Using remote sensing to map wetland water clarity and permanence: approaches for identifying wetlands requiring management in large catchments

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Abstract

Protecting wetlands is a major NRM activity across Australia, especially under NHT funding. Programs that provide funding for on-ground works and encourage best management practices are intended to enable improved management of wetlands. However, the reality is that of the many thousands of potential candidate wetlands that would benefit from funding, only relatively few will be the subject of such investments, thus requiring the dispersion of the limited funds to be more strategic. This is a very difficult task, especially when current knowledge of the number, location, variety, ecological character and management needs of wetlands are poorly known. In such situations, and especially in large, remote catchments where little of the required information exists, an archive of satellite imagery is the only feasible means of obtaining the required information in a timely and cost effective manner. Using a combination of satellite imagery, local wetland knowledge, and scientific knowledge of ecological processes, we have developed a process to aid in gathering of strategic wetland knowledge for large remote catchments. Developing such an inventory also contributes to increased land manager knowledge and understanding of regional aquatic resources and wetland management needs, and can feed into other common NRM programs. This paper deals with issues of how to cheaply and rapidly capture substantial wetland inventory information across large remote catchments, and proposes a scheme, based on the principles of wetland permanency, rarity and uniqueness, to prioritise their values and investment priority. Results of ongoing trials of the scheme in the Burdekin and Gulf of Carpentaria catchments of north Queensland are presented.

Keywords

Wetlands, ecological character, remote sensing, inundation frequency, turbidity

Introduction

Wetlands in the dry tropics region of Queensland provide a series of important ecological and recreational functions. Protecting and maintaining these functions requires targeted management action that is appropriate to the needs of specific waterbodies. However there are thousands of wetlands within Queensland and relatively limited resources available to support on-ground works. Consequently there is a need to prioritize the implementation of on-ground works, and such prioritization should be based on (amongst other things) permanence and water clarity dynamics. The remote sensing/GIS approach is used because retrospectively gathering information about inundation extent and water clarity dynamics across large (>100 000 km^2) catchments for numerous waterbodies is not possible any other way.

The GIS database provides a framework for integrating field data with detailed spatial and multi-temporal data collected using remote sensing. The following two examples illustrate how remote sensing data can be used to gather information about the temporal dynamics of wetlands. These temporal dynamics, combined with additional information in the database will be used to guide the allocation of devolved grant funding and on-ground works to best protect the environmental, aesthetic and economical values of complex wetland systems. Two of the most important features controlling the ecology of dry tropics waterholes are their flow/permanence regime and their water clarity regime. Both of these are not only major drivers of aquatic ecology in this region, but they are visually apparent to observers and are often used by on-ground managers in making their day-to-day land management decisions. Fortunately, both of these ecological properties can be characterised from remotely-sensed imagery (Finch *et al*., 1997). The strong seasonality experienced in the dry tropics means that there are very large differences in surface water availability and water clarity over the course of a year. Thus waterbodies need to be characterised by their regime rather than by temporally-static measures. Remotely-sensed imagery can be used to gain this temporal view over large geographic areas and considerable time-scales (e.g. up to 34 years since LANDSAT was first launched)(Wass *et al*., 1997).

Water clarity dynamics

Understanding the dry season turbidity dynamics of isolated water bodies is important because the optical water quality that occurs towards the end of the dry season can have significant impacts on the aquatic community that survive in these refugia until the next wet season (Erskine *et al*., 2005). The temporal dynamics of water clarity are an important feature of wetlands as they determine the euphotic depth and thereby determine the amount of primary production and the structure of the food web. It is not possible to fully characterize the optical water quality of wetlands using archival Landsat TM because of the relatively small size, variable depth and variable substrates (Brando *pers. comm.* 2007). However it is possible to use archival Landsat TM to identify various optical water quality scenarios. In this paper, the following four optical water quality scenarios for the mid-late dry season (June-November) are presented: the waterbody is relatively clear in all available scenes; the wetland is highly turbid in all available scenes; the wetland is usually clear but occasionally turbid; or the wetland usually has high turbidity but occasionally goes clear. These scenarios are potentially useful from a management perspective, because they allow the identification of wetlands that are switching between two states and may therefore be more responsive to management intervention as opposed to wetlands that are in a steady state and may be less sensitive to changes in management.

