods for monitoring wetland environments. One approach could be to develop predictive models of the seral progression or regression of different wetland systems in response to common forms of disturbance such as alterations to water regime and water chemistry, siltation, and weed invasions.

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GEOMORPHIC APPROACH TO CLASSIFYING WETLANDS IN TROPICAL NORTH AUSTRALIA

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ABSTRACT

Geomorphic classifications provide a basis to inventory. Both inland and coastal wetlands are classified at two scales: at the local scale to define the wetland type, and at the regional scale to characterise the natural groupings of wetlands. Inland wetlands are classified at the local scale primarily on their attributes of landform setting and hydroperiod, and thereafter on descriptive attributes of size, shape, water types, soils and vegetation. Coastal wetlands are classified at the local scale as to geomorphic setting (= physical habitat). At regional scale, inland wetlands are grouped into naturally related suites, and coastal wetlands are correlated to the regional coastal types or setting.

Keywords: wetlands, geomorphic, hydroperiod, consanguinity, mangrove, habitat, small scale, regional scale

1 Introduction

Wetlands of wet, northern tropical Australia can be classified at a primary level for purposes of inventory using a geomorphic approach. Wetlands are divided into inland (ie land-based open and closed systems) and coastal wetlands (ie open systems of deltaic, estuarine, and marine wetlands, but mainly mangroves). For both types of wetlands, there is a classification at the local level, and a system for identifying suites of wetlands at regional level. The former is important for descriptive purposes in documenting wetlands; the latter is important in identifying the natural regional variability of the resources for conservation purposes. Geomorphic attributes are emphasized for both inland and coastal wetlands because these determine the basic structure of a wetland in terms of landform shape, soils and hydrology which, in turn determine the wetland type and the biotic response. A sound classification of geomorphic setting for wetlands should be the primary approach to identifying the various types - understanding of the biological variation would then logically follow.

A geomorphic approach not only addresses the fundamental components of wetlands, but also allows the inherent complexity of wetland ecosystems to be addressed at several levels. To begin with, wetlands may be categorised according to geomorphic setting. With the accession of information from more intensive surveys, the initial classification may be extended in a systematic and hierarchical manner. This is particularly important when it is considered that wetlands are distributed over a wide climatic and geological/geomorphic range, and exhibit an array of variable characteristics, maintenance mechanisms, habitats, and functions. This approach is comprehensive with only a minority of wetlands requiring individual categorisation.

2 Inland wetlands

For inland wetlands, the geomorphic classification of individual wetlands at local level utilises the underlying features of most wetlands, ie their landform setting and their various types of hydroperiod

(Semeniuk 1987, Semeniuk & Semeniuk in press). Landforms host to wetlands include: basins, channels, flats, slopes and hill/highlands. The degrees of wetness (water permanence, or hydroperiod) include: permanent, seasonal, or intermittent inundation, and seasonal waterlogging. By combining landform type with hydroperiod, we recognise thirteen primary types of wetlands (table 1).

Table 1 Thirteen primary types of wetlands formed by combining landform type with hydroperiod

			Landform Types		
Water Permanence	Basin	Channel	Flat	Slope	Highland
Permanent inundation	lake	river	-	-	-
Seasonal Inundation	sumpland	creek	floodplain	-	-
Intermittent Inundation	playa	wadi	barlkarra	-	-
Seasonal Waterlogging	dampland	trough	palusplain	paluslope	palusmont

Wetlands are complex ecological habitats but their analysis is simplified by a classification which uses their important underlying non-genetic features of landform and hydroperiod. Wetlands can also be separated initially on criteria other than vegetation. The proposed classification, if applied methodically, is useful for management, resource allocation and conservation: various wetlands having different ecological functions and hydrologic and geochemical roles in the landscape are clearly separated at a primary level - eg lakes vs sumplands vs floodplains vs rivers and creeks, and as more detail is added through descriptors, comparison can be made within a single wetland category. Thus a sumpland, separated at a primary level from other wetlands, can be further highlighted as being similar, or dissimilar to other sumplands.

Since there are only thirteen primary wetland types, they form manageable mapping units to bring out regional patterns in wetland distribution useful for planning (eg a regional picture of land capability), and relationship to other features such as soils, geology, and contours.

