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Land Change Analysis of Moon Point Vegetation on Fraser Island, East Coast, Queensland, Australia

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ABSTRACT

This study investigates vegetation thickening and encroachment at Moon Point wetlands on Fraser Island using historical aerial photographs with present day data and a land change modeller to identify the extent of thickening and encroachment of three major vegetation types, forest, *Banksia* and wetlands. Through quantified assessment of the aerial photographs using fine-gauged graticules, vegetation types were manually assessed and counted to identify changes in woody vegetation density. Further vegetation polygons were created of the three vegetation types for analysis through a land change modeller for change analysis to identify percentage gains or losses of vegetation types, transition potential for change and change prediction to fifty years into the future. Both the quantified assessment and land change modeller identified vegetation thickening with percentage gains for forest and *Banksia*, with forests having the greatest percentage gains. Wetlands showed an overall percentage loss to forest and *Banksia*, which increases fifty years into the future.

Key Words: Land Change Modelle;, Fire Regimes; Frequency of Burns; Vegetation Dynamics.

INTRODUCTION

Fire is a driver of vegetation variability (van Wilgen 2009) and any changes to the fire regime impacts these dynamics that may result in significant ecosystem changes (Bond and Keeley 2005). In particular, it is a major ecological driver for the production of pyrogenic vegetation that is associated with the development of coppicing and serotiny mechanisms to survive the impacts of fire (Russell-Smith et al. 2001). However, regardless of the importance of fire in shaping the vegetation dynamics (i.e. structure and patterns), it is still poorly understood as to how frequency, season, intensity and sequence of fire interact in influencing vegetation structure (Smit et al. 2010). According to Higgins et al. (2007) tree density is not influenced by fire, only the size structure and biomass of trees are affected through fire frequency but the precise response of vegetation to a prevailing fire regime is not readily known.

Vegetation thickening is a change or increase in the density of woody vegetation and is known to occur where fire has been withheld for years in sand environments (Vigilante and Bowman 2004). Edwards et al. (2003) found that with an increase in woody thickness there was a corresponding decrease in cover and species richness of herbs with areas experiencing lower frequency of fires. Bradstock et al. (1996) found that obligate seeder heathland species such as *Banksia* became locally extinct when subjected to infrequent fires due to senescence. Further, fire season and intensity are important as it has been shown that cooler earlier fire season fires favours and encourages woody vegetation thickening (Smith et al. 2010). For instance, in tropical northern Queensland pastoralists have changed the fire regime by withholding fire for several years and burning only in the early dry season resulting in a loss of grasslands while increasing the woody vegetation (i.e. expansion in *Melaleuca viridiflora*) (Crowley et al. 2009). According to Russell-Smith and Edwards (2012) canopy density is negatively correlated with fire frequency.

Within heathlands in the Sydney sandstone region and alpine heaths it has been recorded that fire stimulates and increases vegetation density that levels off after approximately 10 to 15 years post fire (Keith et al. 2002, Walsh and McDougall 2004). For example *Empodisma minus* (Restionaceae), a key wet heathland species on Fraser Island and a rhizomatous perennial (Wagstaff and Clarkson 2009), increases in growth significantly within the first 2 years after fire, with density levelling off approximately 6.5 years post fire (McFarlane 1988). Therefore changing fire regimes may impact on the ability for particular heathland species and especially non-dicotyledons such as *E. minus* to remain dominant, allowing for possible forest or woodland species to invade wet heathlands (Watson 2001). According to Moss (2014) *E. minus* is an ecosystem engineer responsible for creating fens and bogs where it forms dense mats of horizontal rhizomes holding water up to 15 times their dry weight, and is an important component of both patterned and non-patterned mires on giant sand masses of subtropical eastern Australia (Moss et al. 2016).

Many Restionaceae do not reach full reproductive ability until 4 to 8 years post fire therefor having a low reproductive ability and as obligate seeders can become locally extinct if periods between fires are too short (Meney et al. 1994). *E. minus* are however resprouters and fire plays an important role in the development of restiad dominated wetlands where the underground parts of *E. minus* are protected and survive fire (Moss et al. 2016). *E. minus* resprouts within weeks of a fire and recovers rapidly and can reach pre-fire levels within 2 years of burning and will continue to grow considerably for up to 17 years post fire (Wahren and Walsh 2000, Wagstaff and Clarkson 2009).

This study investigates possible vegetation thickening and encroachment, related to changes in fire regimes, at the Moon Point wetlands, Fraser Island. This analysis will be based on historical aerial photographs combined with contemporary field data, using Idrisi' TerrSet Land Change Model, a land change modeller to identify alterations of three major vegetation types: sclerophyll forest and woodlands (Forest), *Banksia* forest monocultures (*Banksia*) and restiad wetlands (Wetlands). Through quantified assessment of the aerial photographs using fine-gauged graticules vegetation types were manually assessed and counted to identify changes in vegetation density. Further vegetation polygons were created for the three vegetation types for analysis through the land change modeller to identify alterations in the three vegetation types, transition potential for landscape change and to predict alterations in the Moon Point community structure into the future.

STUDY AREA

Fraser Island (Figure 1) is situated within subtropical coastal eastern Queensland (25.2167° S, 153.1333° E) and is approximately 124 km long and 20 km wide. The average annual rainfall is between 1300 to 1700 mm/year with mean temperatures ranging between 14 °C in winter and 29 °C in summer (Donders et al. 2006). The soils are composed of marine and aeolian sand deposits with few scattered bedrocks of basalt, with the central portion of the island being composed of complex sand dunes that are vegetated and with numerous lakes occurring in the depressions between the dunes (Gontz et al. 2015). Vegetation is composed of coastal scrub and sandy plains, *E. minus* wetlands, open heathlands, open dune forests, and open forests on leached soils, *Syncarpia* forests, notophyll vine forests, as well as wet and dry sclerophyll forests that are dominated by *Eucalyptus* and *Corymbia* species and to open 'Wallum' heathlands (Srivastava et al. 2013). The vegetation of Fraser Island is laterally zoned following the contours of successive parabolic dune systems that run parallel to the islands coastline (Donders et al. 2006) older dunes generally lying to the west, overlaid partly by progressively younger dunes to the east (Lennon 2012, Moss et al. 2016). Nutrient availability increases with the age of the sand and amount of detritus initially then declines due to leaching through a retrogressive successional process (Walker et al. 1981, Longmore and Heijnis, 1999, Donders et al. 2006). Zonation and succession of plant communities are dictated by salinity, water table, age and nutrient status of dune sands, exposure and frequency of fires, which creates an east to west sequence of vegetation (Lennon 2012, Moss et al. 2016).

