Identifying land use/land cover trends for Future Scenarios in the Northern Rivers Region of New South Wales

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1.0 Introduction

Population change worldwide has resulted in an ever changing mosaic of natural vegetation and human land uses (Pathan *et al*. 1993, Schmidt 1998, Seto *et al*. 2002, Weng 2002). Many of the changes reflect both direct and indirect interaction among human activities and the surrounding environment. Although changes occur, determining the linkage between human activities and environmental change can prove problematic (Engelen *et al*. 1995). Furthermore, our ability to determine the cause of change can influence policymakers and their ability to inform the general public (Shearer *et al*. 2006). Subsequently, there is a need to produce results where speculations over the cause of change may be done to allow for the projection of future environments.

A widely used method to assess environmental change is based on land use/land cover trend analyses to provide an indication of land cover change over time ranging from months to years (Fung 1990). Generally, a land use/land cover trend analysis attempts to portray what has happened in the past thereby allowing for a clearer trajectory into what might happen in the future. Alternatively, a land use/land cover trend analysis may also be used to search for potential cause and effect relationships. Such relationships are likely to be related to various past policies, planning instruments and socio-economic change.

In general, land use/land cover trend assessments fall into two broad categories determined by the methodology used to identify land use/land cover change. One method focuses on the identification of specific land use/land cover types while another uses analogous information portraying plant growth or lack thereof (Friedl *et al*. 2003, Homer *et al*. 1997). Studies with a cover type focus generally utilise a classification methodology or expert identification process resulting in categorical dataset (Hansen *et al*. 2000). Studies with an analogue approach generally use a classification process resulting in a continuous dataset representing the relative amount of plant growth. The technique utilised reflects the objective and goals of the study. Both methodologies often utilise a form of aerial or satellite image for use in measuring plant production or identification of land use/land cover types. Where ground surveys have been conducted, imagery is not required to perform a land use/land cover trend analysis.

Within Australia, population change is occurring and future projections show the majority of the change is expected to occur along the Eastern coast (Gaffin *et al.* 2006). The objective of the study is to perform a trend analysis along the Eastern coast of Australia focusing on changes in human uses. The study attempts to identify the trends in land use/land cover change, and goes a step further by linking the change in urban land cover with changes in population for the region.

While an exhaustive procedure, the history of land cover and land use change provides a comprehensive grounding for understanding future probable scenarios and alternatives for the region.

2.0 Methods

2.1 Landsat satellite imagery

The study area comprised the far north coastal area or "northern rivers" of New South Wales (NSW) approximately from the Grafton-Clarence Shire, north to the Queensland border and bounded by the Shires at the bottom of the Great Dividing Range escarpment (Figure 2.1). The region encompasses the Local Government Areas (LGAs) of Tweed, Byron, Kyogle, Lismore, Ballina, Richmond and Clarence.

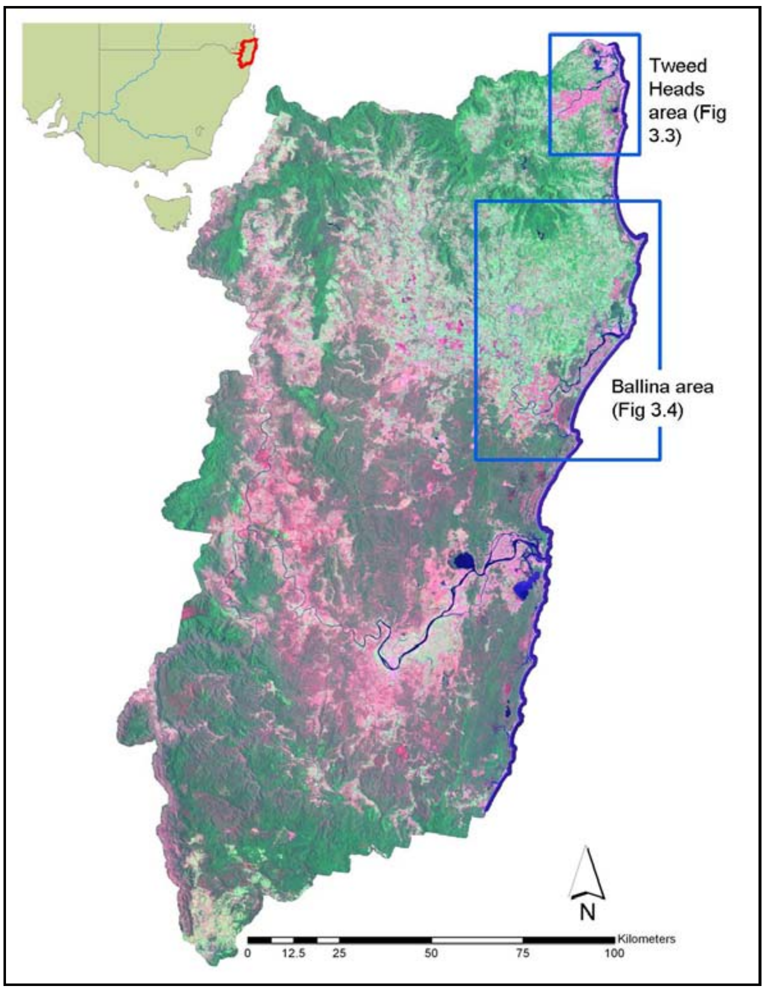


Figure 2.1. The "Northern Rivers" region of the study; the LGAs of Tweed, Byron, Kyogle, Lismore, Ballina, Richmond and Clarence.

The use of satellite imagery for regional land use/land cover identification can provide a relative indication of urbanisation and vegetation change. Although various forms of satellite imagery from a variety of sensors exist, a relatively small subset of the available satellite imagery/sensors provides the necessary information for assessments of land use/land cover change. Within the context of this study and over a 24 year time span the Landsat satellites in operation at the time of image acquisition highlighted land use/land cover characteristics of interest. Subsequently, image acquisition followed roughly a five year interval with Landsat satellite images acquired for the years 1980, 1985, 1990, 1995, 2000, and 2004. Whenever possible, images acquired reflected time periods where the possibility of vegetation discrimination was at its highest. Cloud cover and Landsat image corruption limited the availability of usable satellite images for specific areas within the Far North Coast study area. When images meeting cloud cover and corruption requirements could not be acquired for the desired time period, secondary image acquisition occurred during a less favourable time period.