Water, landform, and vegetation descriptors can augment the nomenclature of the primary units (eg salinity of water, size and shape of landform, structure and floristics of vegetation) so that the different wetland types can be further differentiated (table 2).

At regional level another approach is used to classify wetlands, whereby wetlands are grouped into suites of similar types (consanguineous suites) (Semeniuk 1988). If climate, hydrology, geomorphology, geomorphic processes and developmental history are similar, it may be expected that a suite of similar wetlands will result. Several criteria are used to establish consanguinity, and it is preferable to apply all of them in any analysis of wetland variability.

These criteria are outlined as follows in order of application:-

- occurrence of wetlands in reasonable proximity to each other
- similarity in wetland size and shape
- recurring pattern of similar wetland forms or heterogeneous pattern representing a spectral range of inter-related wetland forms
- similar stratigraphy
- similarity of water salinity and its dynamics
- similar hydrological dynamics
- similar origin

Table 2 Wetland components for use in classification

Criteria Used To Develop Primary Wetland Categories

	Wet	Land	
Permanently Inundated			Highlands, Hills
Seasonally Inundated	Water Permanence	Cross-Sectional Shape	Slope
			Flat
Intermittently Inundated			Channels
Seasonally Waterlogged			
			Basins

Terms For Use As Descriptors

Fresh			
Subhaline			Megascale
Hyposaline			Macroscale
Mesosaline	Water		Mesoscale
Hypersaline	Salinity	Size	Microscale
Brine			Leptoscale
Poikilohaline	Consistency Of Water Salinity	Plan	Linear
Stasohaline		Shape	Elongate
			Irregular
			Ovoid
			Round
			Fan-Shaped
			Straight
			Sinuous
			Anastomosing
			Irregular
		Vegetation Cover &	Periform
			Paniform
		Internal Organisation	Latiform
			Zoniform
			Gradiform
			Concentri-
			Form
			Bacataform
			Heteroform
			Maculiform

(After Semeniuk 1988, Semeniuk et al 1990)

The types of wetland associations that qualify to be termed consanguineous are illustrated in figure 1.

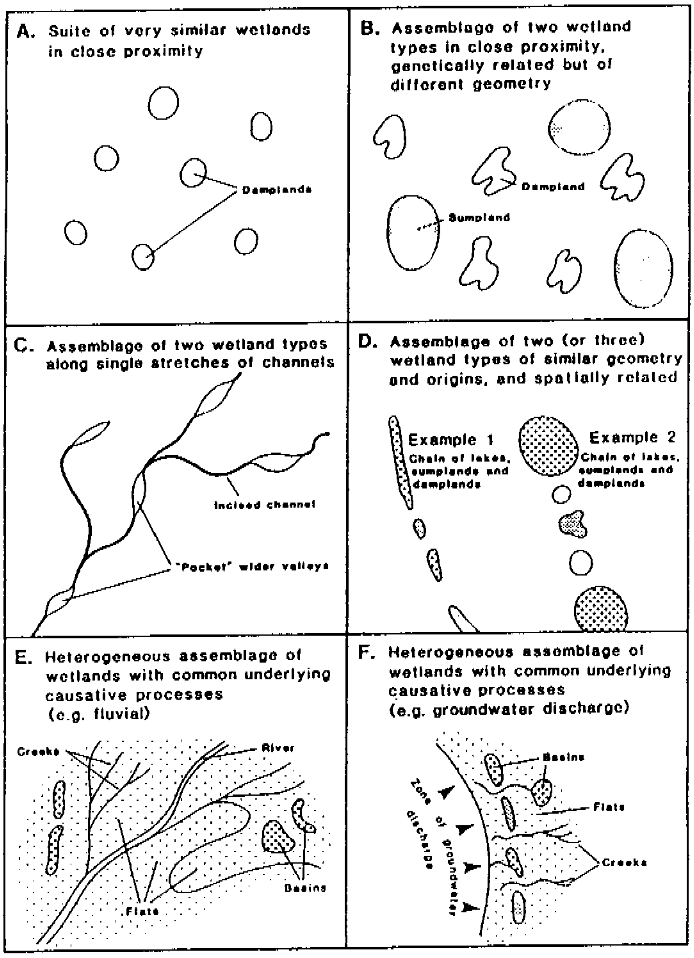

Figure 1 Idealised diagram illustrating range of wetland assemblages that qualify as consanguineous sets (after Semeniuk 1988)

Recognising the distribution of suites of similar wetlands is a powerful tool for recognising the diversity and representativeness of wetlands, and useful for allocating reserves.

