Delta Green – a new metric for predicting trends in riparian vegetation recovery

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Key Points

- Delta Green, which we calculate as the average annual increase in landsat-derived Persistent Green, can be used to hind- and forecast vegetation changes in the riparian and littoral zones of the Manning, Great Lakes and Karuah Catchments.
- High resolution lidar has been cross-referenced with contemporaneous Landsat data to develop a model relating Persistent Green to tree cover, hence changes in persistent green (i.e. 'delta green') observable in the Landsat data can be used to define a vegetation cover time series.
- Based on an estimated cost of establishing new riparian vegetation of ~$16.7k / ha, we calculate that "natural" regeneration is currently providing $2.45M of ecosystem services per year. Since the beginning of the Landsat record this amounts to almost $75M.
- Only 117 ha of woody vegetation, on top of the amount predicted to establish via natural regeneration, is required for all riparian and littoral zones in the study area to exceed 70% cover by 2040. This assumes the underlying causes of vegetation increase (most likely reductions in cattle grazing) persist through this time.

Abstract

We used high resolution lidar to develop a digital elevation model, canopy height model and water mask for the Manning, Great Lakes and Karuah Catchments. Using these datasets we calculated vegetation density across ~2000 1km long riparian and littoral study reaches. We cross-referenced this lidar-derived vegetation density data with contemporaneous Landsat data to develop a model relating Persistent Green to tree cover. We then used the entire Persistent Green record (beginning 1988-89) to derive the historical trend in vegetation cover, by combining "Delta Green" (here defined as the average annual % increase in Persistent Green observed through the Landsat record) with the observed relationship between persistent green derived from landsat data and lidar derived vegetation density. We then projected forward from the observed trend in vegetation change to arrive at a likely year 2040 vegetation status for all riparian and littoral zones.

We predict that over the next 20 years ~3000ha of additional woody vegetation will become established in the riparian and littoral zones of the catchments, without any direct intervention – assuming the socio-economic drivers responsible for reducing land-use intensity continue. Particularly important will be a continued reduction in riparian cattle grazing. This 'natural' increase will result in all but 10 streams or lakes achieving a woody vegetation cover greater than 70% . The ten remaining streams and lakes require amongst them a total of just 117ha of additional woody vegetation to be established, by direct intervention, for all streams and lakes to have a 70% or more cover by 2040. Thus equates to just under 6ha/year.

This work indicates that in excess of 95% of the revegetation task could be achieved by continuing to support natural regeneration.

Keywords

Manning Catchment, Riparian Vegetation, Littoral Vegetation, Lidar, LANDSAT, Persistent Green

Introduction

This paper is focused on determining the distribution and condition of woody vegetation within the riparian and lakeside environments of the Manning, Great Lakes and Karuah Catchments using currently available Lidar and Landsat datasets. Characterizing the spatial and temporal distribution of riparian vegetation plays a critical role in developing catchment management plans, given the central role played by riparian vegetation in reducing channel boundary erosion, improving and/or maintaining water quality, providing habitat, and mitigating the negative impacts of flooding. Managing riparian vegetation is the principle tool available to natural resource managers to effect catchment-scale improvements in the river environment, both in terms of its intrinsic values, and its impacts on society. Hence mapping the distribution of trees in the riparian zone, as we have done here, provides the first step in prioritising catchment works. Brooks et al. (2016) argued for a holistic river management strategy focused on riparian vegetation to address four key objectives:

1. Minimising channel erosion, thereby protecting riparian land and reducing sources of sediment to downstream reaches and receiving waters.

2. Maximising sediment deposition and nutrient retention within the channel network (thereby improving end-of-system water quality and reducing the "leakiness" of energy flows through the network)

3. Maximising ecosystem functioning through increased habitat complexity (e.g. increased low flow pool habitat availability)

4. Minimising flooding in the lower catchment, through increasing in-channel roughness in upstream channels with reduced flood celerity in key tributaries.