This information also provides a valuable starting point for dialogue with landholders about water bodies on their properties and any information/observations they may have about how those waterbodies a. respond to existing management practices b. behaved historically (of particular interest if the landholder has a long association with the water body(ies) in question), and c. whether there was anything exceptional about the year(s) in which a water body went turbid.

Inundation dynamics of shallow ephemeral wetlands

Shallow ephemeral wetlands are a feature of semi-arid and dry tropics floodplains. They typically form immediately following a rainfall or flood event, and then dry out in the following months as the dry season progresses. In some instances these ephemeral wetlands are connected to smaller permanent water bodies, or they may be large areas of impeded drainage that dry out completely every year and may remain dry for many years before the next rainfall event. Large ephemeral wetlands provide valuable habitat for many local and migratory birds (Jansen & Robertson, 2001). However collecting information on these wetlands has been hampered by difficult access and their episodic nature. To characterise these large ephemeral wetlands requires large scale, high-return-interval data. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor provides such data, and can be used to provide insight into the inundation and subsequent growth of large macrophyte dominated wetlands. These data can be analysed to provide information on how frequently the wetland is inundated and how long it remains inundated for. When placed in a spatial context this provides valuable information about the local importance and uniqueness of each wetland. Identifying and characterising these wetlands is of particular importance because of a. their unique habitat values and b. their distinct management needs.

Methods

Water clarity dynamics

The approach described in this study is designed for application to archival Landsat data. To make the approach applicable across large areas at low cost necessitates the use of a relatively simple and robust approach. The approach requires the use of a large number of Landsat TM scenes to characterize the water clarity of the waterholes throughout each scene. Landsat TM is relatively cheap to acquire for large areas and its archive extends back to 1986 with earlier versions of Landsat data available back to 1972. With a pixel resolution of 30 metres, smaller waterbodies are not able to be included, but for the limited cost and extensive temporal and geographic coverage, it provides useful management data for a significant proportion of waterbodies within a catchment. To demonstrate this method dry season scenes from seven different years between 1989 and 2001 were analysed. These scenes cover the main channel of the Mitchell River and four off-channel lagoons (from 800 metres to 2.5 kms long) at the intersection of the Mitchell and the Palmer Rivers in northern Queensland to determine the consistency of dry season water clarity between years. When applying this technique across large catchments, to atmospherically correct such a large number of scenes would be prohibitive, so an analysis technique is used that can be applied to the uncorrected digital numbers (raw data) and will allow characterization of the water clarity dynamics using the ratio of Band 3/Band 2 (high values of this ratio indicate higher suspended sediment, leading to lower clarity). The approach used in this paper is similar to that described in Nellis *et al.* (1998) but has been simplified to enable calculation from raw digital numbers rather than atmospherically corrected scenes.

Inundation dynamics
Data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite can provide new insight into the dynamics of large wetlands and wetland complexes. The MODIS satellite generates a large number of products, the one used in this study is the 16 day composited Normalised Difference Vegetation Index (NDVI) product (MOD13Q1)(Zhang *et al*., 2003). The data has 250 metre pixels which means that it can only be analysed for larger wetlands, however its main advantage lies in its temporal coverage. The data is collected daily and then composited every 16 days to get rid of clouds, smoke and atmospheric effects, meaning that cloud free data is typically available for most areas throughout most of the year. The MOD13Q1 data archive extends back to May 2000 and a time series of NDVI for each 250x250 metre pixel is available Australia-wide at no cost. For vegetated areas NDVI ranges between 0.4-1 (3000 to 10000) and increases with increasing leaf area or 'greenness'. Areas of bare soil range between 0.2-0.4 (2000 to 4000), and in the timeseries shown below values below 2000 indicate that the pixel contains predominantly water. An example of the application of this product is shown from a wetland complex in the Burdekin catchment associated with a basalt spring province known as the Great Basalt Wall, approximately 100 km SW of Townsville. The 16-day composite MODIS imagery from May 2000 to the end of 2005 for the area was acquired for the analysis.