3 Coastal wetlands

For coastal wetlands, classifications for inventories should endeavour to be holistic and hierarchical, combining information on geology, geomorphology, sedimentology, soils, groundwater hydrology and hinterland/shore interactions, with ecological and biological information such as mangrove composition, structure, physiognomy and population maintenance.

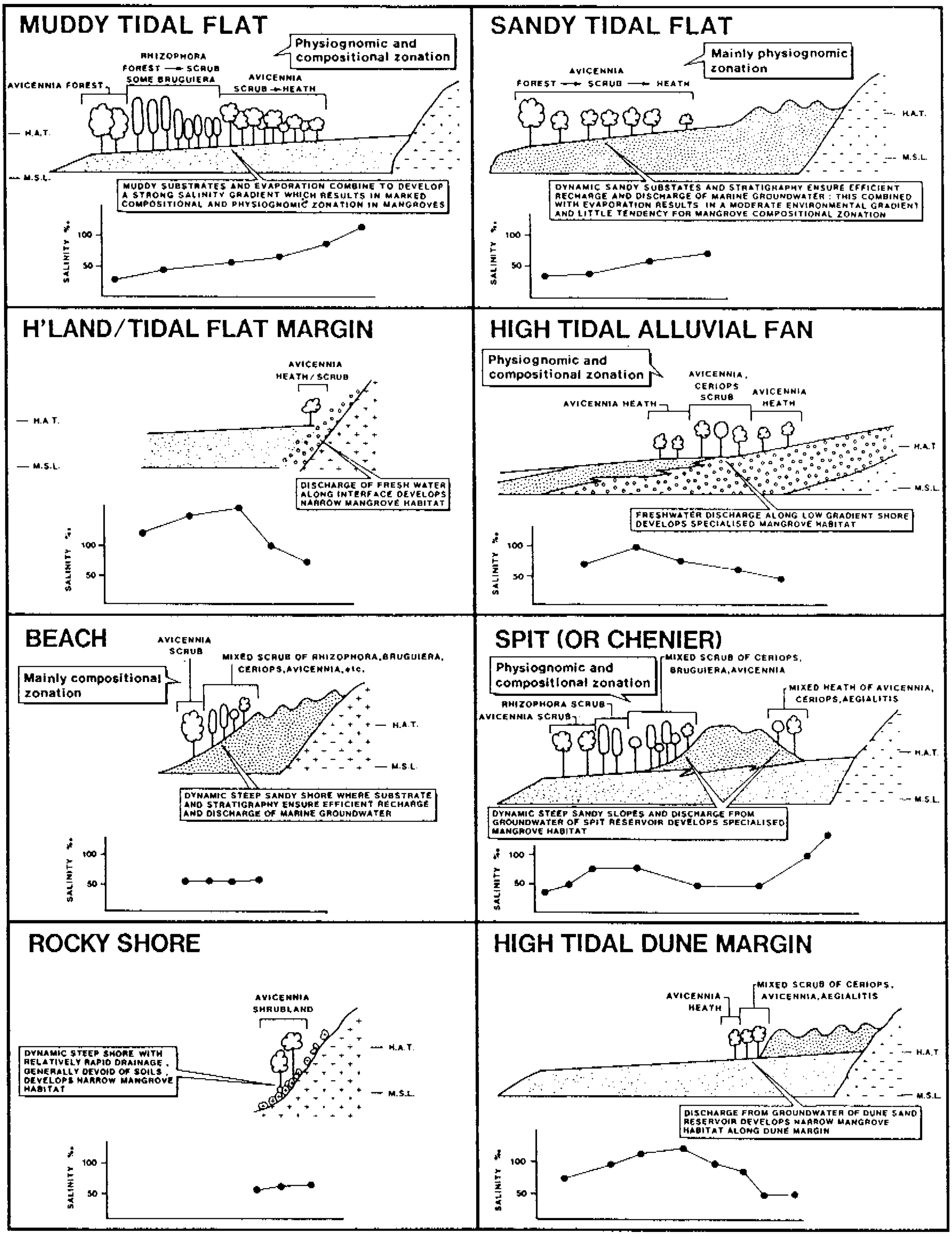

Figure 2 Key habitats in eight environments in a ria coastal setting in the Dampier Archipelago, illustrating the relationship between geomorphic setting, slope, salinity gradients, substrates, physico-chemical processes, mangrove composition, structure, and physiognomy (after Semeniuk & Wurm 1987)