The spatial extent of the Northern Rivers study region required multiple images for all sensors in any given time period. With multiple images comprising all time periods and to expedite the image classification process, images were mosaiced. The mosaic process used the overlap areas to standardise spectral values among the images (Homer *et al*. 1997). The earlier years, 1980 and 1985, required four Landsat satellite images from MSS sensors be acquired and mosaiced. The other four time periods —1990, 1995, 2000, and 2004 — required two images from TM sensors. Table 2.1 highlights the dates, sensor, path, and row for each time period.

Table 2.1. Date, sensor, path, and row of Landsat satellite images used to develop the New South Wales Far North Coast change analysis

Date	Sensor	Path	Row
Aug. 1980	MSS II	94-95	80-81
Feb. 1985	MSS V	94-95	80-81
Aug. 1990	TM V	89	80-81
Apr. 1995	TM V	89	80-81
June 2000	ETM VII	89	80-81
Nov. 2004	TM V	89	80-81

2.2 Landsat satellite image classification

When classifying mosaiced images a possible disadvantage occurs through an increase in the spectral variability which may result in an increase in misclassification rates. The advantage in the classification process is the need to only conduct the image classification process once per time period. Although the study area has a broad spatial extent, the overall land use/land cover heterogeneity remains fairly constant. Thus, the advantages override the potential disadvantages for classifying mosaiced images.

For all time periods the classification process generated unsupervised spectral clusters using the Imagine™ Isodata algorithm. Prior to clustering, urban areas throughout the region were masked from the image to reduced spectral variability. An iterative process provided an optimal number of spectral clusters to use in the land use/land cover classification process. With each iteration came an evaluation by examining average per band signature standard deviations. The total number of spectral clusters increased by 10 until the average per band standard deviation was 1. For each time period the number of spectral clusters approached 60.

Beyond the spectral clusters, a number of other ancillary datasets provided additional information prior to the land use/land cover classification. The ancillary datasets represent GIS layers describing the physical properties or context of many land use/land cover types of interest. The intent of incorporating ancillary datasets into the classification process is to reduce the potential for misclassification of specific cover types. When ancillary datasets are used in combination, the descriptive power and subsequent level of detail of the physical landscape can often increase. Table 2.2 highlights the ancillary datasets used in the classification process and their role or interval.

Table 2.2. Ancillary datasets used in the land use/land cover classification.

Elevation	Elevation divisions at roughly 90 meter intervals
Slope	Slope divisions smaller at lower slopes and greater at higher slope values
Aspect	Followed the eight dominant directions
Distance from Ocean	Used to identify beaches and the inland extent of coastal vegetation
Sugar cane locations	Used to identify and limit potential sugar cane field locations
Orchard locations	Used to identify and limit potential orchard locations

With the spectral clusters and ancillary datasets generated, cover type rule-sets had to be developed. General rule-sets developed for the 2004 time period were applied to the other time periods with small modifications. The 2004 time period comprised the most recently acquired satellite images and closest approximation to April 2006 training site acquisition. All training sites identified and visited during April 2006 provided the foundation for land use/land cover classification. Mobile GIS technology incorporating global positioning systems (GPSs), computer laptops, and PalmPCs allowed for correct location information to be derived and labelled according to the cover type present at each training site. Training site cover type overlaid on spectral cluster and ancillary datasets created a database where classification rule-sets could be generated for each cover type. Rule-set generation reflected the per-pixel distribution of spectral cluster values within each training site. Rule-set revision followed with further refinement by ancillary dataset. As an example, a spectral cluster value of 22 may be indicative of vegetation comprised of corn, sugar cane, and native rainforest. With the spectral cluster value limiting the possibilities to three types of vegetation further refinement may ensue. Rainforest occurs at higher elevations on steeper slopes. Sugar cane is located in flat areas within a sugar cane mask. Corn is in the mid range elevations away from sugar cane and in relative flat areas. Thus, by using the ancillary datasets the spectral clusters are refined through a discrete rule-set.

With a rule-set developed land use/land cover classification for each time period ensued. Eight dominant cover types could be readily identified with what was believed to be little misclassification error (Table 2.3). The eight cover types readily identified through the above described procedure are forest, coastal complex, beach, water, sugar cane, pasture/crops, orchard, and urban. Higher discrimination among cover types could not be obtained through all time periods even though attempts at doing so were made.

Table 2.3. Mapped cover type descriptions

Cover type	Description
Forest	Sclerophyll forests containing mostly species of *Eucalyptus* trees with various levels of density ranging from rainforests to dry and open forests.
Coastal complex	Vegetation communities found only within 15 km of the coast ranging from shrubs to mangroves.
Pasture/crop	Natural and exotic pasture land including mostly annual vegetation, primarily grassland communities. Isolated crops including corn, tea tree, or other plants which are cultivated mainly for human consumption.
Orchard	Orchards dominated by plantations of macadamia and avocado trees.
Sugar Cane	Fields where sugar cane production is the dominant activity. With a crop rotation system in place and sugar cane harvesting occurring every two years, the crops grown may be sugar cane or a legume.
Water	Locations dominated by either fresh or salt water.
Beach	Sandy beaches located within 150 meters of the Pacific Ocean.
Urban	Manmade features dominated by commercial or industrial buildings; the cover type includes urban residential, semi-urban residential or rural residential houses readily identified on satellite imagery.

2.3 Spatial classification generalisation

With the land use/land cover classification complete to a single pixel resolution of 25 meters, a generalisation algorithm was executed to create cover type GIS layers at a 2 hectare minimum mapping unit resolution (Edwards *et al*. 1995). The generalisation algorithm produced topologically simpler GIS layers by reducing the overall number of small polygons present. Furthermore, the process of eliminating very small polygons is intended to lesson misclassification results produced when single pixels contain a mix of cover types therein.

The generalisation process runs in an iterative fashion doubling the elimination area with each iteration. The entire process begins by subsuming polygons composed of a single pixel during the first iteration, two pixels during the second iteration, four pixels during the third iteration, and so on until a 2 hectare minimum mapping unit is reached. Throughout the iterative process determination of how polygons not meeting the minimum pixel area requirement are subsumed, is done through user defined weights assigned in a matrix and based on the cover type of the small polygon and other adjacent polygons. Where no priority weighting is given, small polygons are subsumed within the largest polygon sharing the longest edge boundary. The entire generalisation process when followed produces land use/land cover maps at a 2 hectare resolution for all time periods.

2.4 Population census collector district assessment

Census collector district information obtained from the Australian Bureau of Statistics provided a useful layer for comparison with the urban cover type identified in the land use/land cover classification process. Urban areas are also made up of a combination of dwellings (of various types), infrastructure, utilities, roads, schools, light industry and commercial areas. Increasing (or decreasing) population might therefore be reflected in a proportionately larger increase (or loss) of the urban land cover type. Detection of urban areas in this study excluded detection of small acreages or “hobby” farms.

