Redefining the past - The impact of digitising historic data on our understanding habitat change over time.

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Abstract

In 1985, NSW Fisheries produced “An Estuarine inventory for NSW”. This report outlined the distribution and area of seagrasses, mangroves and saltmarshes and became the primary baseline to which all subsequent estuarine macrophyte mapping in NSW was compared. This data set and the associated area calculations were based of a method of manual tracing with area calculations derived using what is known as the dot grid method. All subsequent estuarine habitat mapping has been based on more accurate digital GIS methodologies.

The West et al. (1985) hard copy maps have recently been digitised and are now more comparable with more recent estuarine macrophyte mapping and will enable more accurate assessments of areal change over time. The new area calculations generated from the digitally-corrected version (DCV) of West et al. (1985) are, in many instances, substantially different from those originally reported.

This paper presents estuarine macrophyte area estimates derived from the DCV maps and describes the consequences for interpretations of temporal trends in these habitats by focussing on the estuaries showing the greatest changes in trends. The DCV maps will provide a new baseline from which we can better assess of changes in estuarine habitats over time.

Introduction

Estuaries and coastal environments have long been the primary areas of human settlement, resulting in centuries of exploitation, modification, transformation and pollution (Lotze et al. 2006). The net result of this has been the decline in the extent of many important estuarine habitats, the reduction of populations of many marine species of both commercial and recreational importance, and a significant decline in overall ecosystem health (Rogers et al. 2016). In addition, habitats such as mangroves and saltmarshes are under increasing threat from sea level rise (Ross & Adam 2013, Rodríguez et al. 2017).

Of the many habitats found in estuaries, macrophytes such as seagrasses, mangroves and saltmarshes are under considerable threat globally and play important ecological roles

(Airoldi & Beck 2007, Waycott et al. 2009, Morrisey et al. 2010). Seagrasses are significantly affected by environmental and physical disturbances. Increased turbidity, changes in salinity, storm events, dredging, moorings, boat anchoring and propeller scaring are all known to have a significant impact on the health and distribution of seagrasses in NSW (Evans et al. 2018, Glasby and West 2018, Larkum and West 1990, West 2012). Mangrove and saltmarsh are impacted by land clearing, agricultural, urban and industrial uses, storm water runoff, dumping of waste and human access resulting in losses in area leading to increased habitat degradation and fragmentation (Feller et al. 2017, Stewart and Fairfull 2008, Rogers et al. 2014, Daly 2013). Sea level rise and the potential expansion of mangroves is also problematic as it may be at the expense of saltmarsh, which may have limited available habitat to expand into (Ross & Adam 2013, Rodríguez et al. 2017). All mangroves and seagrasses in NSW, Australia, are protected under the NSW (Fisheries Management Act 1994). *Posidonia australis* is listed as endangered in six NSW estuaries and as a threatened ecological community under national legislation. Coastal saltmarsh in NSW is listed as an Endangered Ecological Community under the NSW Threatened Species Act.

Seagrasses, mangroves and saltmarshes play numerous ecological roles, including acting as sources of food and shelter for juvenile and adult stages of numerous species (Mazumder et al. 2006, Sheaves et al. 2015), cycling nutrients (Maxwell et al. 2017) and storing carbon (Macreadie et al. 2017). There are numerous species of seagrasses in NSW with the dominant ones being*; P. australis* which is restricted to only 17 estuaries, *Zostera muelleri* subsp. *capricorni* (hereafter *Z. capricorni*) and multiple species of *Halophila* (Stewart and Fairfull 2007, Creese et al. 2009). There are two dominant species of mangroves in NSW, *Aegiceras corniculatum* and *Avicennia marina*. Tropical species such as *Rhizophera stylosa, Bruguiera gymnorrhiza, Ceriops tagal* and *Exoecaria agallocha* are occasionally encountered in the northern estuaries of NSW (Duke 2006, West et al. 1985, Stewart and Fairfull 2008). Saltmarsh is a more diverse vegetation community with as many as 250 species being recorded (Daly 2013). Saltmarsh occurs on the extreme upper tidal limits of estuarine shores on soft muddy sediments often adjacent to mangroves.

Monitoring the extent of these habitats requires reliable methods and accurate estimates. Remote sensing and to date primarily air photo interpretation has been used extensively in NSW to map and monitor the extent of these habitats. This method has been shown to be a reliable means of mapping and monitoring habitat status and trends (Kendrick et al. 2000, Williams and Meehan 2004). The first comprehensive inventory of estuarine macrophytes in NSW was conducted between 1981 and 1984 and surveyed 133 estuaries (West et al. 1985). This study used aerial photography and the Camera Lucida technique (CL) to create a series of 1:25,000 scale maps showing the distribution of seagrass, mangrove and saltmarsh. Estimated areas of each habitat per estuary were calculated using what is known as the Dot Grid (DG) method. While the final maps discriminated some individual species of seagrass and mangroves, the final report only reported total area of each of the three habitat types (all species combined) per estuary along with a list the species present. West et al. (1985) was followed in 2003 by the Comprehensive Coastal Assessment (CCA) (Williams et al. 2007) which aimed to update of the status of seagrass, mangrove and saltmarsh north of Newcastle and south of Wollongong and used aerial imagery and advanced GIS methodologies (Williams et al. 2007). The Seabed mapping project (Creese et al. 2009) was the most recent large scale macrophyte mapping project in NSW and this focussed on estuaries between Newcastle and Wollongong and when combined with the CCA created the second complete inventory of estuarine macrophytes in NSW. Both data sets have been the primary source of information for reporting the status and trends of estuarine macrophytes across the state and have been included in the NSW State of Environment report, the NSW Monitoring Evaluation and Reporting (MER) (Roper et al. 2011) program and as background information in the NSW Marine estate threat and risk assessment (MEMA 2018a).

Given that changes in area of macrophytes are being used to indicate the condition of these habitats (and indeed the estuaries themselves), it is therefore important that methodological differences in area estimates over time are minimised. As such, it was important to update the original DG habitat area estimates using the current GIS technologies. This paper presents the results of digitising the West et al. (1985) data. This new digital data set, referred to here as the Digitally-Corrected Version (DCV), will be analysed to determine change from those calculated using the DG method and the impact this may have on redefining the previously interpreted trends. The newly digitised data set will also enable the reporting of area estimates for different species that were previously only listed as being present. While the species data will not be reported here, it will allow for the analysis and monitoring of change at the species level in future projects.

Methods

Camera Lucida & Dot Grid Techniques

The CL method used by West et al. (1985) used a Bausch and Lomb Zoom transfer scope (Figure 1) to manually capture the habitat boundaries from aerial imagery ranging in scale from 1:16,000 to 1:40,000. The line work was transferred to 1:25,000 scale sheets traced over 1:25,000 scale topographic maps. This method operated at a fixed scale and did not allow for zooming in to capture fine details or patchy habitats. The original imagery was not rectified, but rather visually aligned with the corresponding map sheets. Habitats were delineated based on texture, colour and position within the estuary and, where possible, were delineated to species. Presumptive maps were taken out into the field and validated/annotated and updated to reflect the species and distributions found in the field.

The maps were updated to reflect the field notes and the habitat boundaries were then transferred to 1 mm grid paper for area calculation. To estimate areas, a dot was placed in each corresponding 1 mm grid and were totalled for each of the three habitat classes; Seagrass, Mangrove and Saltmarsh (Figure 2). Final 1:25,000 scale hard copy maps were then created for each estuary based on a combination of the original air photo interpretation and field survey results with species indicated as different cross hatching (Figure 3).