Moon Point (Figure 2) is situated on the most westerly coast of Fraser Island (25.1239^{0} S, 153.0413^{0} E) consists of mixed open sclerophyll forest/woodland, *E. minus* wetlands, mangrove communities, *Melaleuca* and *Banksia* forests, as well as salt marsh and dune vegetation. Common species of plants found within the ecotone (study area) between the *E. minus* wetlands and sclerophyll forests are listed in Table 1. The ecotone is the transition area between the *E. minus* and sclerophyllous

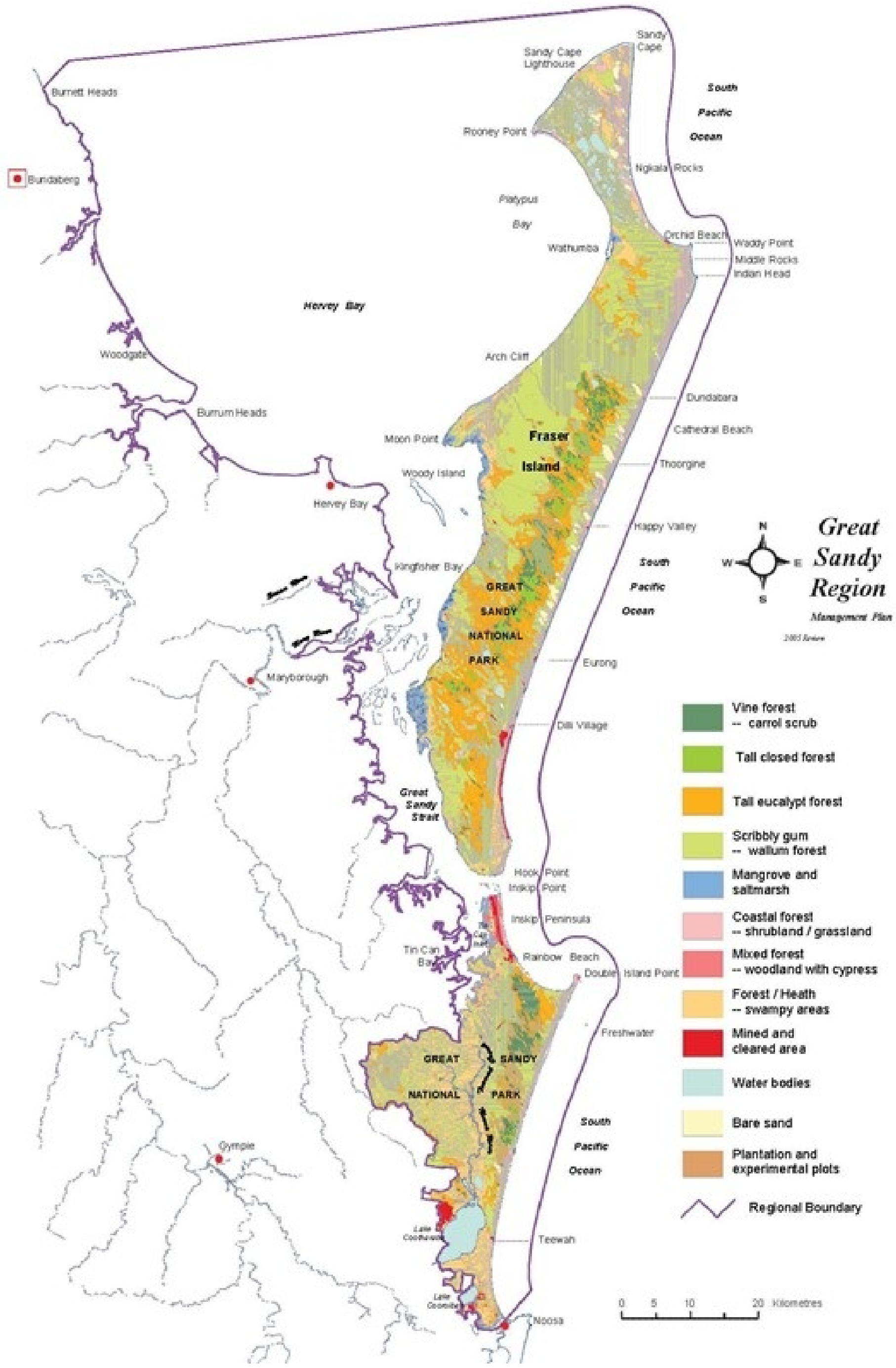

Figure 1 Fraser Island on the east coast of Queensland forms part of the Great Sand Region National Park which is World Heritage listed and the World's largest sand island. Source The State of Queensland. Great Sandy Region Management Plan 1994

forest ecosystems that occur along an ecological gradient showing the diversity of both boundary types (Odum and Odum 1953, Warman et al. 2013). The entire area is subjected to fire, which seems to play a role in reducing shrub cover Present fire management of Fraser Island is prescribed burning to promote biodiversity and reduce wildfire risk (Moss et al. 2016).

Table 1 List of common plant species found within the ecotone of *E. minus* and sclerophyll vegetation periphery

Moon Point Vegetation

Species	Common name	Species	Common name
Acacia concurrens Pedley	Black wattle	*Eucalyptus tereticornis* Sm.	
Angophora leiocarpa (L.A.S.Johnson ex G.J.Leach) K.R.Thiele & Ladiges		*Eurychorda complanate* (R.Br.) B.G.Briggs & L.A.S.Johnson	
Baeckea frutescens L.		*Gahnia sieberiana* Kunth.	Red-fruited saw sedge
Baloskion tetraphyllum (Labill.) B.G.Briggs & L.A.S.Johnson	Tassel cord-rush	*Gahnia clarkei* Benl.	Tall saw sedge
Banksia robur Cav.	Swamp Banksia	*Gleichenia dicarpa* R.Br.	
Banksia serrata L.f.	Serrated Banksia	*Gleichenia mendellii* (G.Schneid.) S.B.Andrews	
Banksia aemula R.Br.	Wallum Banksia	*Hakea actites* W.R.Barker	
Banksia oblongifolia Cav.	Dwarf banksia	*Hibbertia salicifolia* (DC.) F.Muell	
Blechnum indicum Burm.f.		*Hypolaena fastigiata* R.Br.	
Boronia falcifolia A.Cunn. ex Endl.		*Lepironia articulata* (Retz.) Domin	
Callitris Columellaris F.Muell		*Leptospermum liversidgei* R.T.Baker &H.G.Sm.	
Calytrixtetragona Labill.	Fringe myrtle	*Leptospermum neglectum* Joy Thomps.	
Cassytha glabella R,Br.	Dodder	*Leucopogon ericoides* (Sm.) R.Br.	
Cassytha pubescens R,Br.	Dodder	*Livistona decora* (W.Bull) Dowe	
Casuarina littoralis Salisb.		*Melaleuca quinquenervic* (Cav.) S.T.Blake	
Caustis recurvata Spreng.		*Melaleuca dealbata* S.T.Blake	
Conospermum taxifolium C.F.Gaertn.		*Monotoca scoparia* (Sm.) R.Br.	
Corymbia intermedia (R.T.Baker) K.D.Hill & L.A.S.Johnson		*Ochrosperma lineare* (C.T.White) Trudgen	Straggly haekea
Corymbia gummifera(Gaertn.) K.D.Hill & L.A.S.Johnson		*Petalostigma pubescens* Domin	
Corymbia tessellaris (F.Muell.) K.D.Hill & L.A.S.Johnson		*Petrophiles hirleyae* F.M.Bailey	Conesticks
Empodisma minus (Hook.f.) L.A.S.Johnson & D.F.Cutler	Wire rush	*Plachonia careya* (F.Muell.) R.Knuth	
Epacris microphylla R,Br.	Coral heath	*Platysace linearifolia* (Cav.) C. Norman	
Epacris obtusifolia Sm.	Common heath	*Pseudanthus orientalis* (Baill.) F.Muell.	
Epacris pulchella Cav.		*Ricinocarpos pinifolius* Desf.	
Eucalyptus signata F.Muell.	Scribbly Gum	*Sprengelia sprengeliodes* (R.Br.) Druce	Lemon scented tea tree
Eucalyptus racemose Cav.		*Strangea linearis* Meisn.	
Eucalyptus pilularis Sm.		*Utricularia uliginosa* Vahl	Bladder wort
Eucalyptus exserta F.Muell.		*Xanthorrhoea fulva* (A.T.Lee) D.J.Bedford	Swamp grasstree

METHODOLOGY

Two aerial photographs of the same spatial area and extent with different temporal scales (1958 and 2010) for the Moon Point area were digitised and georeferenced (WGS 1984 UTM Zone 56S) using ESRI ArcMap. Fieldwork was undertaken in March 2016 for ground-truthing using a Garmin GPS to capture 42 waypoints to create polygons and to identify the present position of the three key vegetation types used in the land change analysis and consisting of Forest (surrounding sclerophyll and *Melaleuca* forest), *Banksia* (*Banksia* forest monoculture) and Wetland (predominantly *E. minus* dominated mire, including the patterned fens). The aerial photographs and ground truth data were then prepared for use in TerrSet's Land Change Modeller where a quantified assessment of vegetation change was undertaken. Collecting of ground truthing data was undertaken on the 4th to the 9th March 2016 tracing the boundaries with GPS.