The studies for inventory purposes have had two objectives: 1) to unravel the coastal evolution from regional scale to small scale to undersatnd the development of habitats, and 2) to relate biotic assemblages, populations and zonation to habitats and their internal gradients. In this regard the focus has been on mangroves. The classifications are based again on geomorphology at regional and local scale. Regionally, mangroves of tropical Australia occupy ria shores, tidal embayments, limestone barrier coasts, beach/dune shores, wave-dominated deltas, tide-dominated deltas, and alluvial plains, amongst others. Within the regional scale coastal types there are recurring patterns of habitat types for mangroves. These habitats are the fundamental units that support the various mangrove assemblages, and for a given climatic region in response to physio-chemical gradients will support a distinct floristic assemblage and structural zonation (figure 2). Information linking small scale habitats to mangrove species composition, structure, physiognomy, and population can be important in a number of ways:-

- understanding the distribution of different types of mangroves
- understanding of the types of coast, and the structures and processes that make them host to mangroves
- understanding the effects of a potential sea level rise in response to global warming
- the selection of coastal reserves

This approach facilitates analyses of variability, maintenance, and linkages, in mangroves and coastal wetlands and allows strategies to be formulated for their preservation and management.

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CONSERVATION OF WATERBIRDS IN TROPICAL WETLANDS OF THE NORTHERN TERRITORY

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ABSTRACT

Management of tropical NT wetlands for conservation of waterbirds is necessary, especially to meet international obligations on migratory species and to maintain spectacular waterbird concentrations. Monitoring of populations of Little Curlew and Magpie Goose is required due to the global significance of their populations in NT wetlands. Further inventory of most inland and some coastal wetlands is required since knowledge of waterbird conservation values is insufficient. The locations and global significance of major breeding colonies of geese, herons and other waterbirds and major shorebird roost sites, should be made known to local managers and wetland users. Wise management of pastoral grazing, exotic pasture grasses and fire in NT wetlands requires basic research on impacts on waterbirds. Current efforts to reduce saltwater intrusion and weed infestations in wetlands probably are of net benefit to waterbirds. Effective progress in conservation of waterbirds in the NT will require close consultation between agencies and local managers and may be facilitated by a regional consultative group.

Keywords: waterbirds, tropical wetlands, conservation

1 Introduction

This paper addresses the Northern Territory (NT) north of latitude 20° South. Wetlands in this area normally are inundated from monsoonal rainfall that falls during October-April. Included wetlands in the Sturt, northern Tanami Desert, Barkly and Georgina drainages are near the southern limit of regular monsoonal influence and receive highly variable inflows. The region south to latitude 15° S is generally wettest and is referred to as the humid zone; the remainder is generally drier and is referred to as the sub-humid zone.

Waterbirds are dependent on wetlands for their survival and include inconspicuous species (eg rails, some warblers) as well as the conspicuous cormorants, herons, waterfowl (ducks and allies), shorebirds and terns. More than 130 waterbird species occur in the NT (Jaensch 1994a).

Conservation of waterbirds will be addressed with respect to three wetland systems: intertidal flats (bare mud; mangrove forest), sub-coastal floodplains (grassland/sedgeland; swamp forest; permanent billabongs), and wetlands of the sub-humid zone (shrub swamps, wooded swamps, open lakes). Collectively these systems support the most significant and extensive waterbird habitats in the area considered.

The following is based mainly on the results of wetland research and management conducted by the authors and/or other officers of the Conservation Commission of the NT (CCNT) during the past five years. Points for action ('Desired Actions') are given, though these imply no specific commitments by CCNT and are not listed in order of priority.

2 Wetland inventory

In the NT, management of waterfowl harvest and waterbird pests of agriculture have driven much of the past research on waterbirds. World-wide, waterbird research has also been driven by the great public appeal of waterbirds and their value for education on functioning and conservation of wetlands. At present, however, NT research is mainly driven by tourism and international obligations: first, preservation of spectacular waterbird concentrations; and second, the need to monitor populations and improve understanding of movements of species that migrate between Asia, the NT and other parts of Australia.