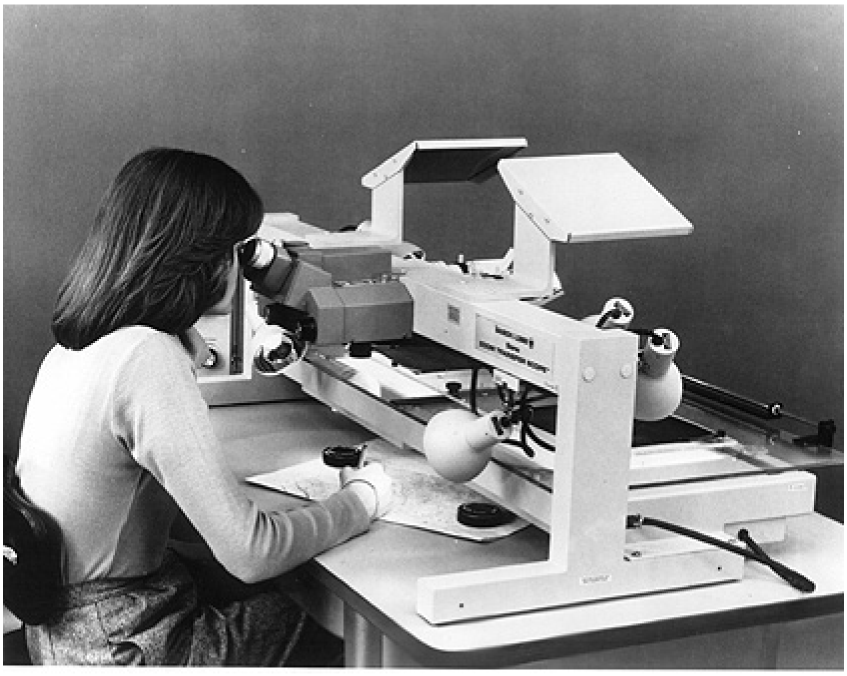

Figure 1. An example of the Bausch and Lomb Zoom transfer Scope used for capturing the boundaries of the estuarine habitats for the West et al. (1885) report. (Image source – The Remote Sensing Tutorial, http://geoinfo.amu.edu.pl/wpk/rst/rst/Sect15/Sect15_3.html)

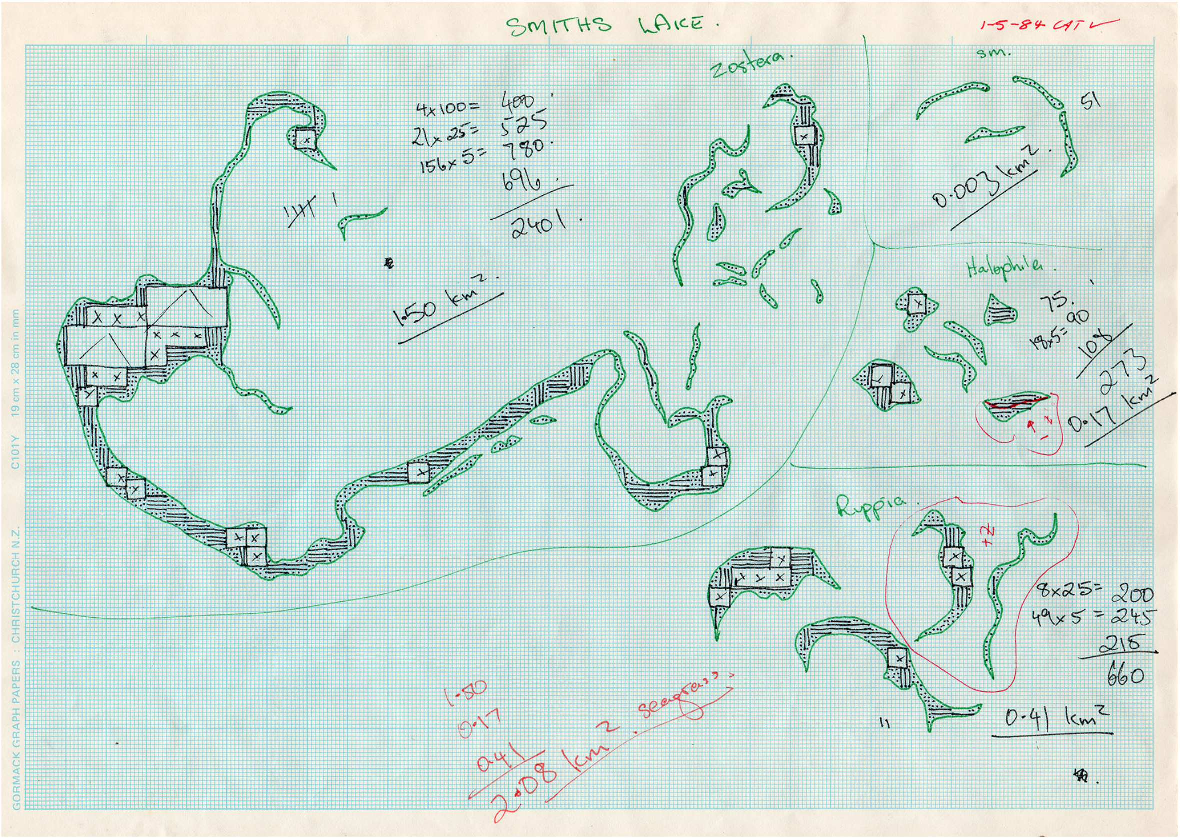

Figure 2. Area calculations for the estuarine habitats of Smiths Lake. As can be seen above, area was calculated for different seagrass species, however, only total area of seagrass was reported for each estuary together with a list of species present.

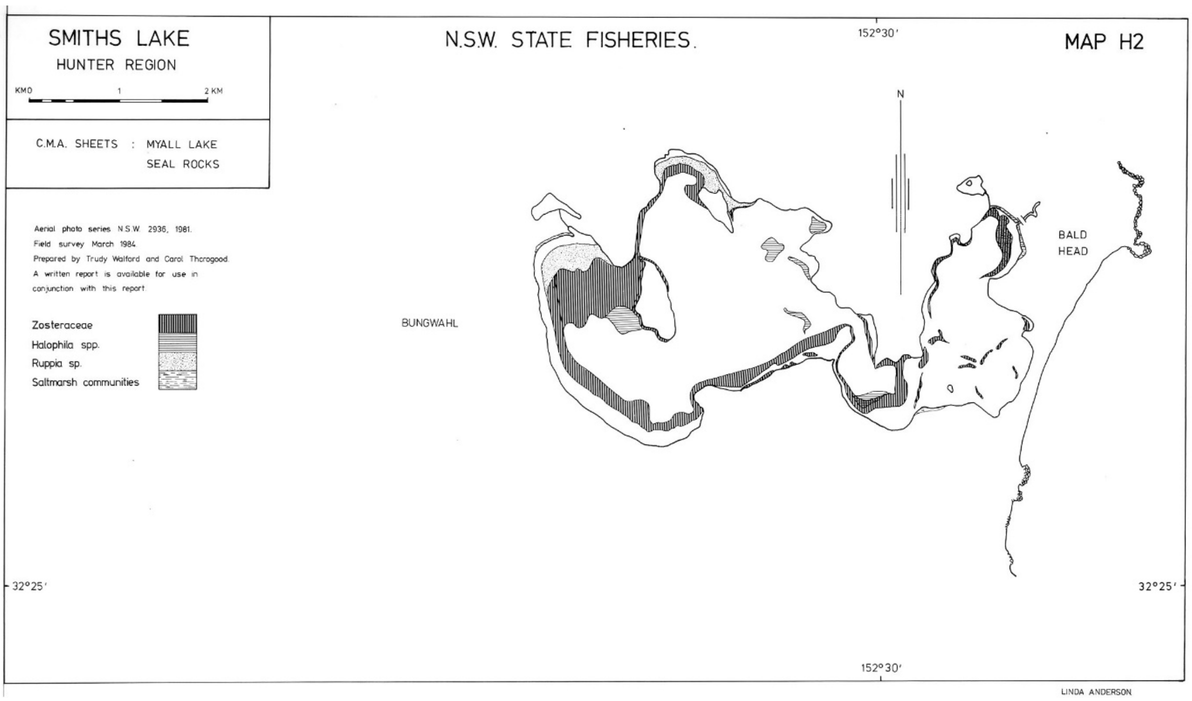

Figure 3. An example of one of the 1:25000 scale West et al. (1985) maps.