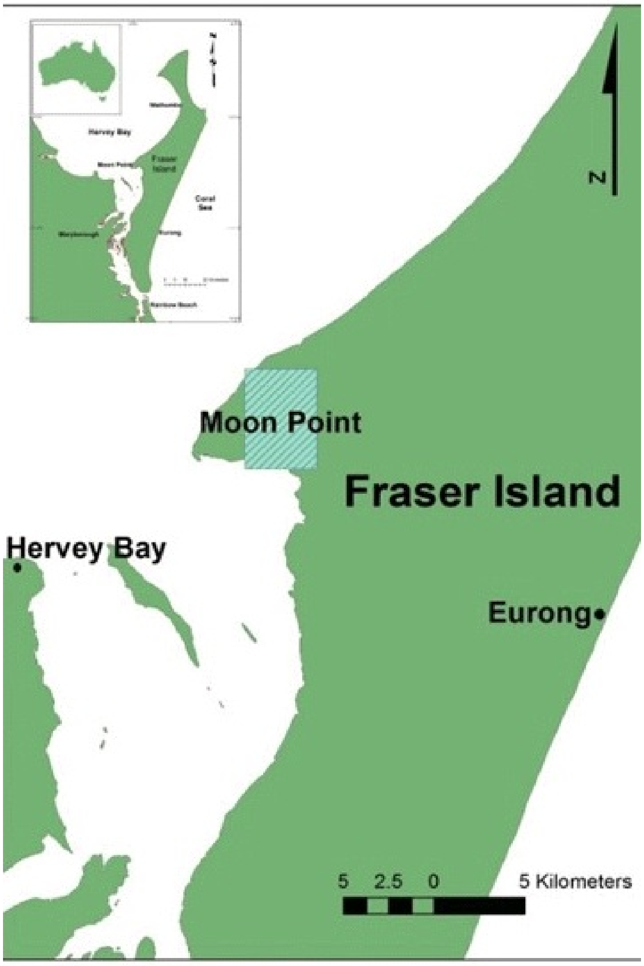

Figure 2. Moon Point is situated on the most westerly coast of Fraser Island

Land Change Analysis Modeller

The two georeferenced aerial photographs of 1958 and 2010, along with the 2016 ground truth data were processed in ESRI ArcMap where the three broad vegetation types were created and added as polygon layers, merged, converted to a raster and then exported as ESRI image files. The three sets of data 1958, 2010 and 2016 were then imported into TerrSet and saved in Idrisi raster format for use in the land change modeller as land cover files. All three files prepared for use in TerrSet Land Change Modeler have the same spatial parameters and reference system. This includes the same projection, cell size, spatial extent, spatial resolution, rows and columns. Further the three land cover maps contained the same categories and sequential order. The land cover files were loaded into TerrSet LCM projects parameters panel for change analysis in date sequential order, with 1958 and 2010 first followed by 1958 and 2016 and then 2010 and 2016, and the underwent change analysis, with the spatial trend of change assessed to the 3rd order polynomial. Sub-models were grouped and run through the LCM transition potentials and finally through change prediction for future projections of vegetation alterations.

Quantified Vegetation Assessment

Grids and Graticules were created for the 1958 and 2010 Moon Point aerial photographs using meridians and parallels, placing parallels 1 second of latitude and meridians 1 second of longitude. At the equator an arc-second of longitude is approximately equal to an arc-second of latitude, which is 30.87 meters. Arc-seconds of latitude remain nearly constant, while arc-seconds of longitude decrease in a trigonometric cosine-based fashion as you move toward the Earth's pole. At -25.21 degrees south latitude, an arc-second of longitude equals 30.87 meters * 0.90476 (cos 25.21°) providing grids of 27.5 by 30.87 meters. The grids of the georeferenced 1958 and 2010 aerial photographs of Moon Point were used to identify Forest, *Banksia* and Wetland vegetation as well as change over time by summing all vegetation cover of each of the 3 classes that was >50% cover within each grid for each vegetation type (Figure 3).

RESULTS

Land Change Analysis

In the first step the 1958/2010, 1958/2016, and 2010/2016 land cover maps were assessed for change between time 1 and time 2, with a focus on areas that transitioned from one land cover state to another. The dominant transitions are grouped and modelled and termed sub-models. These sub-models were combined and not run separately.

The second step in change prediction was transition potential modelling where the potential for land to transition was identified and transitional potential maps were produced, which were organised within an empirical evaluated transition sub-model with the same underlying driver variables. The variables were used to model historical change process. The transitions were modelled using the multi-layer perceptron (MLP) neural network and once calibrated were used to predict future scenarios.