Overlays between the 2 hectare land cover/land use and the collector district GIS layers allows for a change comparison among population and cover type to be conducted. Specifically, the change in area for the urban cover type for the time periods 1980, 1990, and 2000 when compared with the change in population for the 1981, 1991, and 2001 census collector districts may provide insight into the performance of the land use/land cover classification. For overlays among the two GIS layers to reflect similar information the urban land cover area was summarised by census collector district. The change in population between the time period 1981 and 1991 may then be compared with the change in urban area for the time period 1980 and 1990. The same process may then be conducted for the 1991 and 2001 population change and the 1990 and 2000 change in urban area.

3.0 Results

3.1 Land use/land cover type distribution and change

Cover type distribution for all time periods show an abundance of vegetation in the forest and coastal complex cover types (Figures 3.1 and 3.2). Forest communities dominate mountain and escarpment areas, and inland locations largely void of human habitation. Coastal complex vegetation communities appear relatively close to the coast where urban and agricultural development has not removed the flora. The water cover type is dominated by the ocean shoreline and a mixture of rivers, estuaries, and lakes. The beach cover type only occurs along ocean shoreline locations. Sugar cane fields are present along many of the major rivers in the region with a proliferation of fields located where the difference in elevation between river levels and the surrounding land area is less than 10 meters. Most of the sugar cane fields are located within a close proximity to the coast. The pasture/crop cover type dominates areas located in relative close proximity to residential urban areas in the lower elevations. In general pasture and crop locations are in low sloping areas, however, there are exceptions where pastures extend into foothill locales. Orchards are located in the north-western portion of the study area in areas of rolling hills with a rather limited spatial extent. Orchards are absent during the 1980 time period. A summary of cover type area by time period is presented in Table 3.1.

Table 3.1. Area in hectares for each cover type by time period.

	1980	1985	1990	1995	2000	2004
Coastal complex	80,741	74,122	75,136	64,378	83,015	67,844
Forest	1,299,363	1,279,883	1,277,190	1,212,614	1,287,359	1,248,753
Pasture/crop	694,047	714,817	718,733	790,345	682,429	731,498
Orchard	0	418	3,332	4,376	7,194	8,730
Sugar cane	53,119	53,557	47,941	47,407	57,042	56,073
Water	46,770	48,193	45,510	45,478	45,291	47,989
Beach	2,249	2,192	753	1,387	991	1,089
Urban	6,762	9,240	13,828	16,437	19,101	21,075

Trends in cover types vary for each time period. In general, the urban and orchard cover types show a linear increasing trend with time. The urban cover type has more than trebled over the time period. Beach area appears to have halved, while orchard cover types (e.g., Macadamia) was initiated and grown considerably since just before 1985. The extent of sugar cane fields decreased in the 1990s rebounding in the 2000s.

A single anomaly in year 2000 shows an increase in the coastal complex cover type which can be explained by two factors, the timing of the image in June and the apparent lack of moisture in the image. These two factors would increase grazing and agricultural activities in locations where soils in wet years would be too moist for cattle and human access. Thus, with an increase in coastal complex a concomitant decrease in pasture and croplands occurs. In general, forest and pasture/crop cover types alter year-by-year and may reflect forest clearing and regrowth activities associated with both logging and grazing practices.

A comparison of the combination of the more natural cover types coastal complex, forest, and pasture with the combination of more human cover types orchard, sugar cane, and urban shows a decline in the more natural cover type combination and an increase in the predominately human cover types (Table 3.2). Although the pasture/crop cover type may be presumed to be human induced the majority of the cover type is composed of grasses some of which naturally occur in the region.

The largest change in the human cover types occurs between the years of 1995 and 2000 with more moderate increases occurring between the earlier 5 year time periods of change. In other words, land use change has accelerated in the last decade. Most of the 2 to 3 fold increase in urban area has occurred around Tweed Heeds in the north (Figure 3.3), and Ballina areas (Figure 3.4).

Table 3.2. Area in hectares for the lumped natural and human cover types.

	1980	1985	1990	1995	2000	2004
Natural	2,074,151	2,068,822	2,071,059	2,067,337	2,052,803	2,048,095
Human	59,881	63,215	65,101	68,220	83,337	85,878

landscape change analysis (reported further below and as an attachment), in brief, include:

- Accelerating rates of large land cover change due to urbanisation related to population change – especially Tweed Heads and Ballina areas.
- Urban area change related to newcomers and new dwellings is in many areas only a fraction of total urbanisation change brought about by development of large commercial areas and light industry as well as roads, utilities and other infrastructure.
- The NSW Planning Department's North Coast Strategy is planning on an additional 150,000 in population over the next 20-25 years, however our land use, demographic and socio-economic change analyses provide some evidence of a scenario of 500K population increase for the region over this period.

Figure 3.1. Land use/land cover distribution for 1980, 1985, and 1990.