Digital Conversion of the original maps

The creation of the Digitally Corrected Version of the hard copy maps involved the imaging of the original maps in sections using a high resolution DSLR. Each map section was corrected for lens distortion and merged together to create a high-resolution mosaic image of the original map. These maps were imported into ArcGIS and georeferenced to NSW topographic 1:25,000 map sheets. Habitat polygons were initially captured using pixel-based classification techniques to extract the habitat polygon boundaries. The derived polygons were then refined using a combination of buffering, smoothing and manual on screen digitising. This final process corrected any poorly aligned or incorrect polygon boundaries, overlaps or gaps and to captured any missing features. All digitising and editing was done at a scale of 1:5000. Attributes were then validated against the original maps, field notes and dot grid area calculations. The polygons were then validated for topological correctness and attributes updated to be consistent with the more contemporary GIS mapping methodologies. Final areas were calculated using ArcGIS.

The calculated areas were then compared to those of the original DG calculations for each habitat in each estuary. To help identify potential sources of any discrepancies in area estimates, an analysis of per polygon error was carried out using a random selection of the original DG polygons area estimates compared to the corresponding DCV polygon areas.

Results

The original CL mapping surveyed 133 estuaries, however, not all of the estuaries had estuarine macrophytes present and those that did may not have had all three of the habitats present. It should also be noted that there were some estuaries that were listed in the original report that had habitat present, but the area was too small to map. While in most instances there were no polygons present on the maps for these small features, there were some instances where there were polygons mapped for these features, but no area was originally listed. These polygons were captured as part of the digitisation process. As such, the polygons and areas captured in the DCV are those that were represented on the original published estuary maps (Figure 4). The results of the comparative analysis are summarised below for seagrass, mangrove and saltmarsh habitats (complete list provided in Appendix A).

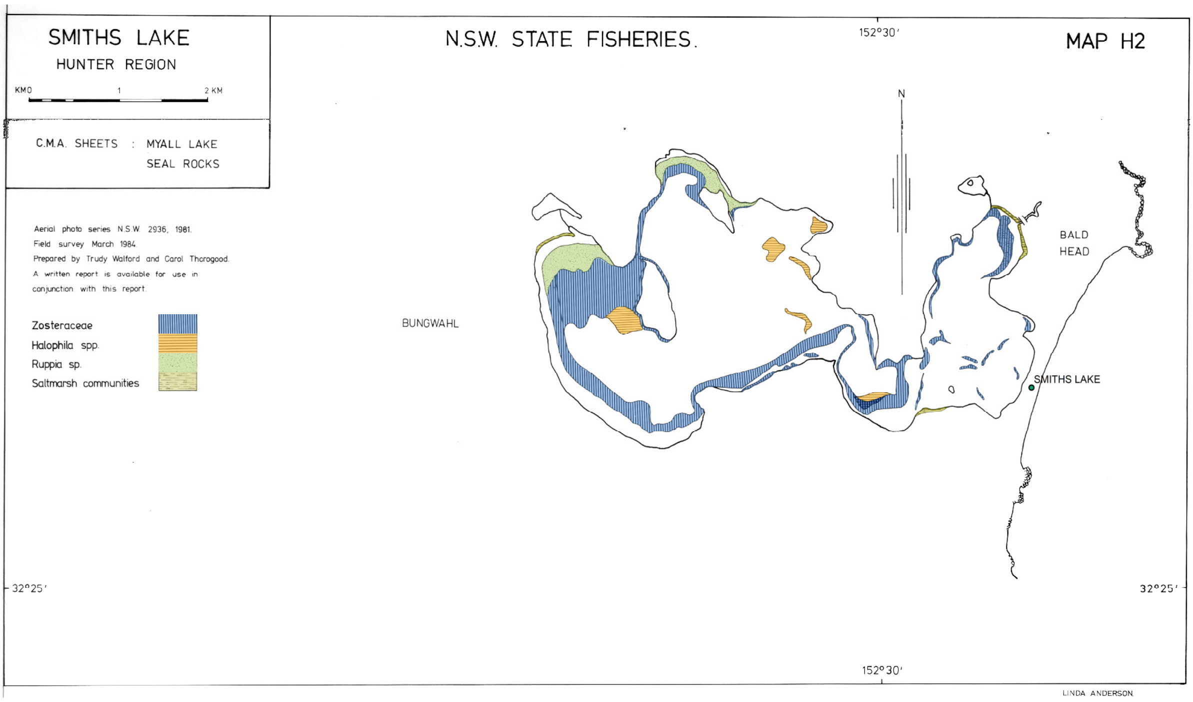

Figure 4. Digital version of the original West et al. (1985) data overlaid on the scanned original Smiths Lake map.

Seagrass

A total of 110 of the 133 estuaries have mapped seagrass polygons, and of these, seagrass areas were underestimated in 95 (or 86%) using the original DG area calculations (relative to the DVC method), with overestimates in the remaining 15 estuaries (Figure 5). Across all estuaries, seagrass area was underestimated by an average of 19% using the original DG method, with some estuaries being considerably greater than this, especially Little Lake (84%) Moonee Creek (83% and Boambee Creek (83%). Of the 15 estuaries with overestimates of seagrass area, the greatest was Kioloa Lagoon (155%), followed by Arrawarra Creek (45%) and Wrights Creek (35%). The DG seagrass area for Merrica River was underestimated by 100% because this estuary was listed as having an area too small to capture at the original mapped scale, but had polygons drawn that could be captured during the digitising process.

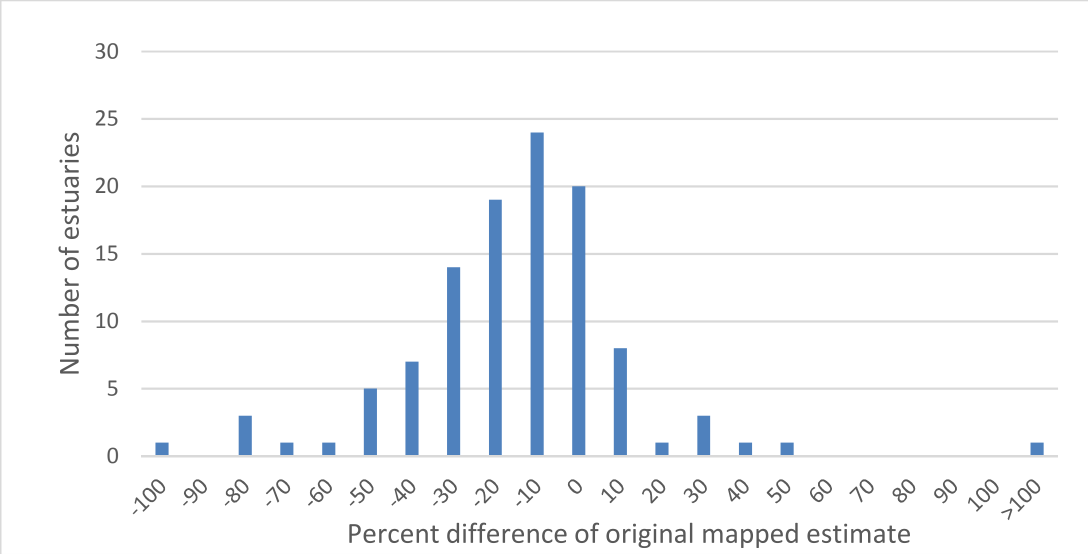

Figure 5. Distribution of Dot Grid area estimates as compared to the digitally mapped area. Values indicate the percent that the original reported values under or overestimate the digitally mapped areas.

Most of the inaccuracies in seagrass area using the DG method occurred in estuaries with small total seagrass area (Figure 6).