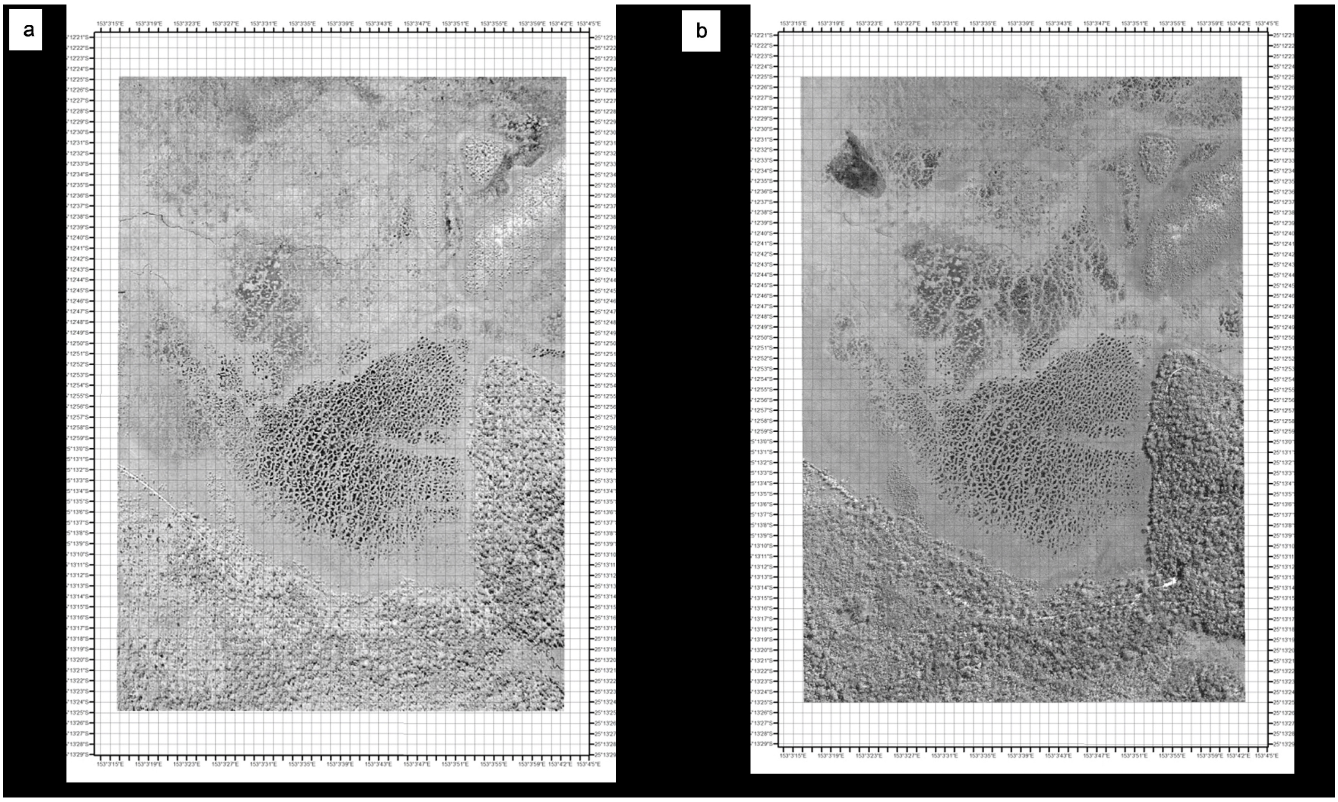

Figure 3 (a) 1958 and (b) 2010 aerial photographs of Moon Point, Fraser Island showing 1 second meridians and parallels or 27.52 meters

The third step was change prediction where we used the historical rates of change and transition potential model in the LCM to predict future scenarios for the specified year 2066, fifty years into the future.

Step 1. Change Analysis

The land cover images (earlier and later land cover image) for (1) 1958 to 2010, (2) 2010 to 2016 and (3) 1958 to 2016 of Moon Point produced gains and losses by category where two units were selected for analysis of land change, (a) percentage change (percent change) and (b) percentage of area (percent of area) (Figure 4), where Percent Change = (number of pixels changed for a class / area of a class in the later land cover image)* 100 and Percent Area = (number of pixels changed for a class / total area of the land cover map)*100.

The analysis produced two Gant charts of gains and losses between Wetland, *Banksia* and *Forest* for the different aerial photograph time scales. The percentage (%) change (Figure 4 a), shows that *Banksia* had the greatest gains for this land cover category of 6.6% with some losses of -1.5%. Forest increased by 4.0% with only minor losses of less than -0.4%. Wetland overall had the greatest losses for the same period to > -2.0% with a minor gain of 0.2%. Between 2010 and 2016 the percentage (%) change shows an increase in *Banksia* to 12% with a 1% loss, Forest gaining to 3% however with a 0.1% loss and Wetland with a loss of -1.9% and a 0.1% gain. Between 1958 and 2016 the gains and losses are similar to 2010 and 2016 gains and losses, however with a decrease in losses for both Forest and *Banksia* compared to 2010 to 2016, with *Banksia* showing a loss of 0.1% and Forest almost zero, Wetlands showing the greatest loss of -3.8%.

The percentage of area gains and losses (Figure 4 b) show that overall Forest has gained substantially over Wetlands, approximately 1.24% for 1958 to 2010, a 1% gain between 2010 and 2016 and a 2.1% gain between 1958 and 2016. Wetlands having the greatest losses, approximately -1.45% for 1958 to 2010 and -3.8% between 1958 and 2016. With *Banksia* showing only minor gains of approximately 0.27 for 1958 to 2010 and 0.4% for 1958 to 2016.

Spatial trend of change to the 3rd order of polynomial were analysed between wetlands and forest and

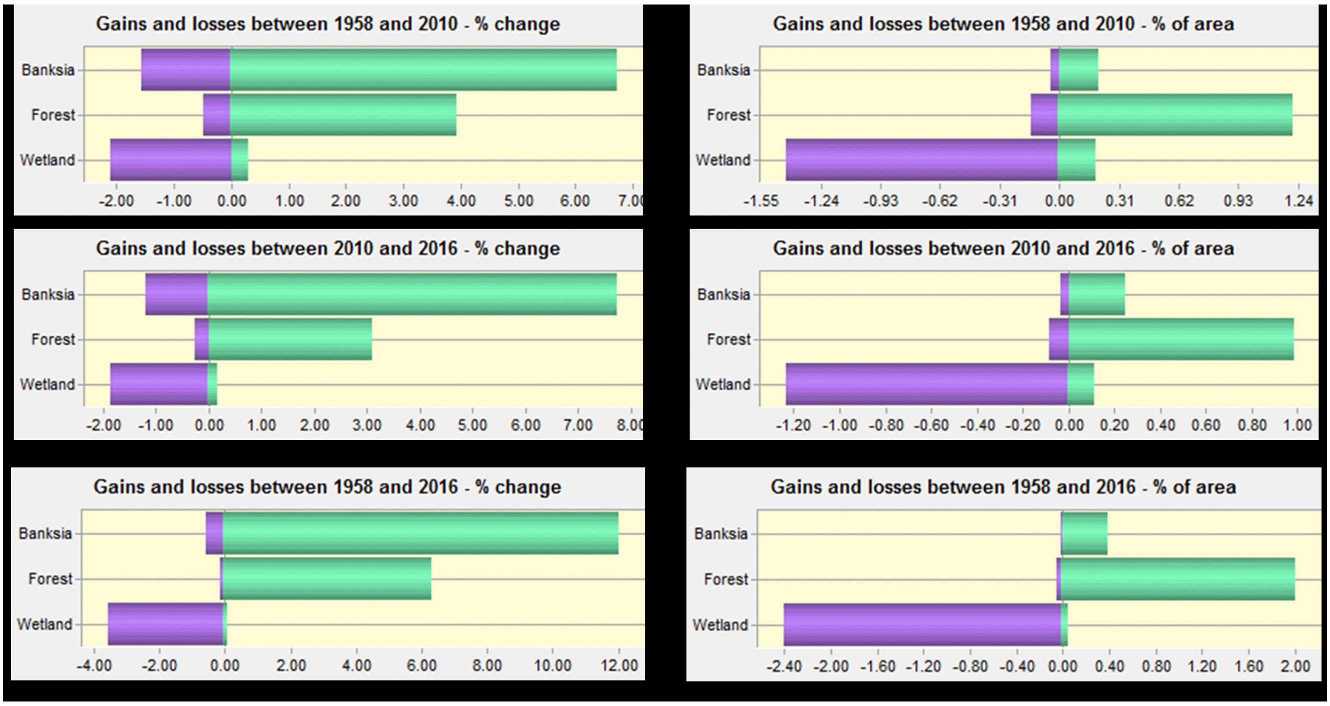

Figure 4. Gantt charts showing the gains and losses between wetlands, forest and banksia at Moon Point between (1) 1958 and 2010; (2) 2010 and 2016; (3) 1958 and 2016. Both (a) and (b) showing substantial losses for wetlands over this period. (b) Forest has gained the greatest % of area during this period

wetlands and *Banksia*. Each forest and *Banksia* were independently mapped. The spatial trend of change wetlands to all shows that wetlands have reduced in area and in a north to north westerly direction with forest increasing from the west, south, and east, with *Banksia* increasing from the east. The spatial trends of change for wetlands to forest and wetlands to *Banksia* confirm this shift (Figure 5 C).