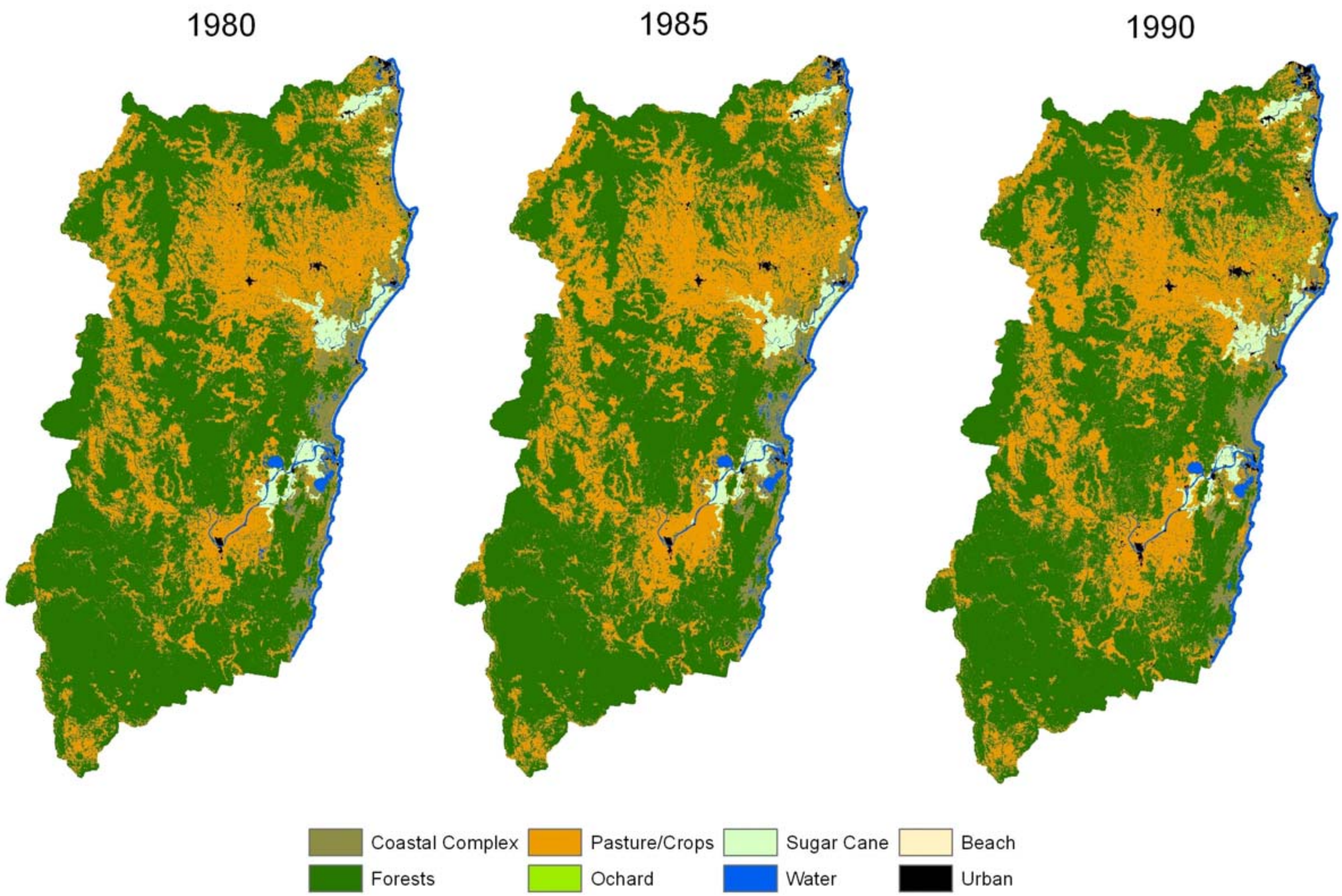


Figure 3.2. Land use/land cover distribution for 1995, 2000, and 2004.

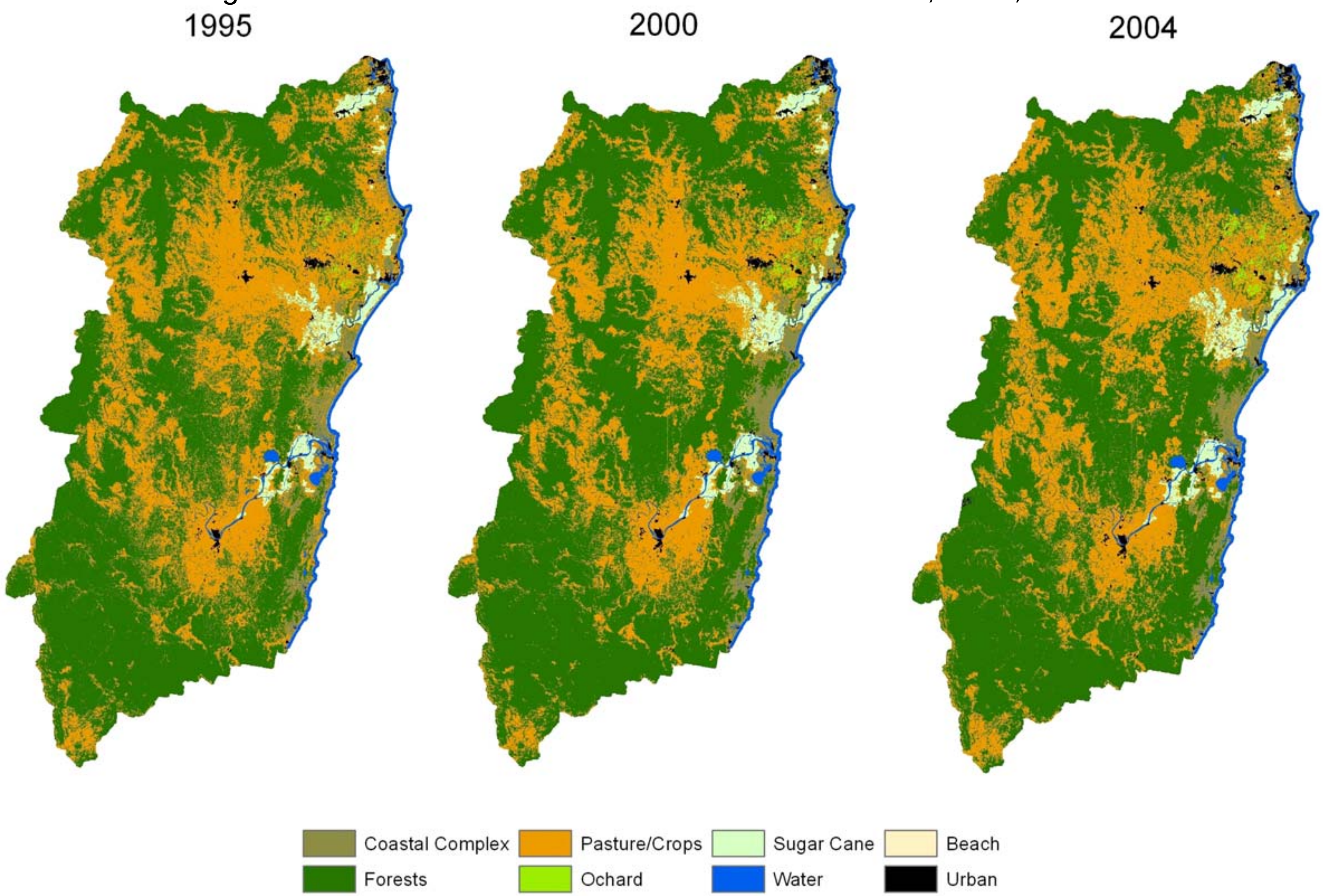


Figure 3.3. Detail of land use/ land cover change between 1980 and 2004 for Tweed heads area