Waterbirds are difficult to conserve because they are highly mobile. In tropical NT this is further complicated by significant variability in the amount and spatial distribution of annual rainfall and irregular movements of waterbirds in response. Despite this, the following scenario generally applies: (1) concentration of waterbirds at permanent wetlands, mainly in sub-coastal floodplains, at the end of the Dry season; (2) dispersal during the Wet season to revitalised wetlands of the humid zone and some wetlands of the sub-humid zone; (3) breeding in these wetlands in the Wet and/or early Dry season; (4) coastwards retreat as the Dry season progresses. (Refer to Action 1 below)

In wet years (eg 1993), large wetlands of the sub-humid zone (eg Lake Woods) may fill and provide habitat for waterbird breeding and refuge for 6–12 months, supporting in the order of 0.5-1.0 million waterbirds and breeding colonies (eg Australian Pelican *Pelecanus conspicillatus*, Straw-necked Ibis *Threskiornis spinicollis*) of regional importance (Jaensch 1994a). Significant numbers of waterbirds (eg Magpie Goose *Anseranas semipalmata*) that otherwise mainly use near-coastal wetlands, are involved.

Similar wetlands occur in tropical Western Australia (eg Lake Gregory: Jaensch & Vervest 1990) and Queensland (eg Lake Galilee: Braithwaite et al 1985). These wetlands form a network on which internationally significant populations of waterbirds depend for survival (Jaensch & Vervest 1990). Despite some recent inventory, high variability of conditions and the vast areas to be surveyed have limited the outcomes, such that further investigation of waterbird usage is required. (Refer to Action 2 below)

In fact, the description of waterbird conservation values of many NT wetlands, including coastal areas, remains incomplete. Most of the major coastal and sub-coastal wetlands of the NT have been surveyed for waterbird usage to some extent. Apart from the Alligator Rivers Region (eg Morton et al 1991) the emphasis before 1990 was on Magpie Geese and data for other species were recorded but not analysed. Over the past five years, CCNT has performed regular aerial surveys of many of these wetlands (R Chatto unpublished data). More than 50 breeding colonies of cormorants, herons, ibises and/or spoonbills, the majority previously not documented, were monitored and most were found to be active each year. The focus of this work and follow-up ground surveys has been wetlands of the Darwin Coastal bioregion, where the majority of the regularly-used colonies occur. However, completion of data analysis is expected to reveal significant gaps in knowledge within this area and for intertidal areas further west and east. Additionally, the role of small upland wetlands in the coastal region and further inland has not been systematically studied. (Refer to Actions 3 & 4 below)

In general, inland tropical wetlands have received little attention. A preliminary inventory of wetlands of the NT sub-humid zone, with emphasis on waterbird conservation values, was conducted in 1993 (Jaensch 1994a) and there have been some follow-up surveys. Some inland bioregions (eg Sturt Plateau) contain distinctive wetlands that have never been surveyed for waterbird usage. Brief aerial surveys of other areas (eg northern Tanami bioregion) have revealed large waterbird populations and high numbers of species in wet years (Jaensch 1994a). (Refer to Action 5 below)

Desired actions

1 Investigate methods for elucidating movements of waterbirds between coastal and inland wetlands and beyond the NT.

2 Set aside funds for opportunistic (wet year) surveys of waterbird usage of inland tropical wetlands, to improve knowledge of the importance of these wetlands for waterbirds, especially breeding and migrant species.

3 Complete analysis of CCNT survey data (coastal wetlands), to identify gaps in knowledge of waterbird usage and then conduct surveys to fill the gaps.

4 Conduct further ground surveys of major shorebird concentrations on the NT coast, to clarify species composition and seasonal occurrence.

5 Complete the inventory of waterbird usage of wetlands of the NT sub-humid tropics begun in 1993 by conducting surveys of wetland suites not yet visited.