Step 2. Transitional Potential Modelling

The transition potential grouped transitions between the two land cover maps into a set of sub-models where each sub-model was identified with a set of driver variables. The transitions were modelled using a multi-layer perceptron (MLP) neural network to predict future scenarios (Figure 6) for the land cover images 1958 to 2010, 2010 to 2016 and 1958 to 2016. Transition potential maps for each transition were derived with an expression of time-specific potential for change. The greatest potential for transition is seen in the land cover images 1958 to 2016 with Forest and *Banksia* showing possible extensive encroachment and thickening (Figures 6.3, a and b).

Step 3. Change Prediction

The LCM used the transition potential model and historical rates of change to predict a future scenario projected to 2066 (Figure 7). The model determined how variables influenced future change and how change took place between time 1 and time 2, calculating transition to 2066. A soft mode of change prediction was chosen as the output is a continuous mapping of vulnerability to change. According to Eastman (2015) soft prediction output is a continues mapping of vulnerability to change, giving the degree to which, the areas have the right conditions to precipitate change, compared to hard prediction that is a commitment to a specific scenario.

The results do not state it will occur, however the degree to which the area has the right conditions to precipitate change. It used an aggregate of the transition potentials of all selected transitions.

Quantified Vegetation Assessment

Total counts of fine-gauged graticule grids for each vegetation type (Forest, Wetland, *Banksia*) for both the Moon Point georeferenced 1958 and 2010 aerial photographs (Figure 3) showing gains and losses, with the

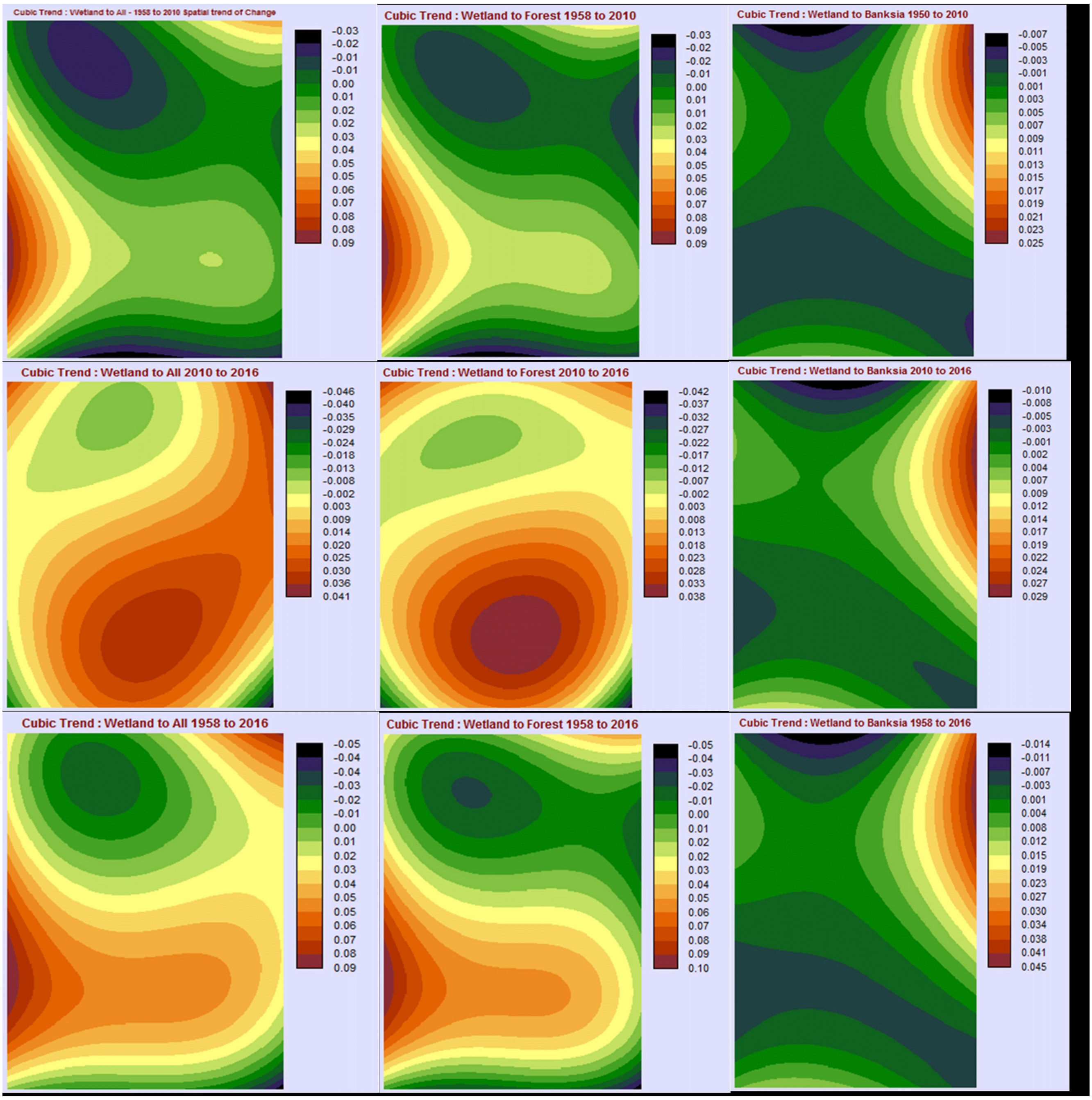

Figure 5. Net change graphs show the total area change in each land cover type for comparison of the three time series in years in square kilometres

greatest change for wetlands with a loss of -2.07% or -58 grid loss between 1958 to 2010, banksia showed a 0.53% gain or 15 grid increase between 1958 and 2010 and forest with a 1.53% gain or 43 grid increase for the same time period (Table 1) % of area.

Comparative analysis of the data taken from quantified analysis and the LCM show interesting similarities in both gains and losses between forest, banksia and wetlands. With the manual count % change giving a -2.07% loss of wetlands with % area change and % change for wetlands showing -1.45% and -1.90% respectively. Both Forest and *Banksia* data showing gains (Table 2) over the time period 1958 to 2010 (52 years).