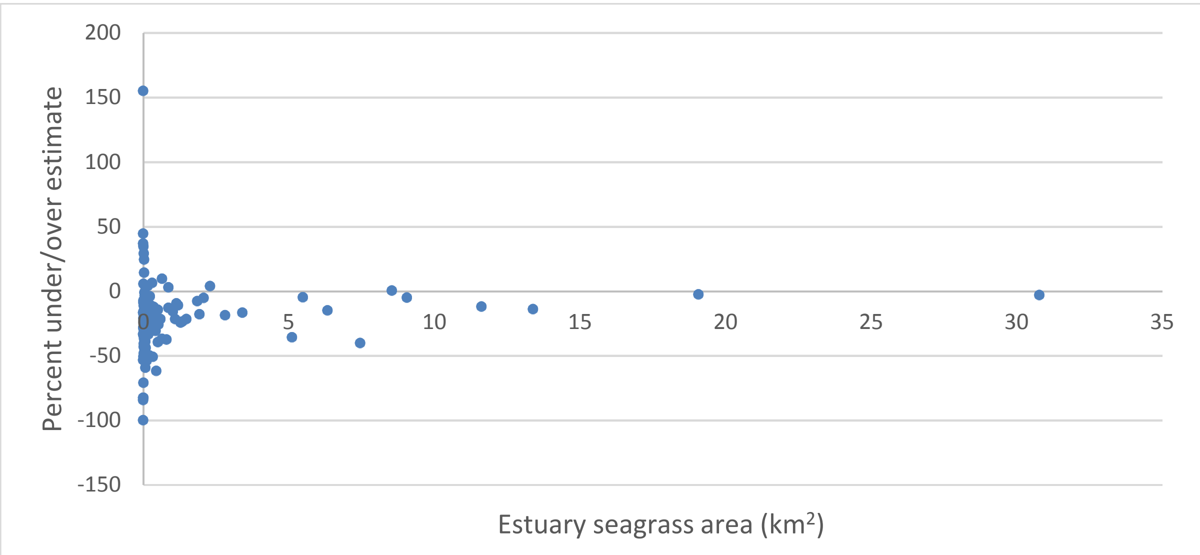

Figure 6. Distribution of mapped percent difference in seagrass in relation to mapped seagrass area per estuary.

Mangroves

A total of 64 of the 133 estuaries have mappable mangrove polygons, and of these, mangroves areas were underestimated in 59 (92%) using the original DG method and overestimated in the other 5 estuaries (Figure 7). On average, mangrove area was underestimated by 30% across NSW using the DG method as compared to the more accurate DCV results. Three estuaries show a 100% underestimate because they were originally listed as having areas too small to map. Excluding these three estuaries, the largest underestimated mangrove areas occurred in Boambee Creek (79%), Lake Cathie (75%) and Moonee Creek (71%). The most significant overestimate using the original DG method occurred in Merimbula Lake (38%).

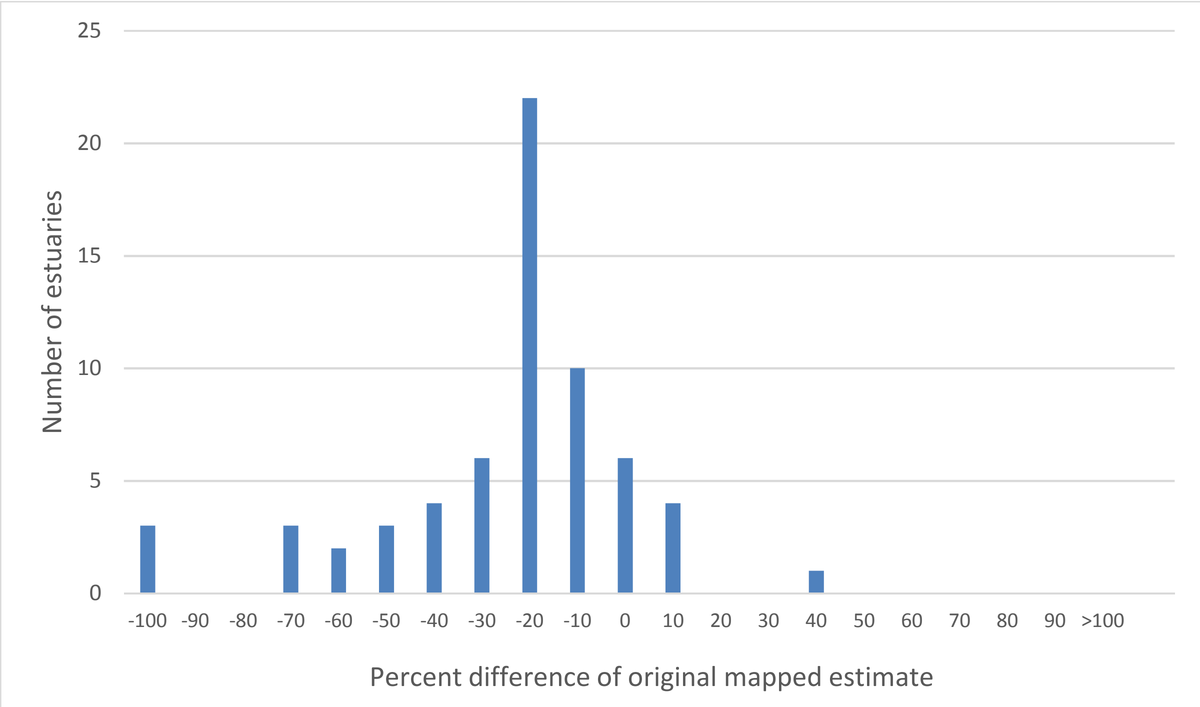

Figure 7. Distribution of percent differences in mangrove area estimates for the digital compared to the original Dot Grid method of West et al. 1985.

The area estimate inaccuracies for mangroves when using the DG method (Figure8) is greatest in the estuaries with total mangrove area of less than 5km^2.

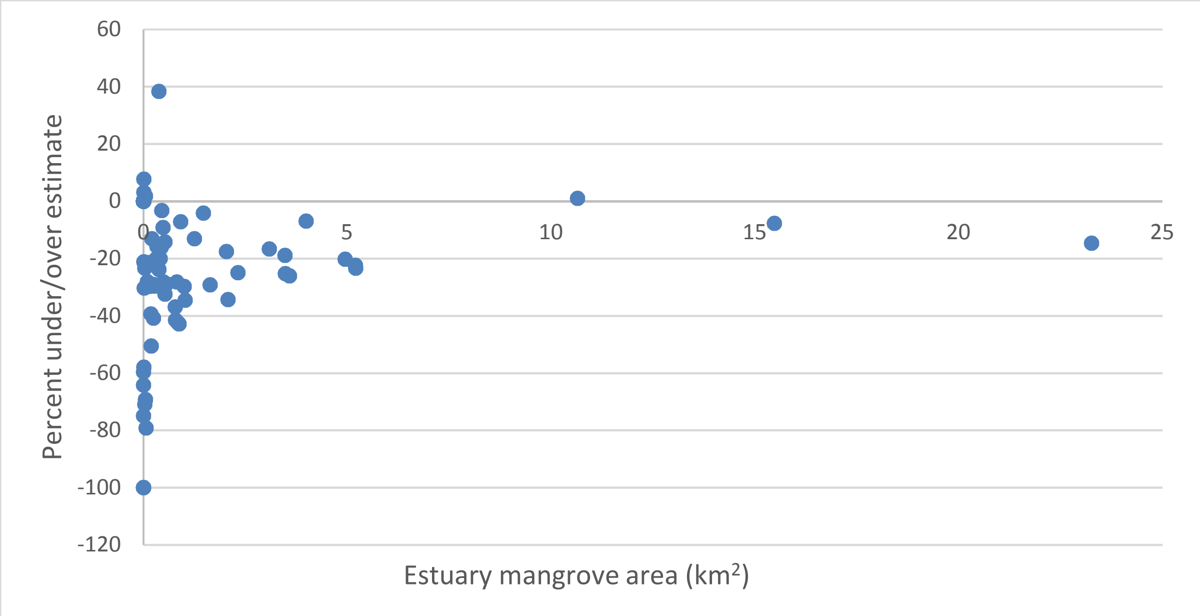

Figure 8. Distribution of mapped percent difference in mangrove in relation to mapped seagrass area per estuary.