3 Waterbird populations

Only one waterbird species, Little Tern *Sterna albifrons*, that occurs regularly in the NT is regarded as nationally threatened (ANZECC List), but several of its known breeding colonies in the NT are monitored by CCNT officers. Two additional NT species (Freckled Duck *Stictonetta naevosa* and Painted Snipe *Rostratula benghalensis*) are considered by the RAOU (Garnett 1992) to be nationally threatened but neither occurs in nationally significant numbers in the NT (Jaensch 1994a). (Refer to Action 6 below)

No waterbird species is endemic to the NT or the Wet-Dry tropics of Australia; most locally breeding species also occur widely in sub-tropical Australia, New Guinea and/or South-east Asia (Blakers et al 1984, Marchant & Higgins 1990, 1993). However, in September–December each year, the bulk of the world population of the migratory Little Curlew *Numenius minutus*, and most of the Oriental Pratincoles *Glareola maldivarum* that migrate to Australia, use wetlands and associated grasslands of coastal and/or inland NT before moving to other parts of Australia (Bamford 1990, Watkins 1993, Jaensch 1994b). (Refer to Actions 7 & 8 below)

Breeding populations of several waterbird species (mainly herons, egrets, spoonbills) in the NT, all in estuarine mangroves or in swamp forest on sub-coastal floodplains (eg Daly, Finniss, Adelaide and South Alligator and East Alligator systems), are probably the largest in Australia (Marchant & Higgins 1990, R Chatto unpublished data). These species all have broad breeding distributions beyond the NT and none are threatened nationally or globally. However, breeding colonies are few, hence breeding populations of colonial species are inherently vulnerable. Colonies are also densely populated and thus vulnerable to human disturbance (eg passing boats). Consequently, awareness of the existence of colonies should be improved. (Refer to Action 9 below)

The only species for which the NT is thought to support the bulk of the world breeding population is the Magpie Goose (Marchant & Higgins 1993). There is little information available on populations in southern New Guinea but recent surveys (S Halse, R Jaensch et al unpublished data) suggest substantial numbers may occur there. Surveys by CCNT have revealed NT populations at times in the order of three million birds (Bayliss & Yeomans 1990), hence there is no immediate threat to this species. However, it has been discovered that the relative importance of individual floodplains for breeding varies year to year, such that this species depends on the entire floodplain system of the Darwin Coastal bioregion for long term maintenance of population (Whitehead et al 1992). (Refer to Action 10 below)

Desired actions

6 The status of each NT waterbird species should be reviewed, to identify any species that may be threatened and/or requiring urgent conservation measures.

7 Ensure that all NT wetlands important for Little Curlew and other migrant waterbirds are identified and resolve any threats to continued use by those species. (This will initially require broad-scale surveys to complete an inventory of the important wetlands, then monitoring over several years to establish chronology of occurrence at each site.)

8 Conduct dietary studies on Little Curlew to develop a better understanding of habitat usage in and beyond the NT.

9 Complete analysis of CCNT surveys of waterbird colonies and identify major sites. Make locations of these sites known to agencies involved in coastal management. Colonies should be taken into account in selection of sites for reserves. Further surveys to fill gaps in knowledge should be planned.

10 International effort is required to establish size of population and breeding colonies of Magpie Goose in New Guinea, to more precisely place NT data in global context.

4 Management issues: all wetlands

Pastoral grazing of cattle and/or buffaloes causes significant changes to wetland vegetation and hence affects waterbird usage. Some research is being done by CCNT on the effects of grazing on floodplain vegetation (Mary River Conservation Reserve) but little research has been done to link the effects on vegetation, to waterbird usage. Heavily grazed wetland provides significant opportunities for feeding by shorebirds and some larger wading birds that cannot readily exploit densely vegetated wetland. Given that many NT wetlands will continue to be subject to pastoral grazing, it is possible that grazing could be managed to produce a patchwork of vegetation types, which may optimise the diversity of waterbird species using these wetlands. (Refer to Action 11 below)

The effects of fire-induced changes in wetland vegetation, on waterbird usage, are not well understood. Most NT wetlands are subject to both grazing and fire and the impacts of each are thus difficult to discern. A diversity of waterbird habitats is probably the most desirable outcome of any regime of grazing and fire. (Refer to Action 12 below)

A season during which hunting of Magpie Goose and certain other waterfowl is permitted, in designated areas of the NT, is generally proclaimed annually (September to November). Some (illegal) hunting occurs in pastoral lands throughout the year, generally at low intensity. Additionally, Aborigines may hunt at any time on their lands. Given the relatively low number of people involved in hunting of any sort and the large areas of wetland that are not readily accessible to hunters, even in the Dry season, it is probable that the impact of hunting is not significant for any waterbird species in the NT. Annual census of Magpie Goose populations over a decade has not revealed any population declines that might be obviously attributed to hunting pressure (Whitehead, Bayliss & Fox 1988).