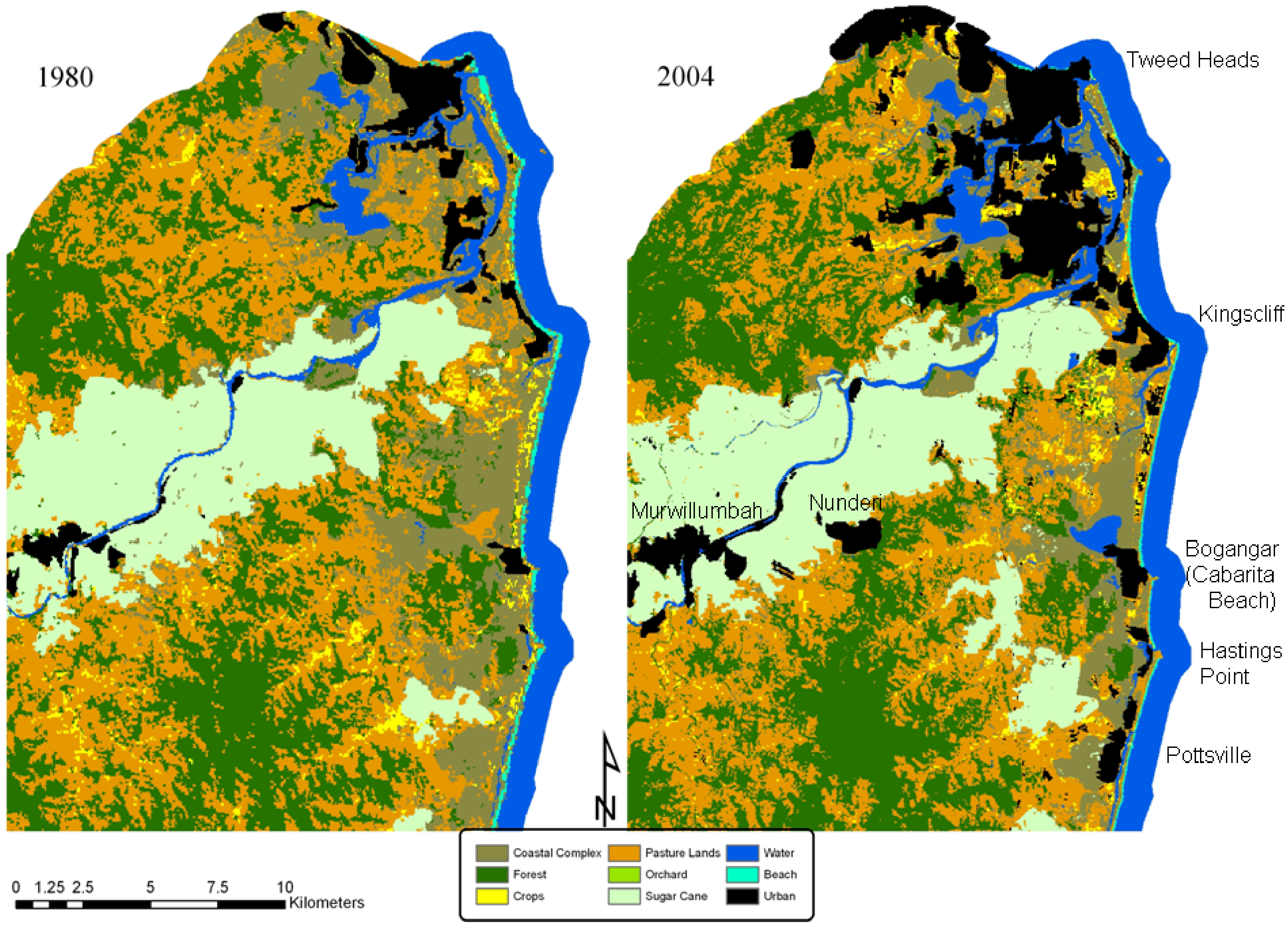
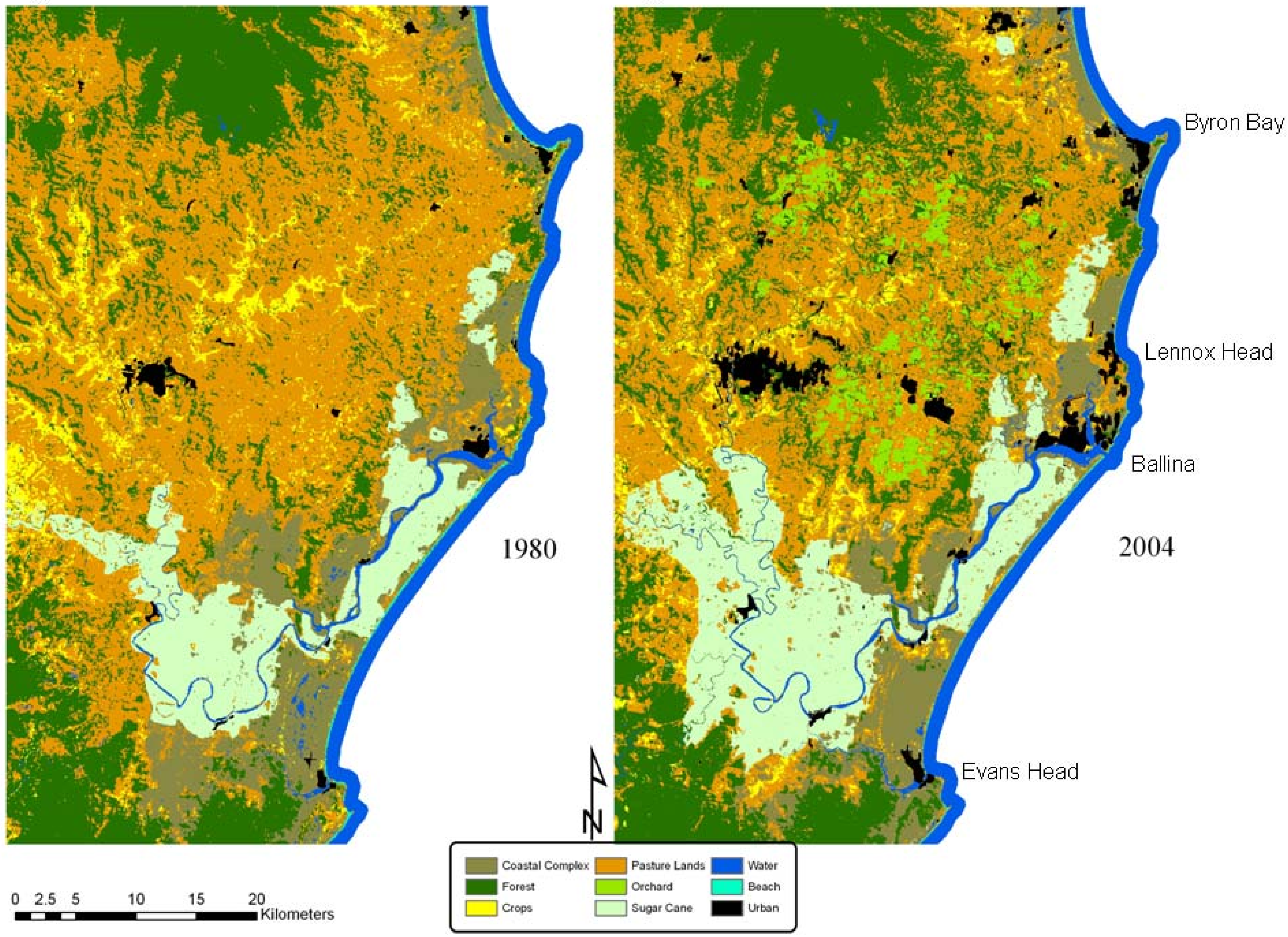