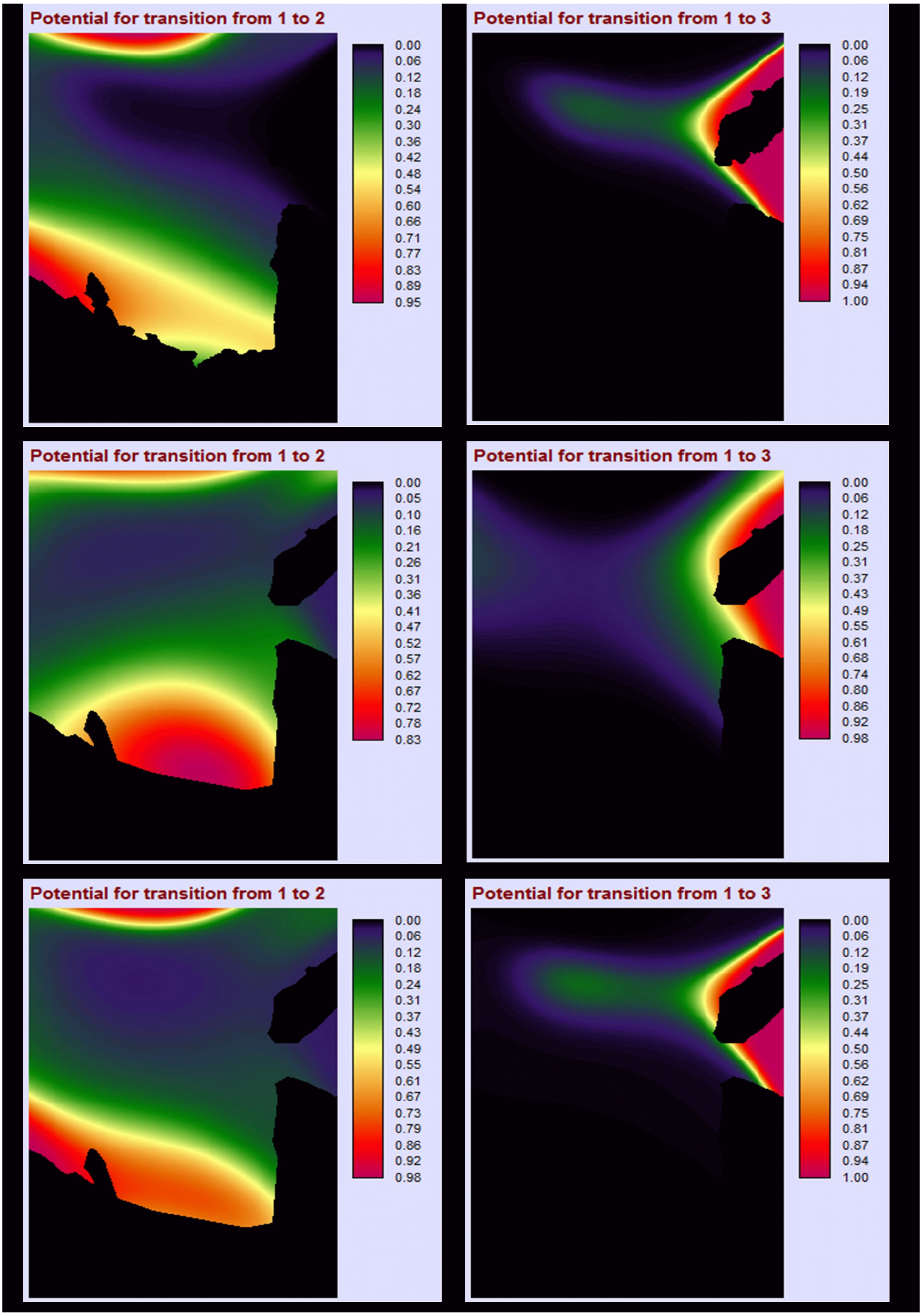

Figure 6. Continued - Spatial trend of change to the 3rd order polynomial for (1) 1958 to 2010, (2) 2010 to 2016 and (3) 1958 to 2016. Positive values reflect transition from wetland to (a) wetlands to all (b) wetlands to forest and (c) wetlands to banksia.

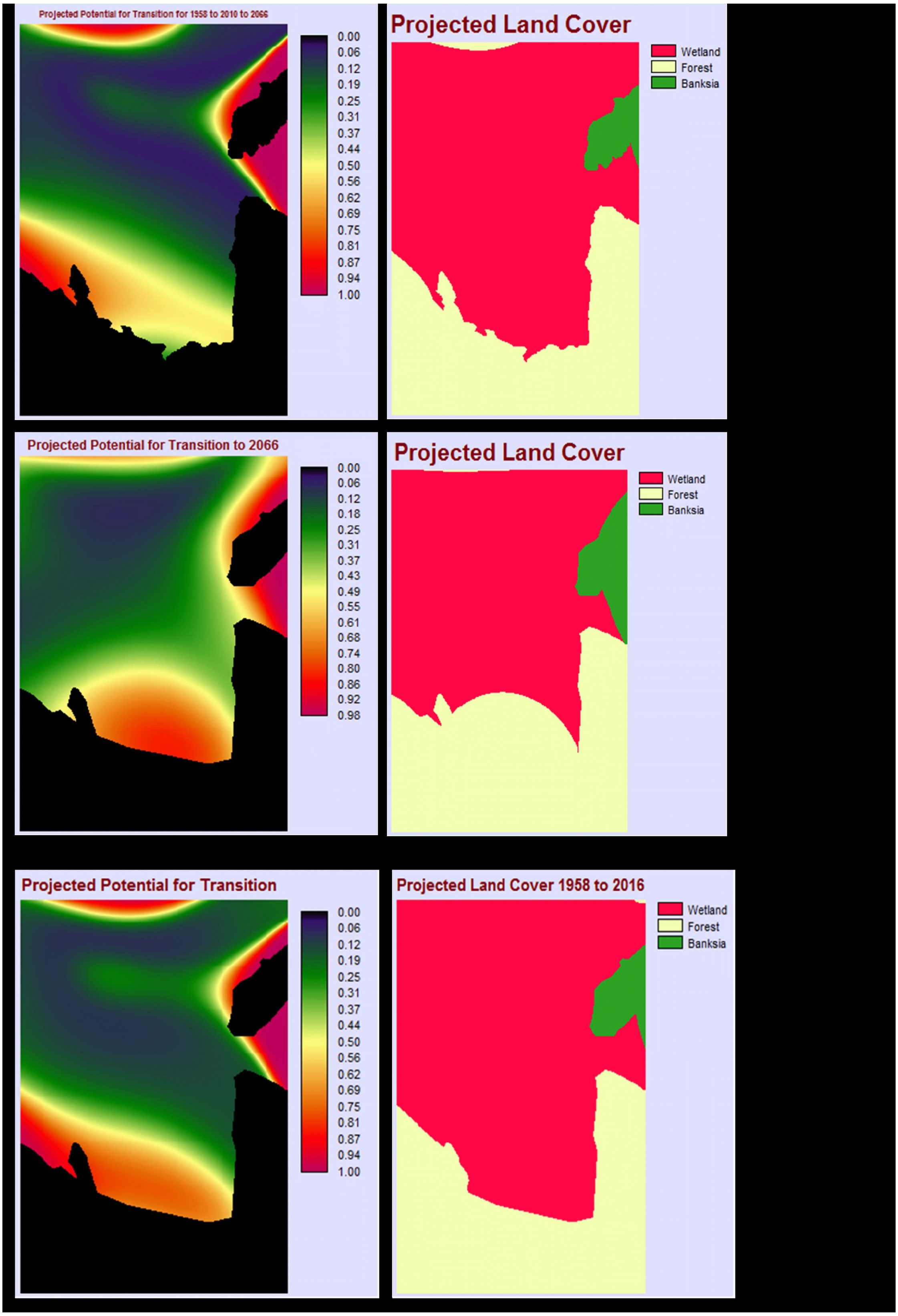

Figure 7. Potential for transition from (a) 1 to 2 and (b) 1 to 3. (a) showing the potential for Wetlands to transition to Forest and (b) the potential for transition from Wetlands to Banksia. (1) 1958 to 2010, (2) 2010 to 2016 and (3) 1958 to 2016 showing potential for transformation.

DISCUSSION

Land Change Analysis

Quantified vegetation analysis has revealed changes in vegetation thickening over the Moon Point landscape for a 52-year period based on the 1958 and 2010 aerial photographs. With the vegetation thickening there has been a corresponding loss of the *E. minus* wetlands as vegetation encroaches onto this area. The change in vegetation dynamics and composition show a positive trend over the past 58 years to present (based on the ground truth data collected in 2016) with the Wetland showing losses (Table 2), while both Forest and *Banksia* displaying gains over this time (Table 3). The LCM show similar results to the manual grid count taken from the two aerial photographs, with losses to Wetlands and gains to both Forest and *Banksia*, however the LCM analysis provided analysis for cubic trend for trans-formation, potential for transition and projected land cover potential for transition to 2066. Further, additional data was used in the analysis where the ground-truthed data for March 2016 was analysed and compared to the 1958 and 2010 aerial photograph data sets.