Woody riparian vegetation, typically shrubs and trees greater than 2m high, are considered particularly important components of the fluvial system (see as examples the work of Erskine and co-workers (e.g. Erskine et al., 2012) in the Hunter; and Gurnell and co workers (e.g. Gurnell, 2014) more broadly) which have historically been mis-managed, often under the belief that they cause erosion and increase the flood hazard. Riparian vegetation is the principle means by which the material strength of the bed and bank material can be increased. Plant roots both protect and reinforce sediments, extending across zones of weakness and potential failure within bed and banks and binding materials together, giving them greatly enhanced resistance to erosion, greatly exceeding that which would be possible without the addition of vegetation (Abernathy and Rutherfurd, 2001). For example, commonly found riparian species such as *Casuarina cunninghamiana* and *Eucalyptus camaldulensis* have roots that can extend many metres into bed and bank sediments, while *Melaleuca* stands can produce extensive root mats holding down otherwise mobile sand and gravel bodies. In addition to increasing the material strength of bed and banks, riparian vegetation reduces the overall erosivity of the flow by slowing it down. Sturdy, somewhat flexible vegetation (e.g. stands of growing *melaleuca* or *casuarina*) plays an important role in slowing the passage of floodwaters, reducing its tendency to erode the channel margins. In addition to reducing the aggressiveness of floodwaters towards channel bed and banks, slowing floodwaters greatly reduces their impact on life and property. Slower moving, albeit more spread out floods, can be anticipated and managed for, whereas fast rising, fast moving floods can be catastrophic. Flood hydrology (how high a flood is, how fast it arrives, and how long it lasts) depends in large part on the density of woody vegetation within the riparian zone upstream (Lane, 2017). Decreases in vegetation density upstream will tend to increase the negative impacts of flooding downstream.

Vegetation can decrease the erodibility of sediments through root reinforcement, and increase water levels and sediment retention though increases in channel roughness. Large woody debris jams can also serve to promote stability or aggradation, especially when established (either naturally or via the construction of engineered log jams) early in the aggradation phase of a streams evolutionary cycle. Flexible vegetation within the water column also absorbs a significant amount of stream energy, reducing the proportion available to erode the bed. Documenting the distribution and condition of riparian vegetation therefore gives us our best picture of geomorphic condition at the catchment scale.

Woody vegetation is a natural indicator community that points to not only the ecological health of rivers, but also their geomorphic condition. Furthermore, the density of riparian vegetation also informs our understanding of flood and erosion risk, and likely causes of water quality degradation. For these reasons a detailed assessment of the distribution of woody vegetation within a catchment provides a necessary, and arguably sufficient, basis for prioritising riparian and littoral rehabilitation efforts.

Catchment Description

The Manning, Great Lakes and Karuah Catchments drain 12,200 km^2 of coastal NSW. Combined the catchments extend from -32.70^o in the south to -31.28^o in the north, and from 151.16^o in the west to 152.80^o in the east, having their greatest latitudinal extent of 150 km (along a meridian near Gloucester) and their greatest longitudinal extent of ~124 km (along a parallel through Crowdy Head). Climatically, the catchments are classed under the Köppen climate classification system for the most part as Cfb (Temperate, Without Dry Season, Warm Summer) to Cfa (Temperate, Without Dry Season, Hot Summer), with areas having Cool Summers in the higher elevation areas. The coastal zone is classed as Subtropical with no dry season.

Riparian vegetation was extensively cleared in the Manning Catchment prior to the 1950s (Ferguson *et al* 1993). Removal of this vegetation, and the associated coarse woody debris, will have increased the potential for expansion of the channel cross section, including destabilisation and degradation of channel beds. Where floodplain vegetation has been removed (and over geological timescales, even where it is present) floodplain stripping is possible (e.g. Nanson, 1986).

An outbreak of blue-green algae in Myall Lakes in 1999 saw an increased focus on catchment management, and this, along with deregulation of the Dairy Industry in 2000 (causing large drop in the catchment cattle population) primed the catchment for a widespread turnaround in riparian and littoral woody vegetation cover, documenting the extent of which forms the basis for this project.