Saltmarsh

A total of 93 of the 133 estuaries have saltmarsh mapped, with 92% of these showing underestimates of saltmarsh area using the DG method and the remaining 8% overestimating the mapped area. Averaged across 93 estuaries, the DG method underestimates the more accurate DCV areas for saltmarsh by 21%. Several estuaries exceed this average value considerably including; Fisheries Creek (73%), Dalhousie Creek (58%) and Khappinghat Creek (57%). The two largest overestimates of saltmarsh area occurred in Clyde River (29%) and Broken Head Creek (26%).

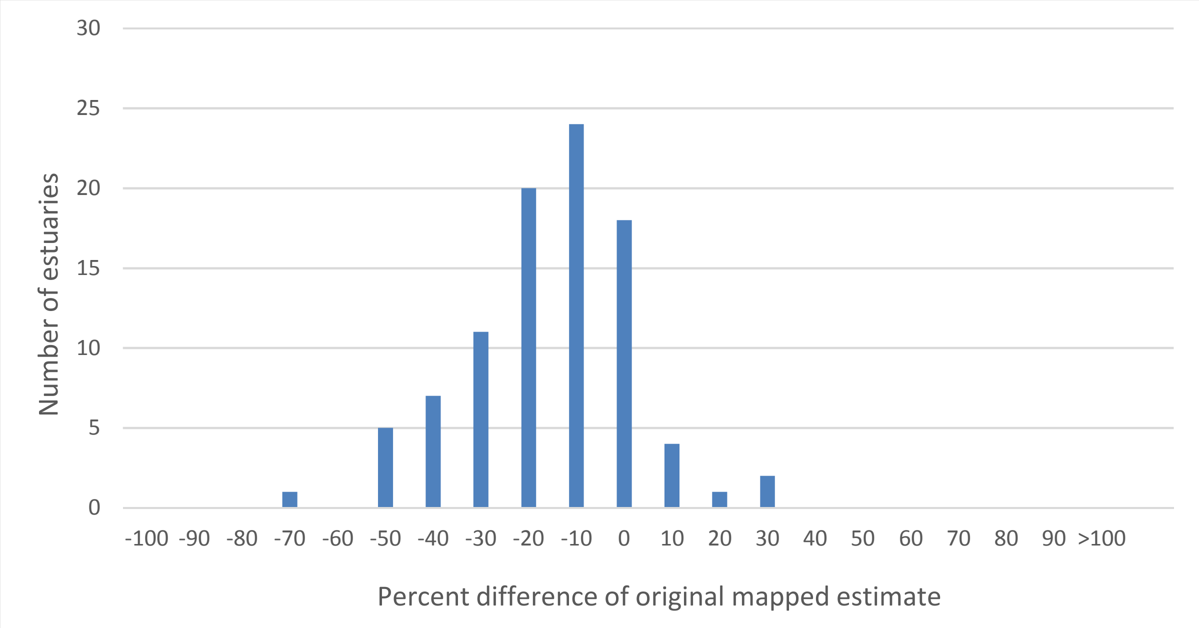

Figure 9. Distribution of differences in saltmarsh area estimates for the digital verses the original Dot Grid method of West et al. 1985.

As for other habitats, inaccuracies in calculations using the DG method were greatest for estuaries that have small saltmarsh areas (Figure 10).

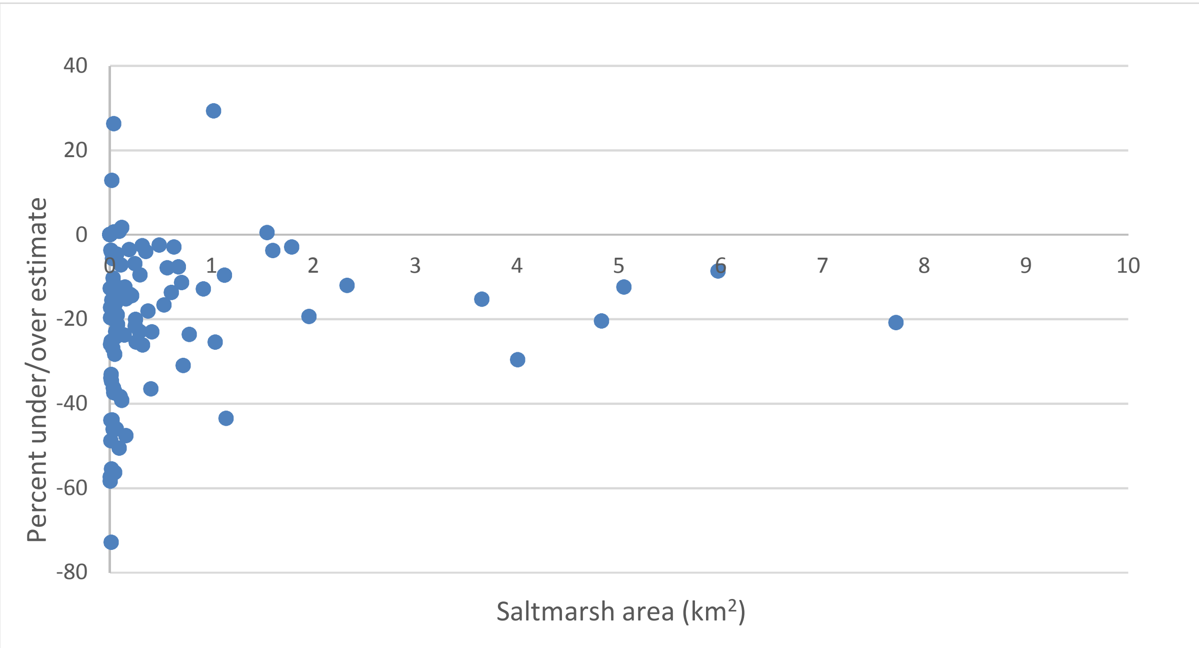

Figure 10. Distribution of mapped percent difference in saltmarsh in relation to mapped seagrass area per estuary.

Influence of polygon size on area estimates

To determine the contribution of polygon size to the error in area estimation, a random sample of 57 individual DG polygons (of any habitat) ranging in from 1 250m^2 to 716 000m^2 were sampled from the original 1 mm grid paper and compared to the corresponding DCV estimates. Inaccuracies of the DG method relative to the DCV were greatest for small polygons (Table 1). Specifically, areas of small polygons (<10 000 m^2) were underestimated by 39%, while areas of polygons >100 000m^2 were underestimated by 15% (Table 1).

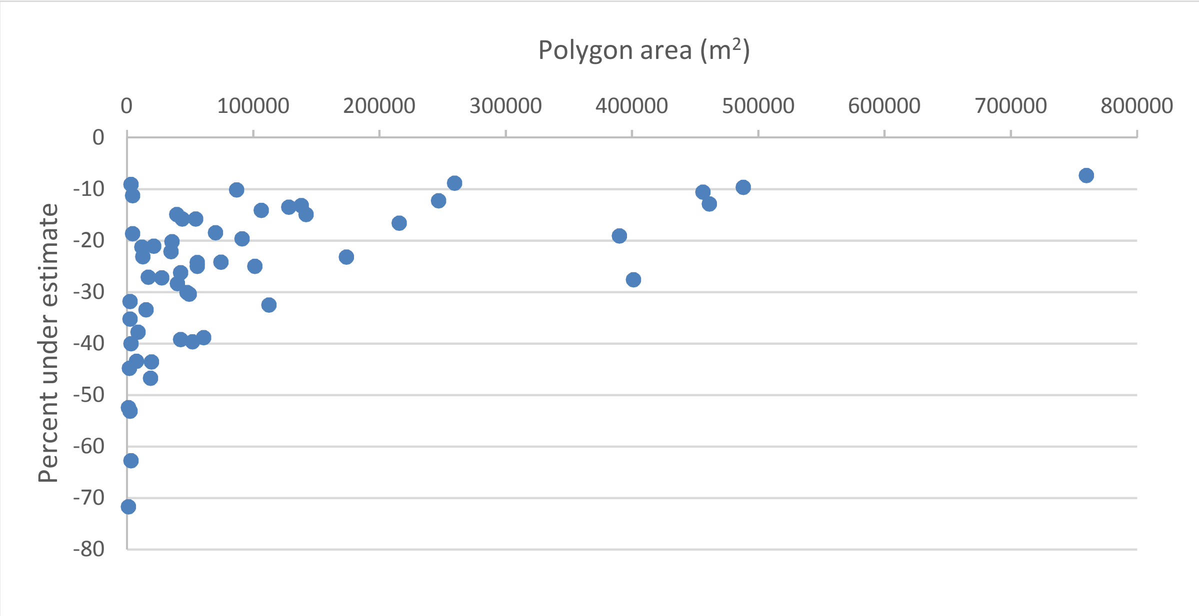

Figure 11. Comparison of original dot grid polygon area estimates and the digital equivalent.