Potential for transition supports the cubic trends, however provides for prediction of 50 years into the future to 2066 using trends from 1958 to 2010, 2010 to 2016 and 1958 to 2016. Projected land cover potential for transition to 2066 show that under the present status-quo Forest and *Banksia* will become more prominent in the landscape with a loss of *E. minus* wetland, which will continue to show losses, decreasing in area substantially over the next 50 years to an expected 30% reduction in current extent under present trends (Figure 7). However there are limits to the actual expansion of forest to wetlands and *Banksia* to wetlands as the wetlands cannot support forest and *Banksia* except on the margins.

Vegetation thickening, the key process that is associated with the reduction of the *E. minus* wetlands, may be associated with changes in fire regime (Moss et al. 2016) with Figure 8 display a fire frequency of approximately every 12 years for the Moon Point region. Fires have been both wildfires and prescribed burns within the area of investigation, with four wildfires one in 1969, with the second fire in 1982, third in 1994 and the fourth in 2006 (Figure 9). A prescribed burn of the area was undertaken in June 2016 (pers.com Linda Behrendorff 24th June 2016). From this it can be seen that fire frequency has been approximately a fire every 11 to 12 years.

Vegetation Thickening

Changes in the fire frequency and lengthening the interval between fires has been shown to rapidly promote the increase of woody species in grasslands near forests (Swaine et al. 1992;) increasing vegetation cover (i.e. thickening) that may have implications for vegetation structure and function into the future (Pricope et al. 2015). Further, it has been shown that prescribed fire and fire return intervals of greater than 10 years can result in transition from open vegetation communities to woodlands within 30 to 50 years (Ratajczak et al. 2016). However, Stevens et al. (2016) suggests that woody encroachment may be due to changes in atmospheric CO_2, changes in land management and rainfall and not necessarily changes in fire frequency. Kgope et al. (2010), has shown that in experimental studies elevated CO_2 levels can help saplings escape fire by increasing growth rates so that the tree height is above the fire threat, which is also assisted by increasing the saplings underground carbon store (Saintilan and Rogers 2015). Kelley and Harrison (2014) state that with vegetation, fire interactions and CO^2 fertilization in wooded areas in Australia, that an increase in fire promotes a shift to more fire adapted trees with an overall increase in forested area, which increases carbon stocks. Further according to Harrison and Kelley (2016), CO_2 effects were found to increase burnt area in arid regions while increasing vegetation density and reducing burnt areas in forested regions, however CO_2 fertilization will be limited when taking nutrient limitation into consideration (Kelley and Harrison 2014). Further, Fensham et al. (2005), states that in semi-arid regions of Australia fire and woody encroachment showed no relationship at all. However, according to Baker and Catterall's (2015) study of Byron Shire vegetation dynamics, changes in vegetation structure following fire exclusion has resulted in the displacement of treeless ecosystems by forest, as well as the transition of open forest to rainforest. Regular anthropogenic fires by Aborigines prior to the arrival of Europeans would have prevented vegetation thickening, however with the settlement of Europeans in Australia and their fire exclusion or prevention techniques would likely have led to changes in vegetation and possible thickening (Gifford and Howden 2001). There is evidence that European fire management has altered the vegetation composition, with an increase in eucalypts relative to Casuarinaceae on Fraser Island and North Stradbroke Island (Moss et al. 2011, Moss 2013, Moss et al. 2016).

According to Moss et al. (2016) vegetation thickening is possibly a longer-term threat to the *E. minus* mires by the increase in myrtaceous arboreal taxa as shown in the post-European settlement sections of the Moon Point record. Further a major cause of vegetation thickening is the result of moving away from traditional fire management practices in the region (Russell-Smith et al. 2003, Moss et al. 2016). Murphy et al. (2015), states that any factor that decreases fire frequency is likely to increase the chance of forest formation, factors being for example, rockiness, topographic fire protection, insularity. Vegetation thickening is evident in sand environments through the accumulation of woody stems in fire-free years with mid-storey trees showing some evidence of structural suppression in response to frequent fires (Vigilante and Bowman 2004). Gill (1975) describes fire frequency as a function of the number of fires experienced by a plant community within a given time period and that fire is a normal environmental variable. Research by Sheuyange and Weladji (2005) shows that vegetation responds differently to fire frequency, confirming the important role anthropogenic fires play in ecosystems. According to Spence and Baxter (2006) habitat structure was strongly influenced by fire frequency.

Implications for Management

Micro and macro charcoal and pollen records show that fire has played an important role at Moon Point with records from 25,000 years ago to present recorded in the peat records (see Chapter 4). Changes in climate and fire regimes have seen a change in vegetation composition and structure of Moon Point from rainforest taxa of predominantly Cunoniaceae, *Elaeocarpus*, Myrsinaceae and *Argyrodendron* to more sclerophyll arboreal taxa with an increase in rush abundances. Both Chapter 4 and Moss et al (2016), reveal a significant change in fire regimes since European arrival and settlement which appears to be related to the increased presence of arboreal taxa supporting this land-cover change analysis (Farrell 2016). Fire is an important disturbance regime of Fraser Island and its role in maintaining and altering forest vegetation is evident in the palaeoecological records of the Island, which, is also recognised by managers as an important driver of ecological change (Whitlock et al. 2003). If present conditions continue it is expected that further encroachment onto the *E. minus* wetlands will continue as projected by the LCM forecast for the year 2066. The *E. minus* wetland is under threat from changes to fire regimes, particularly in a higher

Table 2 Results of a manual count of grids between the 1958 and 2010 georeferenced aerial photographs using parallels of 1 second of latitude and meridians of 1 second of longitude.

	Manual-count Land Change of Moon Point				Change in area (% of total)		
	1958	**2010**	**Net Change**		**1958**	**2010**	**% change**
Forest	867	910	43	**Forest**	30.90%	32.43%	1.53%
Banksia	74	89	15	**Banksia**	2.64%	3.17%	0.53%
Wetland	1865	1807	-58	**Wetland**	66.46%	64.40%	-2.07%
Total	2806	2806					

Table 3. Results for the analysis of the 1958 to 2010 aerial photographs over 52 years of % of area change, manual count and percent change'. Percent of area change' and the manual count percent change' show similar change trends, where percent change' shows overall percentage change that has taken place over the 52 year period for each vegetation type.

	% of Area change		**Manual Count % change**		**% Change**	
Forest	1.24%	Gain	1.55%	Gain	4.0%	Gain
Wetland	-1.45%	Loss	-2.07%	Loss	-1.9%	Loss
Banksia	0.77%	Gain	0.53%	Gain	6.6%	Gain