Methods

Lidar is available for the entire catchment from the NSW Government Spatial Services (accessed via https://elevation.fsdf.org.au). The quality and scale of this data set is such that it enables identification and height measurement of every tree throughout the ~12,000 km^2 study area, following processing of the original Lidar point clouds to construct a digital elevation model (DEM) and canopy height model (CHM). Furthermore, the DEM so constructed also enabled the development of a semi-automated method for riparian zone delineation, based on constructing a detrended DEM for each individual 1km study reach using a method adapted from Pasternak (2017 – Figure 1). Although this approach took considerably longer than a simple hand trace of the estimated extent of riparian zone based on aerial photography, it afforded the opportunity to undertake the mapping with some degree of objectivity, with riparian zones mapped to have a constant height relative to the thalweg, therefore having greater hydrological significance. Finally, the Lidar Data could also be used to identify water bodies, which is useful for mapping lakeshores, and refining riparian zone area calculations; obviously areas of open water should not be included in the calculations of space available to grow trees.

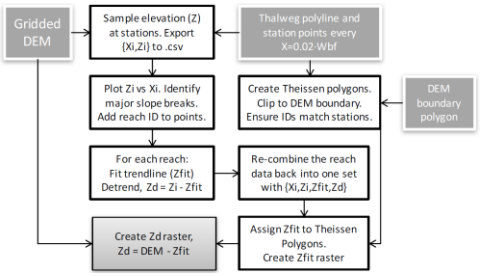

Figure 1: Flow chart describing the Pasternak (2017) method for DEM detrending (after Figure 5 in Pasternack, G. B. 2017. Lower Yuba River Corridor Inundation Zones.)

Each las tile (raw format that the lidar data is supplied in) consists of approximately 6 500 000 points, covering about 4km^2, having a size on disc of about 200MB. More than 3000 tiles (about 600 GB of data) have been processed and analysed. From each Las Tile, and using the proprietary software package 'LasTools' (https://rapidlasso.com/lastools), ground points, vegetation points and regions of low intensity are extracted to construct a DEM, CHM and Watermask for each las tile. From the DEM the centreline of all study streams (with a combined length in excess of 2000 km) have been manually digitised. The thalweg was then divided into 1km reaches, with each reach in turn described by points at 20m intervals, with elevations extracted to these points. To this series of elevations a polynomial fit describing the slope of the channel bed is produced, which is then used as the basis of a detrending operation. Detrending is achieved through the creation of Thiessen Polygons describing regions having a common proximal point on the modelled thalweg. Each square metre within each Thiessen polygon is assigned the modelled elevation of the thalweg point it references, and then this value is subtracted from each corresponding square metre within the DEM to create our Detrended DEM, the value of each cell being equal to its height above the closest point of the thalweg. In this way we can examine surfaces having a varying absolute elevation but a common relative height above the thalweg. The detrended DEM is flooded to a common height above the thalweg, to a level where it just laps the high floodplain. The flooded region is converted to a polygon which describes the riparian zone for that 1km reach. The CHM and Watermask layers are then used to infill the riparian zone. The study reach is now ready to be analysed to determine its vegetation density and other metrics (e.g. vegetation height distribution, change through time, etc).

Trialling the detrending / flooding approach at various parts throughout the catchment showed it to be most reliable in the middle reaches. In the lower tidal areas the topography was far more predictable, in that the riparian zone was inevitably contained within a narrow band between the waters edge and large floodplains. Hence in these locations a simple buffer was used to define the riparian zone, with the width of the buffer set for each stream based on measurement of riparian zone width at locations where the riparian zone forest was intact. Likewise for all the lakes a simple 30m buffer on the water's edge was used to define the shoreline zone. Occasionally, the DEM constructed for the uppermost reaches, where the topography is rugged and tree cover usually very dense, was of insufficient detail to allow the use of the detrending / flooding method. In these reaches manual digitising of problematic reaches was resorted to. The uncertainty introduced by this approach was not deemed problematic however, as in each case the reason for the poor data quality was the presence of thick vegetation (i.e. the very thing being mapped) obscuring the ground surface. Thus minor errors in delineation of the riparian boundary will not result in calculation of an incorrect tree cover estimate.

In addition to the new Lidar data, the Landsat archive, particularly the derived Persistent Green (a proxy for woody vegetation layers were obtained from the QLD SLATS server. Derived layers extending from 1996 to 2015 were incorporated into the analysis.

The persistent green derived layer is based on regularly collected LANDSAT imagery that can be used to monitor the status of vegetation from growing season to growing season. The persistent green derivation is intended to estimate the proportion of vegetation that does not completely senesce within a year, which primarily consists of woody vegetation (trees and shrubs), although there are exceptions where non-woody cover remains green all year round (Trevithick, 2017). Two examples of exceptions relevant to the Manning Catchment are persistently irrigated pasture, and reed beds growing in more or less permanently moist swampy meadow type environments.