Table 1. Area underestimate for the original dot grid method when compared to the digitally corrected area for the same polygons.

Area m^2	Mean %	SE
<10000	-39	5.19
>10 000 - <50 000	-28	2.18
>50000 - <100 000	-24	3.28
>100 000	-15	1.79
Overall	-26	1.92

Approximately 50% of all mapped polygons are < 10 000m^2, with a further 33% between 10 000m^2 and 50 000m^2 (Figure 12). Based on these results and the sampled DG polygons (Figure 11) the greatest inaccuracies are associated with polygons smaller than 50 000m^2, which account for 83% of the polygons, and that these are a major contributor to the overall underestimate.

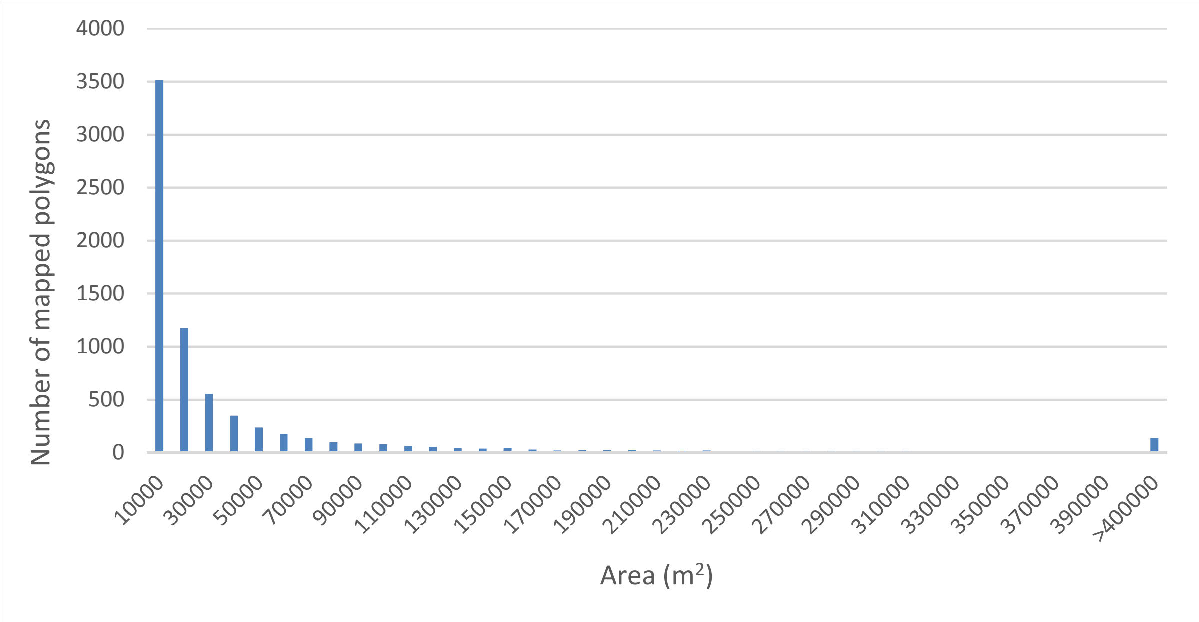

Figure 12. Distribution of all digitally remapped polygons based on mapped area (m^2)

NSW macrophyte areas

The new (DCV) vs original areas estimates for seagrass, mangrove and saltmarsh in NSW estuaries for the period 1981 – 1984 are reported in Table 2. The original DG overall values were underestimated by 23.9 km^2 (seagrass) 23.2 km^2 (mangroves) and 12 km^2 (saltmarsh)

Table 2. The total area estimates (km^2) for seagrass mangrove and saltmarsh for the original West et al. (1985) data compared to the Digital version.

	Original West et al	Digital West et al.
Seagrass	153.8	177.8
Mangrove	108.0	131.2
Saltmarsh	58.5	70.6

Discussion

The results show that, for most NSW estuaries, the original DG method underestimated the actual mapped areas for all three habitats. This result was driven primarily by the smallest polygons. The underestimate error diminishes as DG area increases, but at best the DG area was underestimated by 15%. An evaluation of the distribution of the DCV polygon area indicates that approximately 80% of the polygons are 5 000m^2 or less. The consequence of these underestimates is not only that the previously-reported per estuary habitat area are less than the actual mapped areas, but also that the originally reported total state-wide area estimates for each of the three habitats are also significantly less, with the DG estimates for mangrove and seagrass being some 23km^2 less than they should be.

The original West et al. (1985) macrophyte maps have been invaluable for understanding the distribution of estuarine macrophytes in NSW and the data have been used as the benchmark against which recent temporal changes have been assessed (Roper et al. 2011, MEMA 2018a). Using GIS to more accurately estimate the areas of habitats mapped by West et al. (1985) demonstrates that some of the previously-reported trends in habitat area have been inaccurate. Many of the declines in habitat since the 1980s may have been underestimated by up to 40% meaning that there may have been larger losses than has previously been reported. Similarly, estuaries that may have previously been reported as having relativelystable macrophyte areas may now show losses. Conversely, any estuary that has shown an increase in mapped habitat, may now show smaller increases, or shift from increasing to stable. The next important step, which is currently underway, is to reassess temporal change in these habitats on an estuary-by-estuary basis, and to investigate which estuaries have the greatest changes and where within in them these changes have occurred.

Other studies have also found that historic mapping can underestimates seagrass areas (Cuttriss et al. 2013 and Leriche et al. 2004). Importantly, however, Meehan et al. (2005) found that the method of drawing habitat boundaries (i.e. generating polygons) using the CL technique can result in overestimates of the habitat areas when compared to digitally created habitat boundaries derived from the same original aerial photos. This was most likely a result of the original fixed mapped scale, limitations of the CL technology and the over representation of fragmented habitat and small or very narrow features. Note that this error is related to defining habitat boundaries of polygons and so is quite different from the error associated with calculating areas of the polygons which was investigated here. And while it was not the purpose of this paper to assess the accuracy of the mapped features, it may be an issue that will need to be addressed in the future, particularly when investigating where in estuaries losses have occurred (Cuttriss et al. 2013 and Leriche et al. 2004).

The original West et al. (1985) report is an extremely valuable resource that has been the foundation of many state wide assessments for estuarine habitat change. Prior to 1980s there was no other state-wide estimate for the extent of these habitats. By creating a new digital version of the original paper maps, this study removes one source of error involved with comparing maps created using different technologies. The findings illustrate that the DG method in almost all cases underestimates the actual area of habitat polygons and that this is mostly driven by small polygon areas which account for the majority of the polygons in the data. This work, whilst highlighting the issues relating to the methodology used, in no way undermines the significance to the original work. The new digitally corrected version provides an update to the area calculations that are more reliable and consistent with the current GIS analysis techniques. The results of this study has provided rasterised and georeferenced versions of the original paper maps and an accurate representation of the habitats as vector polygon data. This will provide the basis from which further analysis and assessment can be based. The DCV of West et al. (1985) also enables areas for particular seagrass species to be estimated, which was not previously possible. This species discrimination is critical given the known differences in temporal variability of *Posidonia* (relatively stable over decades in the absence of human disturbance) versus *Zostera* (which can disappear from large areas for years due to natural disturbances).