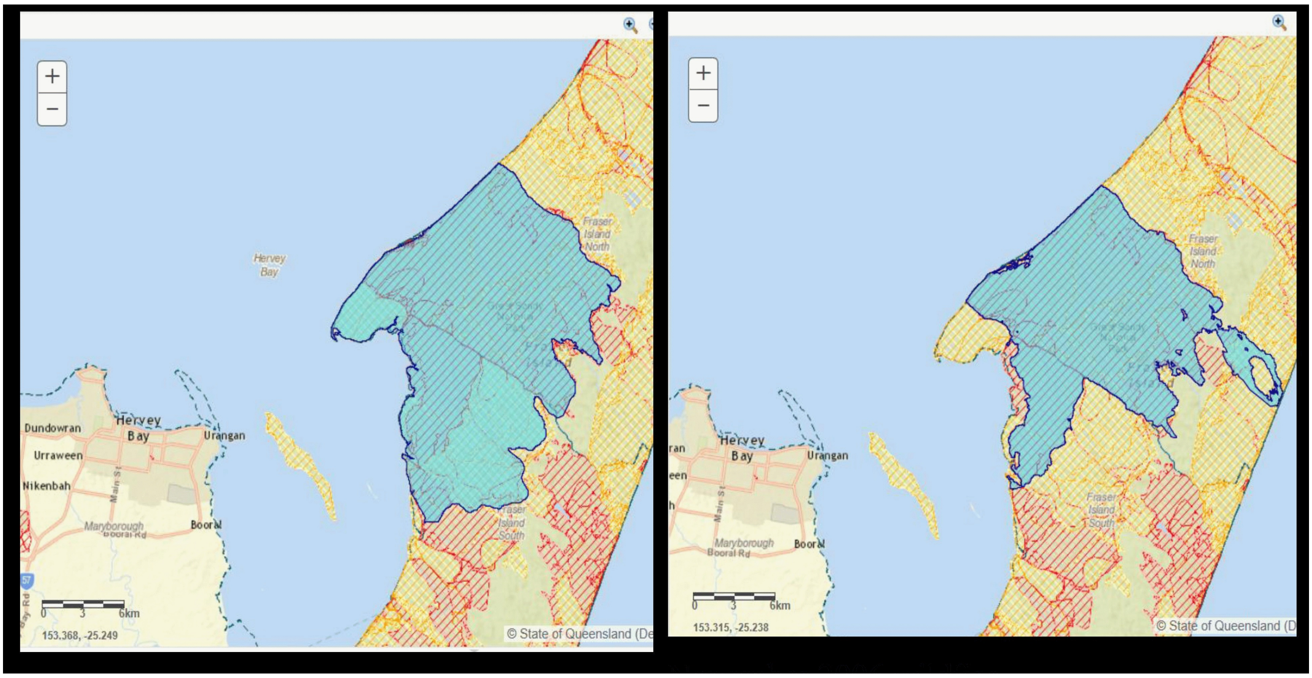

Figure 8. Continued. Change prediction projected to 2066 for (1) 1958 to 2010, (2) 2010 to 2016 and (3) 1958 to 2016. (a) Soft prediction showing vulnerability to change and the degree to which the area has the right conditions to precipitate change. (b) Hard prediction showing change from Wetlands to Forest and Banksia at 2066.

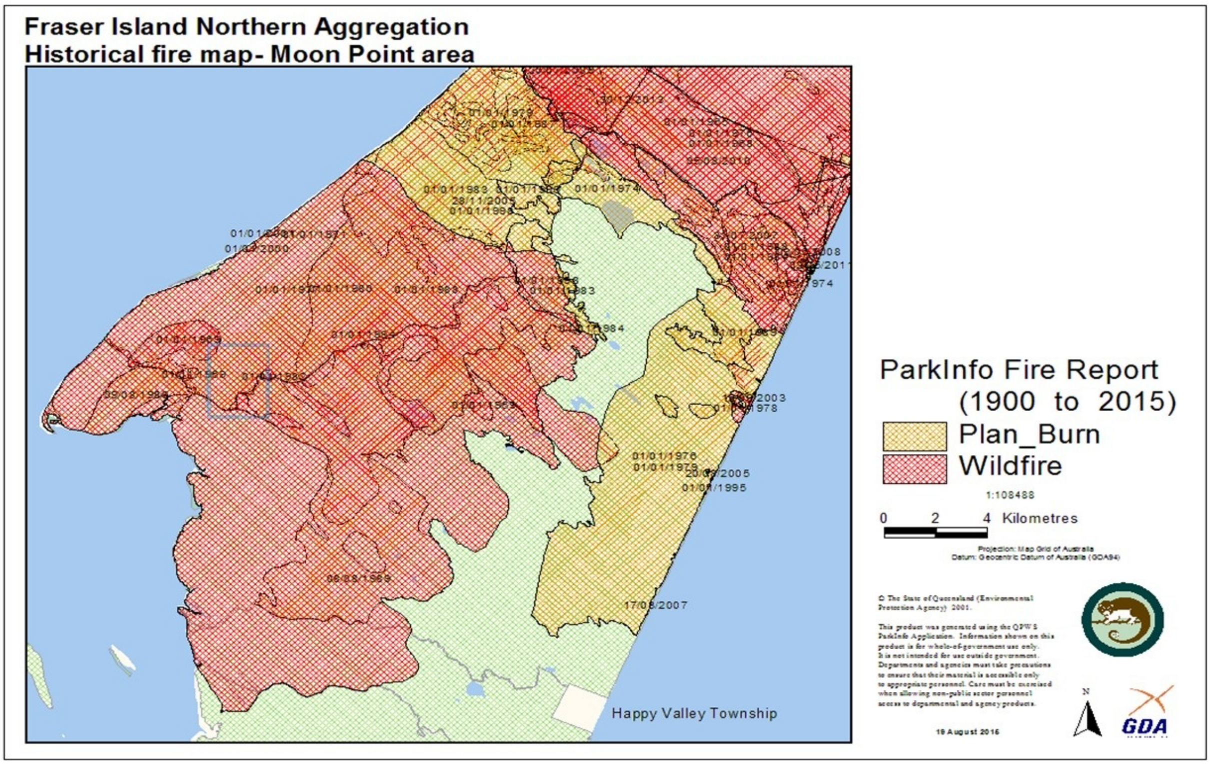

Figure 9. Maps showing area burnt by wildfires at a frequency of 12 years. a Wildfire in January 1994 that burnt an area of 25728.41 ha. b Wildfire in November 2006 that burnt an area of 18917.21 ha. Source: Queensland State Government.

CO_2 world that will include the threat of higher sea-levels and sea-water intrusion into the wetlands requiring important decisions to be made about fire management at Moon Point and other *E. minus* dominated sites. It is suggested that a fire frequency of 7 to 15 years with variation in season be implemented, avoiding set seasonal burns as this can favour particular species within the community over time. Based on the palaeo studies under the right circumstances *E. minus* wetlands are highly resilient and will respond to dramatic environmental changes such as the recovery from the mid-Holocene high-stand event (Moss et al. 2016).

CONCLUSION

There is evidence that the wetlands of Moon Point are changing in the vegetation structure and composition with a decrease in *E. minus* wetland area as vegetation thickening and encroachment is taking place around the periphery of the Moon Point site. Future projection of thickening and encroachment of forest to the year 2066 according to the LCM shows gains over the wetlands between 1958 to present with a prediction to have the highest thickening impact over wetlands to 2066. Between the period 1958 to 2010 there have been limited fires of approximately one every 12 years. In April/May 2016 a prescribed burn of the area was undertaken which was in the cooler months of the year resulting in a cooler burn-off. Fire regimes appear to be the key factor with vegetation thickening at Moon Point, although an increase in CO_2 and changes in temperature and precipitation may also influence the rate of forest encroachment however further studies are needed. Change in fire management is probably the most cost effective adaptation strategy available in combination with continued conservation.

The *E.minus* wetland, sclerophyll forest ecotone is dynamic where fire acts as a destabiliser of the vegetation community. Low intensity frequent fires prevent encroachment and thickening by sclerophyll forest, maintaining a fire induced semi quasi climax state. However the invasion by sclerophyll forest is limited away from dry areas. According to the Queensland Government (2017) regional ecosystem details for 12.2.12a fires are recommended every 8 to 20 years with a burn mosaic of 40 to 80%.

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