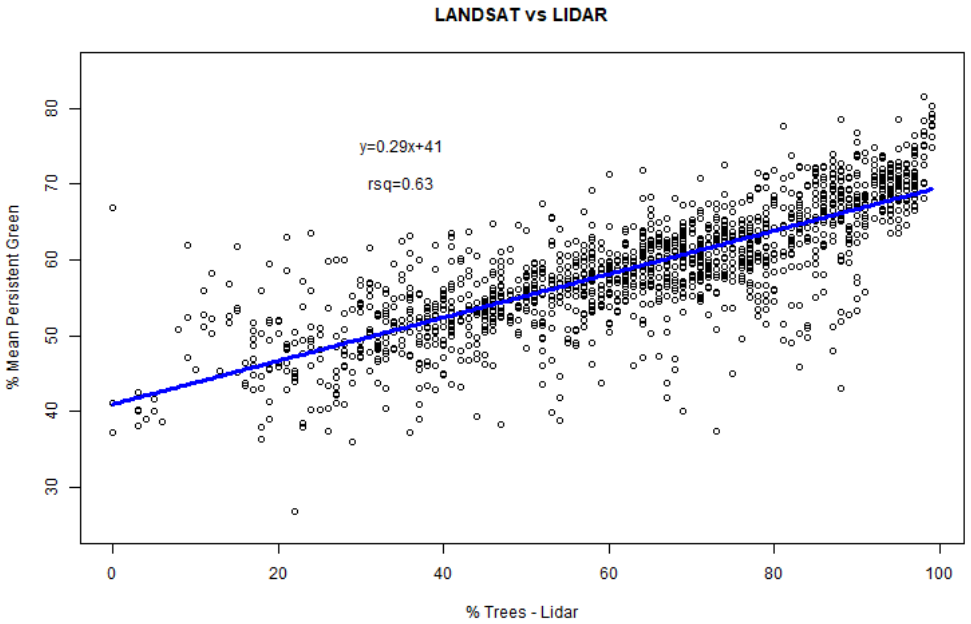

Figure 2: Relationship between LANDSAT derived estimate of Woody vegetation cover (based on % mean Persistent Green) and % Trees observable in our Lidar derived CHMs.

Figure 2 clearly shows, via the scatter around the trend, that there are other contributors to Persistent Green besides woody vegetation. The most significant contributor is likely to be the Landsat pixel size (30mx30m) relative to the size of regions of interest on the ground. Many of the pixels incorporating the littoral zones, and the narrower of the riparian zones, will incorporate some proportion of adjoining tree free water and land. This will cause the absolute persistent green value to be calculated as erroneously low, however it will not impact on the calculated trends. Despite the scatter, the Persistent Green and % Trees are clearly related and this gives us some confidence that the general trends observable in the persistent green data (described below as Delta Green) are reflective of changes in Woody vegetation cover.

Rainfall is an obvious driver of vegetation change, hence we have examined the long term trends in rainfall for each sub-catchment. Sub-catchment shapefiles were imported into VegMachine (vegmachine.net) to extract total monthly rainfall, with the VegMachine data in turn derived from Bureau of Meteorology 5 km gridded rainfall data for the last 30 years (1988-2018) which is averaged across the sub-catchment. For each sub-catchment, rainfall data was analysed via residual mass rainfall curves (Figure 3) to determine long-term trends in above or below average rainfall conditions, which may prove useful in explaining trends in persistent green cover.

At the catchment scale it is possible to detect a connection between rainfall and persistent green (Figure 3), however it is not a simple case of more rainfall equals more vegetation. Note for example, that between months ~160 and ~200, rainfall was declining, whereas persistent green increased over the same period by about 2%, which, when accounting for the relationship observed in Figure 3 amounts to an increase in Trees of 7%, or about 855 km^2. Rather it appears that the changes in rainfall are sufficient to cause some oscillation around a background trend, but the trend itself is heading in a positive direction and is of sufficient gradient to be able to distinguish it from the rainfall induced variability.