The Marine Estate Management Strategy MEMA (2018b) highlights that macrophytes represent significant environmental, recreational and commercial assets that are at moderate or high risk from a range of human activities. This newly revised data will provide a more robust base line that will provide a better understanding of the status and trends of these habitats and help in prioritising where we need to focus our efforts to monitor and manage this essential resource.

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Appendix A.

Area calculations for the original Dot Grid method and the digitally corrected method with percent under/overestimated for each habitat per estuary. The original mangrove area reported in the original West et al. (1985) report combined the area of mangrove and mixed mangrove/saltmarsh into a single mangrove area. For consistency this value has been used for the comparative assessment.

	West et al. Original			**West et al. Digitally corrected**					**Percent under/overestimated as compared to the digitally corrected.**		
Estuary	**Seagrass**	**Mangrove**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Mangrove/Saltmarsh**	**Mangrove + Mangrove/Saltmarsh**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Saltmarsh**
Tweed River	0.331	3.091	0.213	0.409	3.706		3.706	0.249	-19.17%	-16.60%	-14.49%
Cudgen Lake	0.000	0.094	0.561		0.131		0.131	0.609		-28.05%	-7.85%
Cudgera Creek	0.016	0.138	0.016	0.028	0.196		0.196	0.024	-43.21%	-29.72%	-34.69%
Mooball Creek	0.013	0.053	0.000*	0.014	0.068		0.068		-7.11%	-21.73%	
Brunswick River	0.018	0.816	0.056	0.035	1.128		1.128	0.081	-48.14%	-27.65%	-31.21%
Belongil Creek	0.000	0.050	0.054		0.049		0.049	0.065		1.75%	-16.36%
Tallow Creek	0.000	0.000	0.003					0.003			-12.71%
Broken Head Creek	0.000	0.000	0.036					0.029			26.24%
Richmond River	0.189	4.949	0.099	0.256	6.202		6.202	0.161	-26.24%	-20.21%	-38.38%
Evans River	0.000	0.330	0.375		0.392		0.392	0.458		-15.77%	-18.09%
Jerusalem Creek	0.000	0.000	0.021					0.037			-43.92%
Clarence River	19.072	5.208	1.954	19.580	6.794		6.794	2.425	-2.60%	-23.35%	-19.42%
Sandon River	0.028	0.533	0.258	0.032	0.728	0.061	0.789	0.346	-11.71%	-32.44%	-25.43%
Wooli Wooli River	0.028	0.493	0.531	0.043	0.686		0.686	0.637	-34.58%	-28.16%	-16.68%
Corindi River	0.033	0.189	0.293	0.058	0.365	0.017	0.382	0.380	-43.26%	-50.55%	-22.95%
Arrawarra Creek	0.003	0.000*	0.008	0.002				0.016	44.62%		-48.82%
Darkum Creek	0.000	0.001	0.000*		0.003		0.003			-64.14%	
Woolgoolga Lake	0.000	0.002	0.000*		0.005		0.005			-59.64%	
Hearns Lake	0.000	0.008	0.036		0.008		0.008	0.058		3.09%	-37.41%
Moonee Creek	0.004	0.036	0.073	0.023	0.103	0.020	0.124	0.090	-82.65%	-70.91%	-19.04%
Coffs Harbour Creek	0.018	0.167	0.000	0.030	0.212		0.212		-40.64%	-21.37%	
Boambee Creek	0.011	0.066	0.158	0.063	0.317		0.317	0.186	-82.56%	-79.21%	-15.19%

	West et al. Original			West et al. Digitally corrected					Percent under/overestimated as compared to the digitally corrected.		
Estuary	**Seagrass**	**Mangrove**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Mangrove/Saltmarsh**	**Mangrove + Mangrove/Saltmarsh**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Saltmarsh**
Bonville Creek	0.008	0.053	0.148	0.028	0.112	0.060	0.172	0.169	-70.93%	-69.21%	-12.43%
Bellinger River	0.059	0.847	0.029	0.082	1.471		1.471	0.040	-28.46%	-42.41%	-26.87%
Dalhousie Creek	0.012	0.034	0.003	0.018	0.044		0.044	0.007	-34.14%	-23.42%	-58.40%
Deep Creek	0.007	0.008	0.604	0.007	0.019		0.019	0.700	5.75%	-57.97%	-13.67%
Nambucca River	0.224	0.779	1.034	0.446	1.235		1.235	1.388	-49.76%	-36.92%	-25.48%
Macleay River	1.097	5.201	3.652	1.400	6.697		6.697	4.309	-21.65%	-22.33%	-15.25%
South West Rocks Creek	0.024	0.528	0.141	0.028	0.615		0.615	0.185	-15.47%	-14.16%	-23.81%
Korogoro Creek	0.000	0.013	0.014		0.012		0.012	0.015		7.69%	-4.09%
Killick Creek	0.001[#]	0.000*	0.008	0.001				0.008	34.61%		-3.71%
Hastings River	0.804[#]	2.078	1.141[#]	1.284	3.164		3.164	2.019	-37.37%	-34.32%	-43.49%
Lake Innes/Lake Cathie	0.007	0.001	5.972	0.010	0.004		0.004	6.534	-29.01%	-73.28%	-8.60%
Camden Haven River	6.336	0.873	0.780	7.447	1.503	0.025	1.528	1.021	-14.92%	-42.86%	-23.61%
Manning River	0.329	3.582	0.721	0.670	4.845		4.845	1.044	-50.91%	-26.07%	-30.96%
Khappinghat Creek	0.019	0.000	0.002	0.021				0.005	-10.86%		-57.39%
Wallis Lake	30.785	0.786	4.005	31.778	1.343		1.343	5.689	-3.12%	-41.46%	-29.60%
Smiths Lake	2.080	0.000	0.031[#]	2.196				0.057	-5.27%		-46.08%
Myall River[1]	2.815	1.021	1.784	3.454	1.561		1.561	1.838	-18.51%	-34.58%	-2.95%
Karuah River	0.380	3.479	4.828	0.502	3.925	0.733	4.658	6.069	-24.28%	-25.31%	-20.44%
Port Stephens	7.453	23.260	7.719	12.434	9.774	17.476	27.250	9.748	-40.06%	-14.64%	-20.81%
Hunter River	0.153	15.481	5.049	0.147	16.769		16.769	5.765	3.83%	-7.68%	-12.42%
Lake Macquarie	13.391	0.998	0.705	15.534	1.298	0.124	1.421	0.795	-13.80%	-29.79%	-11.36%
Tuggerah Lakes	11.619	0.000	0.007	13.204				0.008	-12.01%		-17.24%
Wamberal Lagoon	0.245	0.000	0.000	0.274					-10.61%		
Terrigal Lagoon	0.046	0.000*	0.000	0.068					-32.43%		
Avoca Lake	0.161	0.000	0.000	0.199					-19.09%		
Brisbane Water	5.490	1.635	0.918	5.763	2.310		2.310	1.053	-4.74%	-29.22%	-12.83%