Given the high susceptibility of Magpie Geese to ingestion of lead shot that has fallen in wetlands (Whitehead & Tschirner 1991), use of lead shot has been banned at three of the four hunting reserves near Darwin.

Pollution of wetlands by effluent from mining could affect food items of some waterbirds but, being relatively localised, is not likely to alter the regional diversity of waterbirds or the conservation status of any waterbird species in the NT.

Desired actions

11 Conduct research to reveal the impacts of various grazing strategies (on sub-coastal floodplains) on a broad range of waterbird species.

12 Conduct research to reveal the impacts of various fire regimes (initially on sub-coastal floodplains) on a broad range of waterbird species.

5 Management issues: intertidal wetlands

Internationally significant numbers of migrant shorebirds occur on intertidal mudflats of the NT coast every year. Important sites for shorebird feeding occur mainly in bays between Port Keats and Port McArthur (Watkins 1993, Garnett & Taplin 1990, Usback & James 1993, R Chatto unpublished data). Shorebirds require secure roost sites at high tide: these tend to be few and often are sited on sandy spits. Thus, roosts near urban areas (eg Buffalo Creek, Shoal Bay) are vulnerable to disturbance by humans. Australia has international obligations under three treaties (Bonn, JAMBA, CAMBA) to protect these migrant species. (Refer to Action 13 below)

Desired actions

13 Complete analysis of CCNT surveys of shorebird concentrations and identify major roost sites. Location of these sites should be made known to agencies involved in coastal management. Further surveys to fill gaps in knowledge should be planned.

6 Management issues: sub-coastal floodplains

Intrusion of saltwater (and/or accelerated drainage of freshwater) on large areas of floodplain, due to past creation of swim channels by feral buffaloes, has destroyed floodplain vegetation and rendered these areas of limited value to most species of waterbirds. Corrective measures (eg artificial levees) have been undertaken in some areas, notably the Mary River floodplain, by collaborating land managers. (Refer to Action 14 below)

The exotic shrub *Mimosa pigra* has invaded large areas on most sub-coastal floodplains in the Darwin Coastal bioregion. Though some waterbirds (eg secretive species) may be favoured, the diversity of waterbird habitats, especially for species that wade in open shallows, is reduced. Other weeds (eg *Salvinia molesta*), if occurring extensively, also may reduce diversity of waterbird habitats. (Refer to Action 15 below)

Exotic pasture grasses, notably para grass *Brachiara mutica*, have been introduced to significant areas of the floodplains and are continuing to expand. While some waterbirds may use this habitat, the reduction in diversity of waterbird habitats resulting from this trend towards monospecific vegetation cover can only be detrimental to overall waterbird conservation values. (Refer to Action 16 below)

Ponded pastures have not yet been established at large scale in the NT though exotic pasture species have been introduced to several grazed floodplain swamps. It is conceivable that ponding may benefit some waterbirds and disadvantage others. However, widespread use of ponding is likely to be detrimental to waterbirds because it would reduce habitat diversity and hence the range of waterbird species supported.

Breeding colonies of the Magpie Goose occur mainly on the sub-coastal floodplains, notably the Daly, Adelaide and Mary River floodplains (Frith & Davies 1961, Whitehead 1987, Bayliss & Yeomans 1990). Large areas of the sedge *Eleocharis sphacelata* and/or aquatic grass *Hymenachne acutigluma* are favoured and colonies may number thousands of pairs (Whitehead, Wilson & Saalfeld 1992). Ecological studies (Frith & Davies 1961, Whitehead, Freeland & Tschirner 1990) have shown that successful breeding may be influenced by adequate supply of an important food, wild rice *Oryza rufipogon*, before and during the nesting period (March-May). Maintenance of an abundance of these native plants on the floodplains therefore seems critical. A network of high quality breeding areas, also drought refuge sites, is required if spectacular concentrations of Magpie Goose are to be preserved. (Refer to Action 17 below)