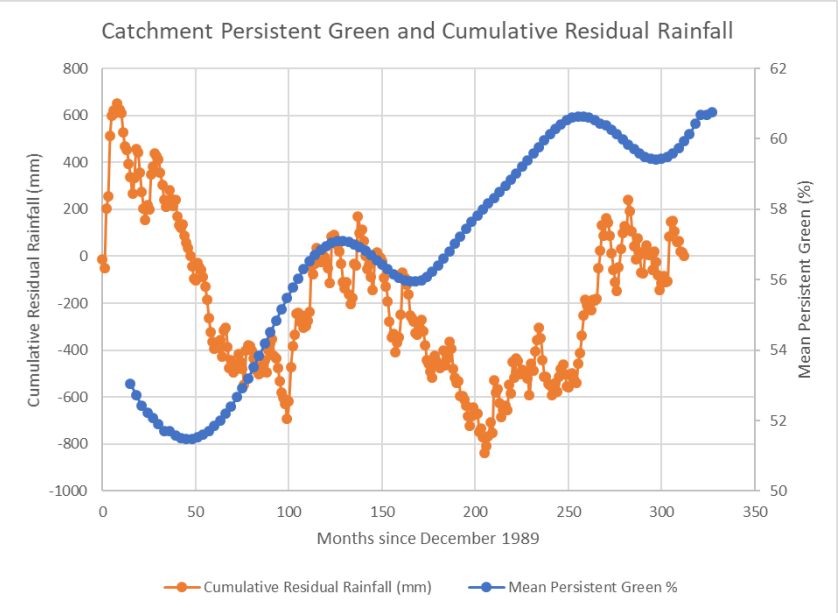

Figure 3: Comparison of Catchment Persistent Green (%) and cumulative residual rainfall for the Manning Catchment.

Persistent Green time series have been constructed for every 1km long riparian or littoral reach. In addition, for illustration purposes we provide in Figure 4 examples of Persistent Green trends for the entire littoral zone for each of the lakes and the entire riparian zone for six example rivers.