Results

Water clarity dynamics
In Figure 1, the Mitchell River main channel has greater clarity than the off channel lagoons. Windermere Lagoon has a low clarity in all years but one (2000), possibly indicating that under a different management regime it may clarify more often. Reedy Lagoon on the other hand has a higher degree of clarity in all scenes except 1995 when the ratio rises above 1, indicating increased suspended sediment. It is interesting to note that the Purumu Lagoon, which is adjacent to Reedy Lagoon, and is located on the same flow path, has an entirely different water clarity regime. It has persistently high suspended sediment (ratio at or near 1.5) for all scenes. Finally, Kingfish Lagoon, which is on the other side of the river, has a relatively greater clarity for all scenes. These results demonstrate that this approach can be used to separate water bodies based on their water clarity regimes. Field verification is required to validate the ecological significance of different ratio values. Once this validation has been achieved eCognition ™ can be used to define inter-annual water clarity dynamics for all large (> 2500 m^2) waterbodies in the Mitchell catchment. These results provide an example of how the method can be used to identify the range of water clarity regimes that may be encountered in order to guide site selection for field validation programs.

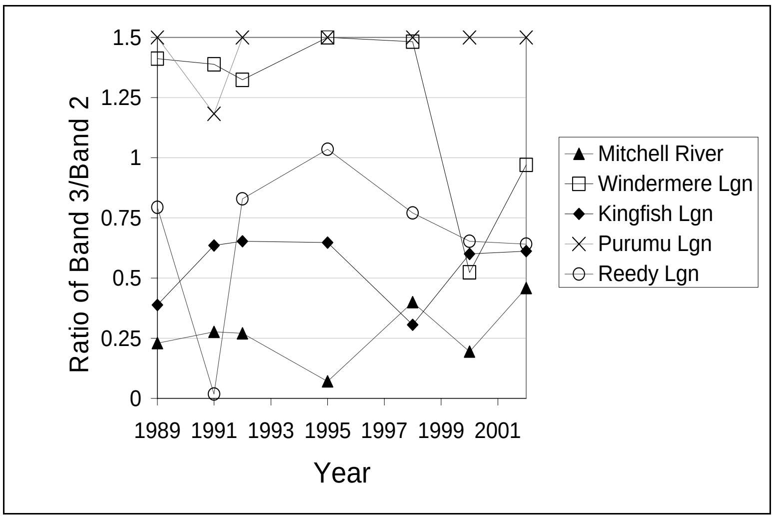

Figure 1. Water clarity dynamics in 5 water bodies (1.5 = low clarity, 0 = high clarity).

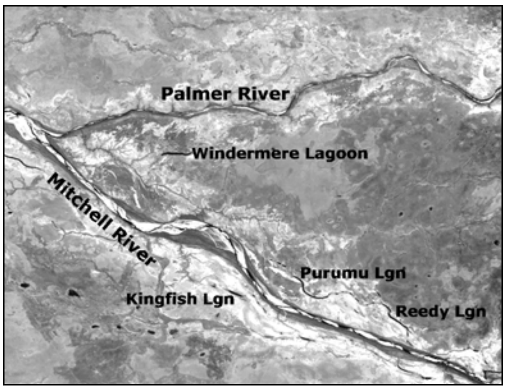

Figure 2. Water bodies at the intersection of the Mitchell and Palmer rivers.