Feral pigs are common on most floodplains and cause extensive disturbance to damp substrate. The impacts on waterbirds are not well understood though there is circumstantial evidence that the combined effects of pigs, cattle grazing and grazing by native fauna (eg geese) may maintain open edges to shallow wetlands, which probably facilitates use by shorebirds and other wading waterbirds that cannot use overgrown wetlands. (Refer to Action 18 below)

Tourism and other recreation in NT wetlands continues to increase. The impacts of fast-moving boats on river banks and on feeding waterbirds has not been well studied but is probably of less concern than other issues, except in sites susceptible to saltwater intrusion. Tours that bring significant numbers of people close to breeding colonies are more likely to be detrimental and should be avoided. (Refer to Action 9 above)

Desired actions

14 Conservation planners and land managers should seek to limit any further salt-water intrusion and repair other salt-damaged areas.

15 From the perspective of waterbird conservation, appropriate efforts to restrict and reduce *Mimosa* infestations are to be encouraged.

16 The full implications for waterbirds (and other wildlife) of pasture grass introductions in wetlands, should be determined.

17 CCNT should continue to disseminate the results of research on Magpie Geese and consult with land managers on maintenance of native wetland plants.

18 Conduct research to reveal the impacts of pig activity (on sub-coastal floodplains) on a broad range of waterbird species.

7 Management issues: wetlands of the sub-humid zone

The most important vegetation for waterbirds in the blacksoil lakes of the Barkly and Sturt drainages is lignum *Muehlenbeckia cunninghamii*, because this shrub (especially the larger plants) supports breeding by a large number of waterbird species including ibises, spoonbills, magpie geese (Jaensch 1994a) and the uncommon Yellow Chat *Ephthianura crocea* (R Jaensch unpublished data). Lignum is subject to grazing by cattle, particularly in drought periods, and has declined or disappeared from parts of wetlands near persistent stock water, apparently for this reason. (Refer to Action 19 below)

The tall shrub river cooba *Acacia stenophylla* is favoured for breeding by colonial egrets and night herons (Jaensch 1994a) but usable stands are confined to several major wetlands. Apparently it is not subject to grazing pressure but factors limiting its occurrence are not known. (Refer to Action 20 below)

It is probable that grazing has caused the disappearance of some plants that are valuable sources of food for waterfowl, notably wild rice *Oryza* spp. (Marchant & Higgins 1993) and probably also wild millet *Echinochloa turnerana*, from most of the Barkly wetlands (P Latz pers comm.).

The exotic thorny shrub *Parkinsonia aculeata*, a declared noxious weed, is widespread in this zone but not yet common in most wetlands. However, some channels and waterholes (eg Playford River system) have become choked with *Parkinsonia* and it seems likely that this limits waterbird access to the water edge, where much feeding and loafing occurs. (Refer to Action 21 below)

There are few permanent wetlands in this zone: most are deep billabongs in seasonal watercourses, eg Longreach Waterhole in Newcastle Creek. Significant numbers of waterbirds use these as refuges in the late Dry season and in drought years. Most are subject to considerable disturbance from cattle (drinking) and humans (recreation, hunting). It is probable that these waterhole populations play a 'seeding' role in repopulation of associated lakes/swamps that fill after dry periods. (Refer to Action 22 below)

Desired actions

19 Quantify the impact of grazing on lignum and consult with pastoral lessees and other land managers regarding appropriate conservation measures.

20 Investigate factors limiting the occurrence of river cooba in the blacksoil swamps/lakes.

21 Collaborate with relevant agencies and pastoralists to plan remedial action against *Parkinsonia*, especially at important wetlands where it is still scarce.

22 Identify the principal waterholes and collate information on waterbird usage and disturbance; investigate means of sustainably accommodating all users of these waterholes.

8 Conclusions

Despite accumulation of considerable knowledge on waterbird use of tropical wetlands of the NT, the conservation of these waterbirds still requires substantial work in the areas of inventory, monitoring, management and research.

Achievement of success in management of tropical NT wetlands - and waterbird populations that use them - will be facilitated by close cooperation between the relevant agencies, including those interstate and in the international arena. Formation of a regional consultative group on wetland management may be appropriate.

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