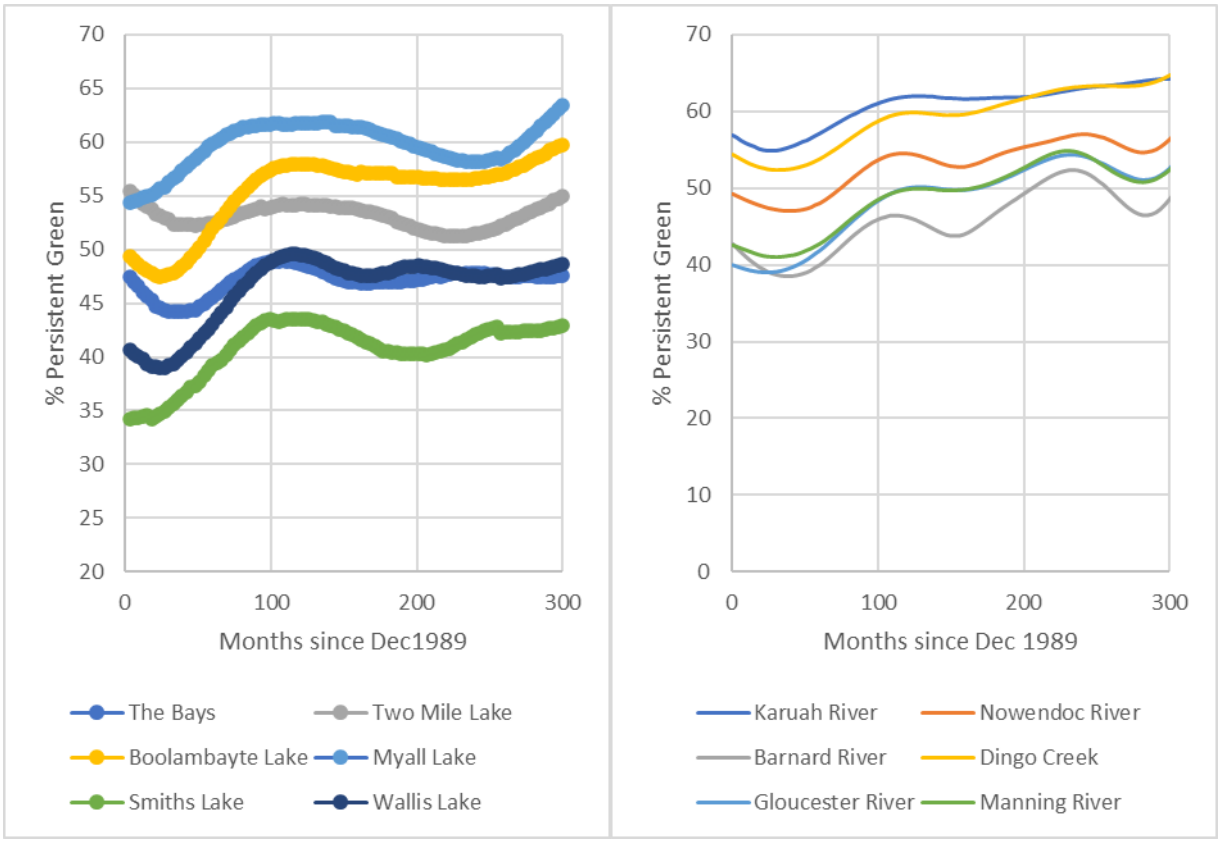

Figure 4: Trends in Persistent Green for littoral zones (left) and six example streams (right).

To reduce the uncertainty introduced by the possible inadvertent mis-classification of riparian pastures and green reed beds as woody vegetation, we have considered only the change in Persistent Green through the sampling period (beginning 1989, with the latest data available being from the 4th quarter of 2015). This value, referred to as Delta Green, is calculated simply as the gradient of the linear regression of % persistent green against time, scaled to year, such that the value represents the average annual % change over the collection period (Figure 5). As can be seen in Figures 4 and 5, this will obscure some of the detail of the development of persistent green through time, but will capture the scale of vegetation change over the 26 years of record.

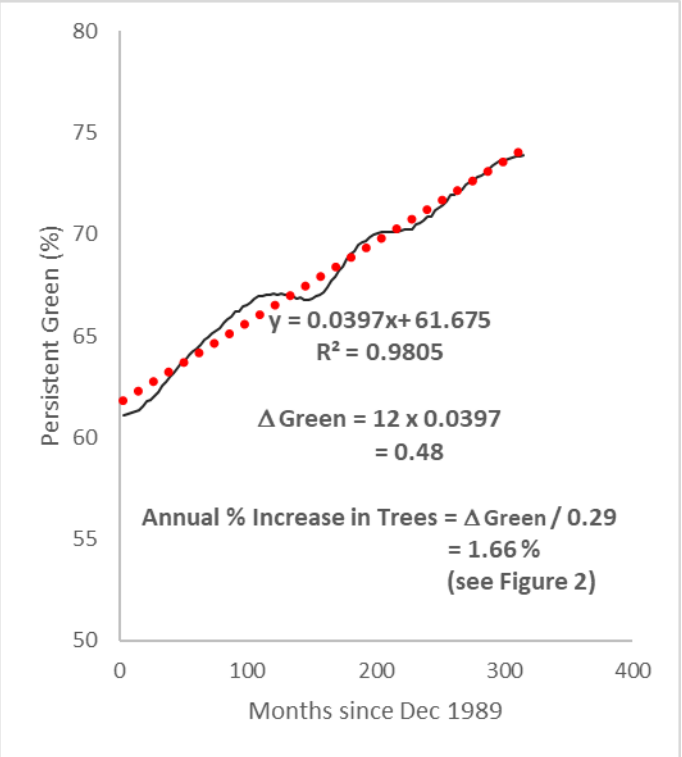

Figure 5: Calculation of Delta Green for a single 1km reach of the Manning River (zone # 13). Black line joins measured monthly persistent green data. Red dots describe linear trend of monthly data. Delta Green calculated by scaling gradient of monthly data to give average yearly increase. Delta Green values converted to average annual increase in vegetation using ratio determined from trend in Figure 2.

Delta Green can be related to changes in vegetation density by considering the relationship shown in Figure 2. This relationship is not 1 to 1, rather a 1 % increase in Persistent Green is equivalent to a 3.45% increase in vegetation density, as measured using a high resolution lidar derived canopy height model.