Figure 3.4. Detail of land use/ land cover change between 1980 and 2004 for Ballina area



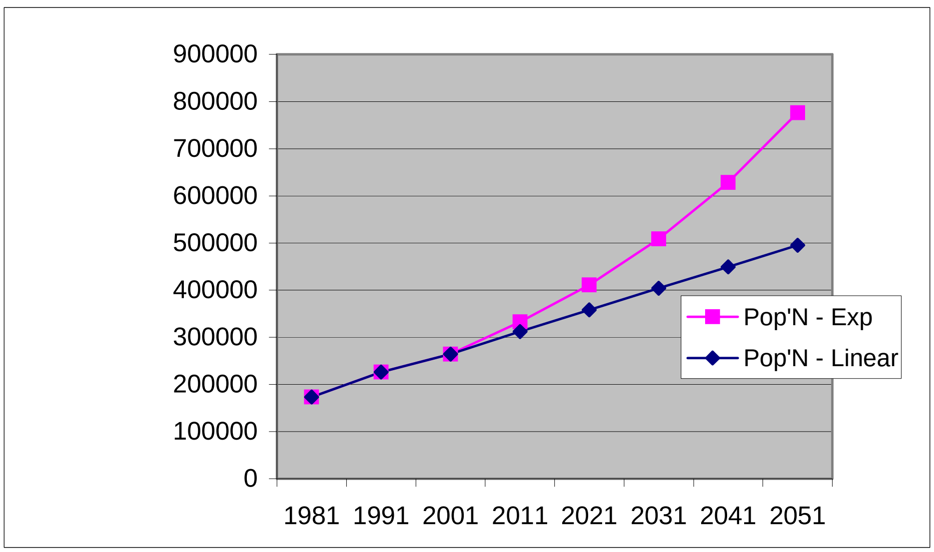
3.2 Relationships of urban land cover change with population change

In the Coastal Northern Rivers region of NSW, the population has increased from 173,000 in 1981 to 266,000 in 2001 (273,000 in 2006). Analysis of past and current trends of accelerating migration and population growth suggest that the population of this region continues to follow linear growth overall, but with exponential growth occurring in particular areas, mostly along the coastal fringe.

The regional population will reach around 400,000 within the first two decades of this century, and quite probably 550-600,000 by 2030. Historical and probable future population growth trend for the whole study region is shown in Figure 3.5 (Note from Figures 3.3, 3.4, 3.7 & 3.8, that there is considerable spatial variability in the location of increasing, decreasing or neutral population change across the region). Overall the trend is for linear growth, however in reality some areas will not increase in population, some will decrease and some areas (mostly along the coastal strip of available freehold land) are likely to grow exponentially (Figure 3.5).

Most of the population growth and urbanization over the past two decades and in the next few decades will be along the coastal fringe – Tweed Heads to Byron Bay, around Ballina, Evans Head, and Yamba area – and some focused around a few hinterland towns – for example, Murwillimbah, Lismore, Grafton (Figures 3.3, 3.4).

Figure 3.5. Historical and Probable population growth for entire study region



An analysis of the change in urban area compared with the change in population shows that, overall for the region, as population increases so does the urban land cover type (Table 3.3). While the population increase was more than 50% between 1980 and 2001, the urban area increased by over 180%. Although the population and urban area increases on a decadal scale the urban area appears to be increasing at a greater rate than population.

Table 3.3. Change in urban area and population by decade.

	Urban area (in hectares)	Population
1980 (1981)	6,762	173,140
1990 (1991)	13,828	226,010
2000 (2001)	19,101	266,459

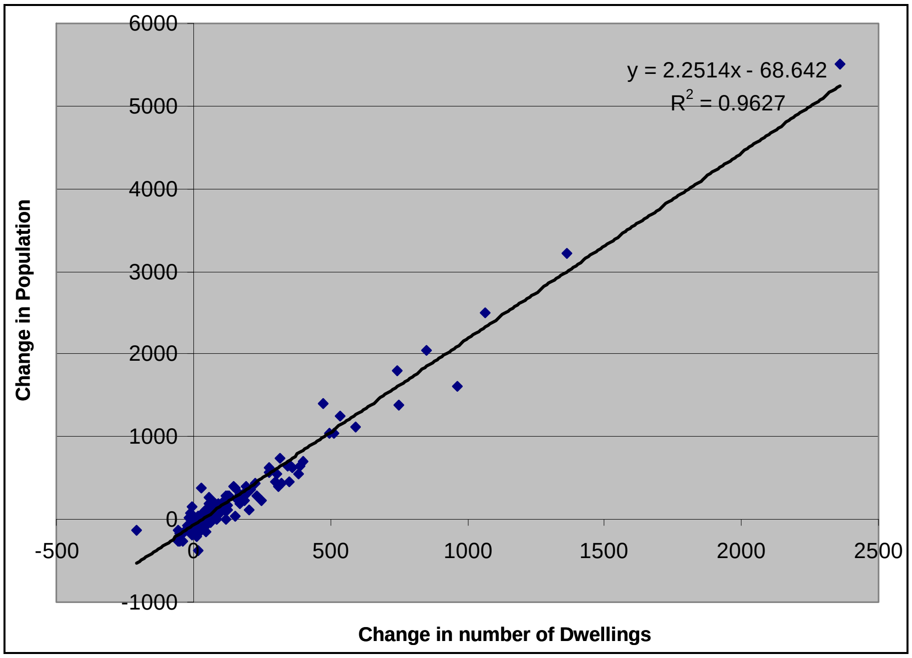
An initial linear regression analysis of change in urban area and population change by census collector district (CCD) shows that a significant relationship (p-values < 0.00) exists such that as population increases the area of the urban cover type increases. Although all the regressions for each time period range are significant the R^2 values are quite variable.