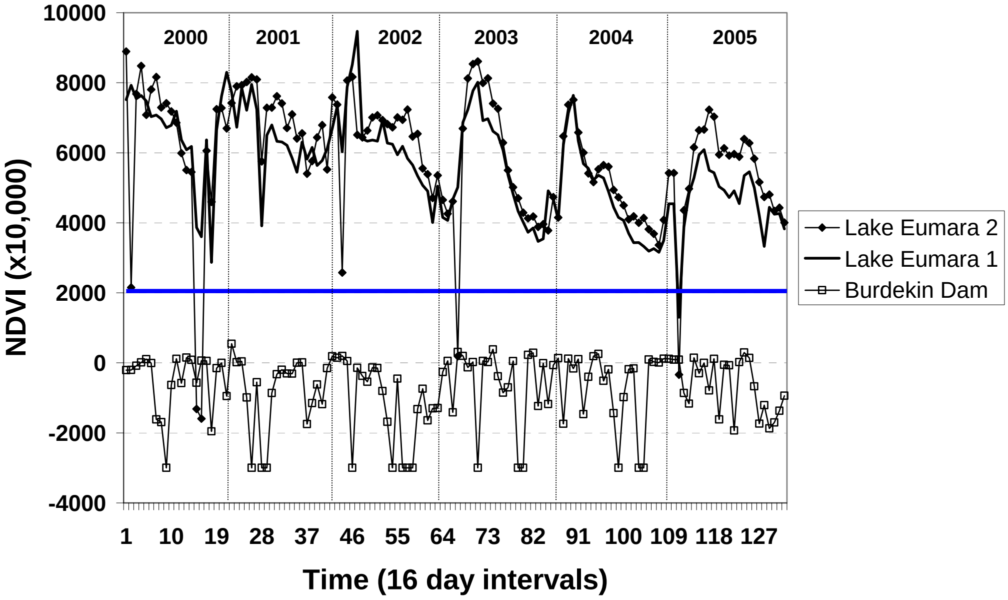

Figure 3. MODIS timeseries for the locations shown in Figure 4, the Burdekin Dam signature is included as an example of an area that remains permanently inundated.

Inundation frequency

The MODIS NDVI time series for three wetland areas is shown in Figure 3. The top two time series represent different areas of Lake Eumara. Locations for these time series are indicaterd by the arrows in Figure 4. The Burdekin Dam (located on the Burdekin River ~100km downstream of Lake Eumara but not shown in Figure 4) time series has been included as an example of a permanently inundated area (NDVI value always below 2000). The two Lake Eumara time series show cycles of macrophyte growth and senescence that are punctuated by periods of inundation. Taking the year 2003 as an example the wetland was inundated to the point where location 2 in Figure 4 was inundated, but location 1 was not. Note that the time series of location 2 drops below the value 2000, whereas the timeseries for location 1 does not. After this period of inundation both sites experience a growth flush (rapidly rising NDVI values) and then senesce off as the dry season progresses.

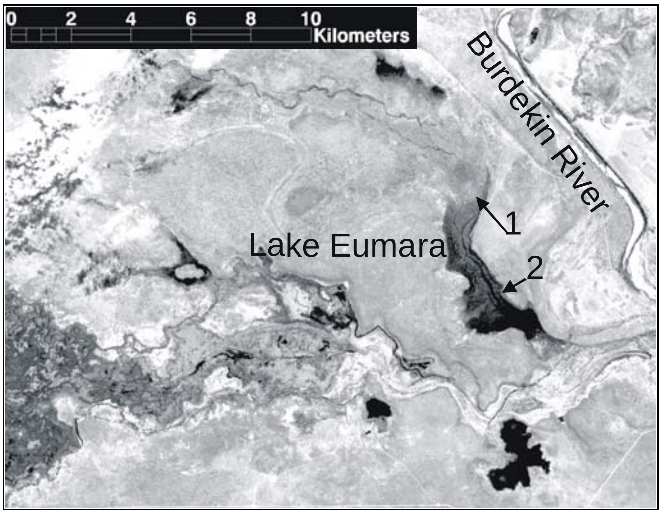

Figure 4. Wetland complex in the Burdekin catchment (January 2003).

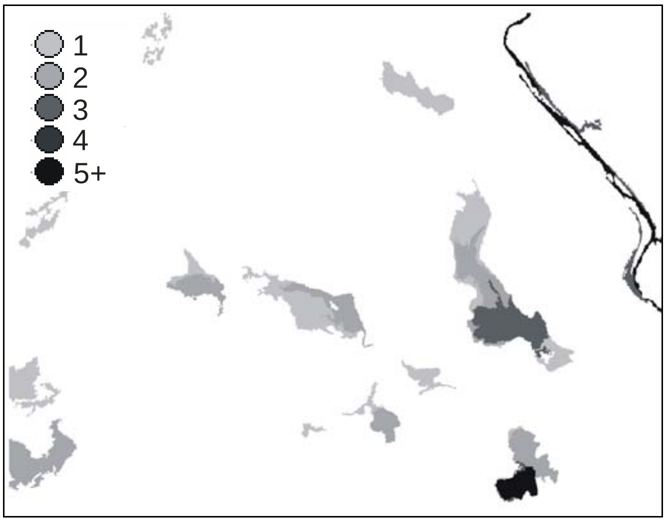

Figure 5. Wet season inundation frequency of different wetlands (number indicates the number of wet seasons the wetland was inundated out of possible total of 6).