The newly available data shows unequivocally that the lakes and streams of the Manning, Great Lakes and Karuah catchments are very well vegetated. Few, if any reaches stand out as calling for direct intervention, with there being ample evidence in the Delta Green data to show that if left alone streams and shorelines will revegetate on their own accord, at rates that are acceptable over management timescales. For example, the Manning River has an average vegetation cover percentage of 37%, and an area weighted Delta Green of 0.47%. Accounting for the conversion factor implied by the relationship shown in Figure 2, we could expect to see an annual increase in woody vegetation of about 1.6%, equivalent to about 32 ha of new vegetation cover every year. This increase will see proportional tree cover almost double in the next 20 years (Table 1).

Carrying these calculations forward to encompass the entire catchment, (that is, converting the Delta Green calculated for each 1km study reach to an estimate of change in Tree Cover based on relationship observed in Figure 2, and applying this to current Tree Cover for each stream or lake) we can predict that across the entire

study area, tree cover in riparian and shoreline areas will increase by 147 ha per year. One estimate of the cost of establishing new riparian vegetation (Fiona Marshall, Pers. Comm.) is $16,700 per ha, hence more or less "natural" regeneration is currently providing $2.45M of ecosystem services per year. Since the beginning of the Landsat record this amounts to almost $75M, not to mention the value added in improved water quality, decreased erosion and decreased flood celerity. Furthermore, we note that this rate of increase in vegetation is more than twice the aspirational ICMP target set out in 2003 (NSW DLWC, 2003).

The quality of the data collected here justifies some considered prognostication, based on forecasting the likely changes that will happen without further direct intervention, and then focusing on those areas that will still not be sufficiently vegetated in 20 years.

For the study area a prioritization is proposed based on projecting forward the likely woody vegetation increase over the next 20 years and then focusing on just those areas that will still have less than, say, 70% coverage, which we could set as an aspiration goal. 70% coverage will see very close to the maximum benefits in terms of erosion control and habitat creation, and is likely to be thence too dense to facilitate further active revegetation.

Table 1 shows just those channels and lakes that will still have less than 70% coverage in 20 years, and the increase in woody vegetation in each case that will be required on top of that likely to occur due to natural regeneration in order to reach 70% cover by 2040. The total increase in vegetation required to reach this goal is just 117 ha, with Port Stephens North, Barnard River, Manning River and Myall Creek together accounting for 90% of this.

Table 1. Prioritisation based on projected vegetation cover in 2040, ranked according to increase required to reach 70% cover.

Name	2040 Tree Coverage (%)	Increase in Trees required to reach 70% (ha)	Investment (assuming $16.7k/ha)
Port Stephens North	43.8	61.8	$ 1,032,080
Barnard River	66.0	24.5	$ 409,714
Manning River	69.5	9.6	$ 161,132
Myall Creek	58.2	9.0	$ 150,173
Scotts Creek	63.1	4.5	$ 74,432
Curricabark River	67.6	2.4	$ 40,584
Bundabah Ck	61.6	1.9	$ 32,164
South Arm	67.7	1.5	$ 25,528
Wallis Lake	69.7	1.3	$ 21,209
Avon River Tributary	68.1	0.4	$ 6,129

Conclusions

There is a strong relationship between lidar derived estimates of woody vegetation cover and landsat derived Persistent Green values. Scatter about the observed trend is readily explainable by differences in resolution. This gives us confidence in hindcasting vegetation density over the last 30 years or so, and extrapolating future increases in vegetation. With this, intervention strategies can be planned in the light of predicted short-term natural increases in woody vegetation. Only 10 streams or lakes are likely to have less than 70% woody vegetation cover in 20 years. Of these, Port Stephens North, Barnard River, Manning River and Myall Creek together account for 90% of the needed increase in vegetation to reach 70% across the catchment. Only 117 ha of woody vegetation, on top of the amount predicted to establish via natural regeneration, is required for all riparian and littoral zones in the study area to exceed 70% cover by 2040. In addition to prioritizing interventions in the few locations outlined in Table 1, efforts should be directed to periodic monitoring of changes in vegetation composition and the possible external drivers that have enabled the increase observed over the last three decades. Of particular importance will be any changes in the cattle population within the catchment, as well as management approaches taken by riparian landholders. Finally, recent flooding in the catchment may have interrupted the recent trend, at least for reaches where the vegetation is sparse.

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