While this might suggest a less predictive capacity for change in urban area with population change per census collector district, there are other relationships that explain the spatially disparate nature of population growth and urbanisation. Urban areas are also made up of a combination of dwellings (of various types), infrastructure, utilities, roads, schools, light industry and commercial areas. Increasing (or decreasing) population might therefore be reflected in a proportionately larger increase (or loss) of the urban land cover type. The recent urban area growth along the coast depicted in Figures 3.3 and 3.4 shows the enormous concurrent increase in “urbanised” areas that are known, from ground truthing, to include large areas of commercial and light industry premises. In addition, speculative housing development in fast growing areas may precede migration, which in turn incrementally fuels further development speculation and land releases.

Trends around highly urbanised areas show large increases in both population and urban area (Figures 3.7 and 3.8). The majority of the coastal increase in urbanisation occurs in the far Northern portion of the study area around, and just to the south of, Tweed Heads (Figure 3.4).

Regressions of population increase (numbers) with urban area return stronger R values (around 0.5-0.6), but are probably still confounded because, in terms of urban area, the population reflects more than the dwellings in which they live. This appears to be well supported by a regression analysis of the relationship between population change and change in the number of dwellings (Figure 3.6), which shows a very strong correlation ($R^2 = 0.96$). Local governments and State planners confirm that there are various “multipliers” for various infrastructure, roads and commercial premises that are applied to new urban land releases. It is therefore reasonable in the current study to use the observed change trends for population and urban area in spatially describing future growth and alternative scenarios.

Figure 3.6. Relationship between change in population and change in number of dwellings



More detailed examination of these relationships is being undertaken to decipher the contributing influences and components of urbanisation. A better understanding of the differences reflected in spatial consequences of these factors along with differences associated with position – proximity to beach and coastal strip or hinterland towns close to popular coastal areas – will provide valuable input to scenarios.

Figure 3.7. Census collector district population change by decade.

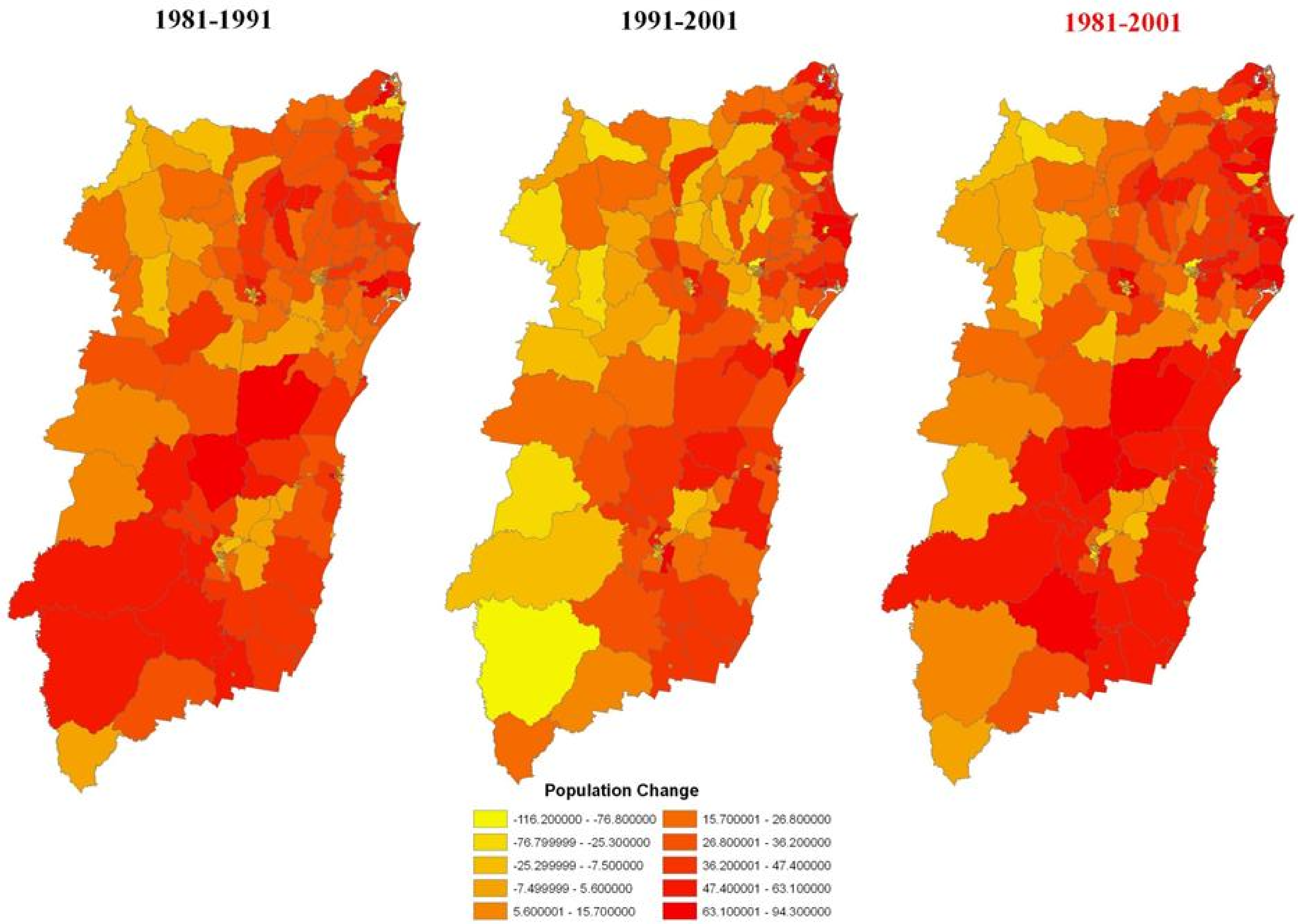
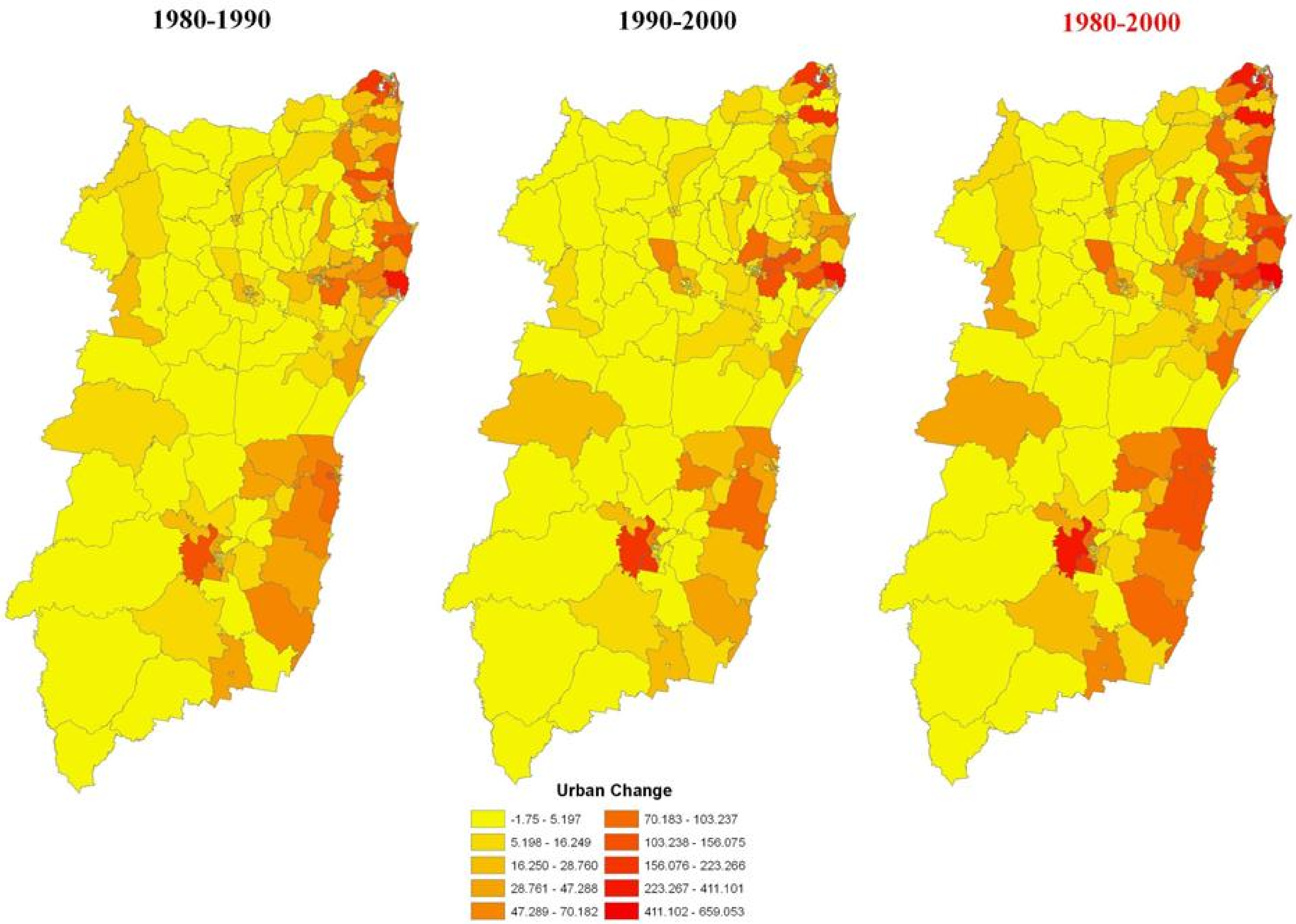