It is interesting to note that the inundated location experienced a stronger growth flush (higher NDVI values) than the non inundated site. Neither site is inundated in 2004, but both experience a wet-season associated growth flush. The black diamond and smooth time series shown in Figure 3 are associated with the Lake Eumara wetland, notice that the smooth series that comes from a drier part of the wetland and only drops below an NDVI value of 2000 in early 2005 (hence a value of 1 in Figure 5) whereas the black diamond time series drops below an NDVI value of 2000 in late 2000, early 2003 and early 2005 (hence a value of 3 in Figure 5).

Figure 4 shows the wetland complex at the eastern end of the Great Basalt Wall. The wetlands shown include the Burdekin river (diagonal feature in the top right), Spring Lake, (bottom right) and Lake Eumara (complex system moving from top left through to middle right. These three represent riverine, lacustrine and palustrine wetlands respectively. The results shown in Figure 5 were calculated by using eCognition ™ to generate polygons that describe the extent of the wetlands shown in the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data. These polygons were then used as a basis for analysing the MODIS data. End of wet season imagery was used to identify which areas were inundated at the end of every wet season. It is interesting to note that both the Burdekin river (riverine) and Spring lake (lacustrine) are inundated during every wet season for the period of observation, however Lake Eumara and its associated wetlands shows a more complex mosaic of inundation frequencies.

Discussion

The example of water clarity dynamics provided here shows how much useful information and understanding of the water clarity regime can be obtained from a desktop study using the approaches outlined. The results of the water clarity dynamics analysis also raise some interesting questions. For example why do Purumu lagoon and Reedy lagoon have such markedly and consistently different water clarity regimes? They are closely located on the same flow path and on the same floodplain of the Mitchell River, so it is likely that they will receive similar input water quality during flood events. However during this series of dry season images, one has persistently high suspended sediment, whereas the other has a greater degree of clarity. There are a number of possible causes, including water depth differences (and associated wind resuspension), cattle access or differences in ground water flushing. It is not possible to distinguish between the different causes using remote sensing, however knowing that these water bodies do have such different water quality trajectories enables targeted fieldwork and on-ground surveys to try and identify the cause(s). Being able to identify these factors from a rapid desktop study greatly enhances the efficiency of field work.

The results presented in Figure 5 provide valuable insight into the maximum extent and frequency of wet season inundation. Both of these attributes are particularly important for migratory birds, particularly when the wetlands are placed in a broader regional context. Both attributes contribute to the uniqueness of a wetland, and the spatial context can further highlight specific wetlands of being of particular importance. The results presented in Figure 5 represent one of a series of inundation frequency and duration products that can be generated from analysis of MODIS data. There is also potential to map the growth and senescence phases of emergent macrophytes in large shallow wetlands using MODIS data too. These data are not presented here in the interests of brevity, but they are being included in our overall wetland characterisation scheme. There are other, more cloud-resistant methods of mapping wetland inundation, including LIDAR, microwave and radar. Whilst the analysis of MODIS data has its limitations, its lower cost and ease of calculation make it attractive by comparison. The main limitation of the MODIS approach is the size of wetlands to which it can be applied and that some portions of northern Australia experience more than 16 consecutive cloudy days, leading to a null value for the NDVI in the areas where this occurs. This limits detection of the true maximum extent of inundation, because of the clouds typically associated with flood events. However, for an ephemeral wetland to be effective bird habitat the wetland needs to persist for a period of time, increasing the likelihood of its detection using the MODIS NDVI threshold approach. The approaches presented here are being used by the Australian Centre for Tropical Freshwater Research to assist in characterisation and classification of diverse and complex wetland systems across the dry tropics, to generate hypothesis for field verification and increase the broader knowledge base and understanding of tropical wetlands. This approach has been developed specifically to provide regional NRM groups with a cost-effective means of prioritizing wetland protection/restoration projects. In future eCognition ™ will also be used to describe the extent of riparian vegetation that surrounds each water body, and will also be used to place the water body into a hydrological context (floodplain, in-channel, non-fluvial).

Conclusion

The information about water clarity and inundation dynamics generated by this approach provides new insight into the ecological character of large wetlands distributed throughout semi-arid catchments. This information can be coupled with field observations through a GIS data base to develop an ecological character description for each wetland. The overall description of ecological character can be used to identify and prioritize management actions.

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