	West et al. Original			West et al. Digitally corrected					Percent under/overestimated as compared to the digitally corrected.		
Estuary	**Seagrass**	**Mangrove**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Mangrove/Saltmarsh**	**Mangrove + Mangrove/Saltmarsh**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Saltmarsh**
Hawkesbury River	0.470	10.654	1.126	0.634	10.216	0.330	10.546	1.245	-25.84%	1.02%	-9.56%
Pittwater	1.934	0.180	0.026	2.358	0.297		0.297	0.028	-17.99%	-39.37%	-5.63%
Narrabeen Lagoon	0.468	0.000	0.000	0.622					-24.77%		
Dee Why Lagoon	0.034	0.000	0.044	0.054				0.070	-37.03%		-36.98%
Manly Lagoon	0.004	0.000	0.000	0.009					-53.31%		
Port Jackson	1.286	1.475	0.073	1.698	1.538		1.538	0.084	-24.26%	-4.11%	-13.60%
Botany Bay	3.403	3.996	1.601	4.084	4.294		4.294	1.664	-16.68%	-6.93%	-3.76%
Georges River	0.268	2.038	0.247	0.347	2.456		2.456	0.332	-22.75%	-17.03%	-25.53%
Port Hacking	0.869	0.328	0.106	0.997	0.410		0.410	0.114	-12.84%	-19.91%	-7.16%
Towradgie Creek	0.036	0.000	0.000	0.039					-8.47%		
Lake Illawarra	5.116	0.000*	0.203	7.965	0.006 [A]		0.006	0.237	-35.77%	-100.00%	-14.39%
Bensons Creek	0.028	0.000	0.000	0.024					14.33%		
Minnamurra River	0.232	0.484	0.197	0.241	0.533		0.533	0.229	-3.92%	-9.19%	-14.13%
Wrights Creek	0.003	0.000	0.000	0.002					36.84%		
Werri Lagoon	0.017	0.000	0.000*	0.021					-18.39%		
Crooked River	0.004	0.000	0.000	0.005					-16.69%		
Shoalhaven River[2]	1.018	3.476	1.542	1.207	4.145	0.141	4.286	1.534	-15.65%	-18.89%	0.50%
Lake Wollumboola	1.145	0.000	0.000	1.266					-9.53%		
Jervis Bay	9.061	1.250	2.330	9.540	1.438		1.438	2.648	-5.02%	-13.09%	-12.01%
St. Georges Basin	8.538	0.252	0.036	8.493	0.356		0.356	0.036	0.53%	-29.12%	0.62%
Swan Lake	0.587	0.000	0.000	0.750					-21.71%		
Berrara Creek	0.006	0.000	0.000	0.008					-20.81%		
Nerrindillah Creek	0.005	0.000	0.000	0.006					-15.82%		
Lake Conjola	0.527	0.000*	0.013	0.711	0.022 [A]		0.022	0.017	-25.92%	-100.00%	-25.24%
Narrawallee Inlet	0.014	0.378	0.091	0.019	0.496		0.496	0.184	-27.92%	-23.79%	-50.58%
Mollymook Creek	0.009	0.000	0.000*	0.012					-27.94%		
Ulladulla Harbour	0.010	0.000*	0.000*	0.011					-8.93%		

	West et al. Original			West et al. Digitally corrected					Percent under/overestimated as compared to the digitally corrected.		
Estuary	**Seagrass**	**Mangrove**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Mangrove/Saltmarsh**	**Mangrove + Mangrove/Saltmarsh**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Saltmarsh**
Burrill Lake	0.508	0.000*	0.157	0.838				0.300	-39.41%		-47.60%
Toubouree Lake	1.199	0.000	0.010	1.346				0.018	-10.91%		-43.97%
Termeil Lake	0.070	0.000	0.000	0.084					-16.58%		
Meroo Lake	0.115	0.000	0.000	0.250					-53.92%		
Willinga lake	0.004	0.000	0.000	0.006					-33.35%		
Kioloa Lagoon	0.003	0.000	0.006	0.001				0.007	155%		-19.72%
Durras Lake	0.509	0.000	0.046	0.594				0.105	-14.30%		-56.34%
Cullendulla Creek	0.064	0.916	0.006	0.066	0.987		0.987	0.008	-2.53%	-7.17%	-25.96%
Clyde River	0.092	2.318	1.017	0.164	3.087		3.087	0.786	-43.95%	-24.90%	29.31%
Batemans Bay	0.071	0.000	0.000	0.087					-18.41%		
Tomaga River	0.046	0.210	0.351	0.046	0.242		0.242	0.365	-1.05%	-13.10%	-3.95%
Candlagan Creek	0.016	0.021	0.031	0.021	0.030		0.030	0.035	-24.53%	-30.32%	-10.26%
Moruya River	0.644	0.380	0.674	0.588	0.477		0.477	0.730	9.61%	-20.29%	-7.62%
Coila Lake	1.862	0.000	0.317	2.020				0.325	-7.81%		-2.59%
Tuross Lake	0.452	0.566	0.401	1.181	0.795		0.795	0.631	-61.73%	-28.83%	-36.50%
Lake Brunderee	0.064	0.000	0.246	0.067				0.264	-4.72%		-6.86%
Lake Brou	0.078	0.000	0.250	0.128				0.313	-38.87%		-20.06%
Lake Dalmeny	0.294	0.000	0.055	0.411				0.073	-28.51%		-24.20%
Kianga Lake	0.011	0.000	0.033	0.022				0.052	-50.67%		-36.41%
Wagonga Inlet	1.484	0.249	0.056	1.891	0.421		0.421	0.069	-21.53%	-40.80%	-18.55%
Nangudga Lake	0.120	0.000	0.115	0.129				0.189	-6.92%		-39.25%
Corunna Lake	0.179	0.000	0.033	0.270				0.052	-33.60%		-36.27%
Little Lake	0.003	0.000	0.047	0.019				0.066	-84.17%		-28.33%
Wallaga Lake	1.343	0.000	0.295	1.755				0.326	-23.48%		-9.56%
Bermagui River	0.338	0.434	0.066	0.485	0.476	0.041	0.517	0.069	-30.25%	-16.13%	-4.58%
Barragoot Lake	0.049	0.000	0.053	0.051				0.067	-3.42%		-20.31%
Cuttagee Lake	0.430	0.000	0.076	0.620				0.096	-30.66%		-21.24%

	West et al. Original			West et al. Digitally corrected					Percent under/overestimated as compared to the digitally corrected.		
Estuary	**Seagrass**	**Mangrove**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Mangrove/Saltmarsh**	**Mangrove + Mangrove/Saltmarsh**	**Saltmarsh**	**Seagrass**	**Mangrove**	**Saltmarsh**
Murrah Lagoon	0.016	0.000	0.109	0.018				0.125	-11.30%		-12.61%
Bunga Lagoon	0.000	0.000	0.018					0.016			12.88%
Wapengo Lagoon	0.360	0.409	0.319	0.410	0.432	0.080	0.511	0.432	-12.16%	-20.00%	-26.17%
Middle Lagoon	0.081	0.000	0.011	0.199				0.016	-59.29%		-33.12%
Nelson Lagoon	0.114	0.271	0.063	0.170	0.385		0.385	0.117	-32.92%	-29.58%	-46.03%
Bega River	0.304	0.000	0.411	0.286				0.534	6.46%		-23.01%
Wallagoot Lake	0.647	0.000	0.014	1.025				0.031	-36.86%		-55.49%
Bournda Lagoon	0.043	0.000	0.000*	0.046					-7.04%		
Back Lagoon	0.204	0.000	0.018	0.236				0.021	-13.38%		-15.49%
Merimbula Lake	2.297	0.377	0.629	2.209	0.272		0.272	0.648	3.99%	38.42%	-2.92%
Pambula Lake	0.868	0.449	0.188	0.843	0.464		0.464	0.195	2.91%	-3.19%	-3.55%
Curalo lagoon	0.058	0.000	0.116	0.062				0.114	-7.01%		1.70%
Twofold Bay	0.026	0.000	0.008	0.028				0.012	-8.40%		-33.96%
Nullica River	0.020	0.000*	0.000	0.022					-7.82%		
Fisheries Creek	0.033	0.000	0.011[#]	0.043				0.041	-22.45%		-72.84%
Towamba River	0.027	0.009[#]	0.090[#]	0.022	0.011		0.011	0.089	24.42%	-21.17%	0.83%
Wonboyn River	0.237	0.000*	0.483	0.266	0.001 [A]		0.001	0.495	-10.90%	-100.00%	-2.45%
Merrica River	0.000*	0.000	0.000	0.001 [A]					-100.00%		
Nadgee Lake	0.075	0.000	0.000	0.073					3.33%		

* Area too small to map at the original 1:25 000 scale

[A] Polygons captured during digitising process that were too small to capture using Dot Grid method

[#] Area corrected based on review of original Dot grid calculations

1 Myall Lakes and Myall River Combined

2 Shoalhaven River and Crookhaven River combined