Figure 3.8. Census collector district urban area (in ha.) change by decade.



4.0 Discussion and Conclusions

The Northern River region's land use/land cover characteristics have changed considerably over the past twenty-four years. The area increase in human dominated cover types is resulting in a decrease in the aerial extent of vegetation communities throughout the region. This research quantitatively presents the change in land use/land cover types. Residents and policy makers in the region will have to determine whether the amount and type of change is acceptable given their individual desires.

The location of change also varies considerably. The greatest amount of urbanisation is occurring on the edges of existing coastal towns – in particular, around the cities and fringes of Tweed Heads and Ballina. New settlements have also appeared and grown in more recent times. The urban cover type shows the most dramatic increase in the cities along the coast showing the need for active planning in coastal towns. The lack of active planning within coastal towns may result in an ever decreasing presence of coastal vegetation which currently is the least represented natural vegetation cover type mapped in the region. Future demand for coastal housing in the region might result in loss of this rare vegetation community along with mangroves in estuarine areas . There is also likely to be a loss of agricultural land along the riverine areas between towns.

There is a strong relationship between population growth and the increasing number of dwellings. The 2-3 fold urban area growth may be indicative of an increase in low density housing, reduction in family size in urban areas, or errors in the land use/land cover type classification, or a combination of the three. Given the strong correlation between increasing population and number of dwellings, despite low density housing being hard to identify at 25m pixel resolution (see also Jenson and Troll 1982), these results would seem to be low in such errors. Nevertheless, further exploration of other social and demographic information contained within the census data would be useful in future studies examining change in population and urban cover type area.

Modern urbanisation is much more than residential addresses. The very strong relationship between increase in the number of dwellings with increasing population, coupled with the land cover change showing 50% population increase resulted in 180% urban area increase, suggests that urbanisation increasingly uses more land (perhaps up to 3 fold) for a wide range of services for the residents than reflected simply in population or dwelling numbers. The amount and specific location of urban area increase is most likely related to an increase in population and concurrent increases in roads, utilities, infrastructure and commercial areas.

The results are important and support the concept of population growth along Australia's Eastern coast presented by Gaffin *et al.* 2006. The increase in urbanisation is likely to result in a concomitant change in coastal community lifestyle. The perception of increased population movement due to in-migration is likely to continue if the current census and land use/land cover trends are followed. The results further point to the need for more thoughtful long term planning of the placement and area used by services to the resident population.

The trend of loss in natural vegetation and increase in human land use/land cover types is indicative of a growing region. Over the 24 years of the spatio-temporal study of landscape change, the Northern Rivers region has seen a nett loss in area of coastal complex vegetation (-16%), Sclerophyll forest (- 5%), ocean beaches (- 51%). Over this period there have been small losses and gains in areas of pasture land and sugar cane. Of note, in the central area of the study region, there has been the appearance since about 1982, and increasing development of orchard like horticulture plantations (e.g., Macadamia) with many small blocks totalling almost 9,000 ha by 2004.

While a time consuming procedure, the history of land cover and land use change provides a comprehensive grounding for understanding future probable scenarios and alternative futures for the region. Regional planners, local institutions, and other stakeholders should consider exploring future scenarios of land use/land cover change. Baker *et al.* 2004 and Steinitz *et al.* 2003 have shown how future projections in land use/land cover can aid individuals interested in planning for a regions future.

The current study will now focus on understanding the spatial ramifications of these change trends in likely future and alternative scenarios for the NSW Northern Rivers region.

The Northern Rivers region, as would other rapidly changing regions, will benefit from the study providing visual geographic data of quantifiable change to allow local stakeholders insights to understand and plan for a future where uncertainties are present.

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