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WISE EXPLOITATION OF NEWLY GROWING LAND RESOURCES
—An Assessment on Land-use Change of Chongming Island Using GIS

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ABSTRACT: Chongming Island, the third largest island in China and the largest alluvial island in the world, is situated in the north of Shanghai Municipality at the mouth of the Changjiang (Yangtze) River. Along the fertile and prosperous sea coast there are a total area of over 120×10^3ha, with a population of 735 000, accruing some 500ha of new tidal land resources come from silt, sand and mud carried by the Changjiang River every year, extending about 140m per year. This dynamic process of alluvial growth has run for some 1500 years. Mudflat on Chongming Island at the mouth of the Changjiang River is a resting ground for migratory birds and host more than a hundred species, including rare cranes and geese. But the local people keep reclaiming the tidal land for economic development. Obviously, it is crucial to have a well-concerted plan for future exploitation. In this study, we attempted to investigate the status changes of land use and wild life habitats on Chongming Island in recent 10 years, and then analyzed different human activities and their effects on wild life habitats using satellite image data (1990, 1997 and 2000) as well as field survey. Based on the analysis, this study explored the relationships between island growth and land use/cover change (LUCC), predicted what the habitat would be like in the future and tried to find more effective use of this new growing resource. At last, this study provided some preliminary management plans for Chongming Island that will coordinate the development of local economies and the conservation of wild life and their habitats.

KEY WORDS: reclamation; land use/cover change; Markov model; biodiversity conservation; Chongming Island

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1 INTRODUCTION

Three well-documented major global changes affecting human beings are increasing concentration of carbon dioxide in the atmosphere, alteration in the biochemistry of the global nitrogen cycle, and on-going land use/cover change (LUCC) (VITOUSEK, 1994). For centuries, human beings have been altering the earth's surface to produce their food and shelters through agricultural activities (REID *et al.*, 2000). Like other countries, China is also subject to land transformation, for instance, about half a million hectares of wetlands have been reclaimed for crop production in Central China since the 1950s (ZHONG and CAI, 1997).

Estuaries, wetlands and riparian region are critical transition zones (CTZs) that link land, freshwater habitats, and the sea (BARDGETT *et al.*, 2001). CTZs provide essential ecological functions, including decomposition, nutrient cycling, nutrient production, as well as regulation of fluxes of nutrients, water, particles, and organisms to and from land, rivers, and the ocean. Sediment associated biota are integral to these functions (LEVIN *et al.*, 2001). Especially the conservation of CTZ habitat near urban area is challenging, because multiple uses must coexist (ZEDLER and LEACH, 1998).

Chongming Island is located at the mouth of the Changjiang (Yangtze) River and facing the East China Sea in the east and near to the biggest Chinese metropolis Shanghai. The island is the third largest is-

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land in China and the island is growing because of sedimentation of silt carried by the Changjiang River. According to historic records, all the islands in the present river mouth were formed in the last 1400 years. The embryo of the present Chongming Island was a small inter-tidal shoal, which was first found in AD 618 (YANG *et al.*, 2001), and it has doubled over the last 50 years to about 120×10^3ha and is still growing 140m a year to the east and 80m to the north (XIE and YANG, 1990; GSCCI, 1988; GSICI, 1996). However, ever eager to wrestle more land from the sea, Chinese farmers have sharpened the clash between human being and nature with aggressive reclamation over the past decade. Over 50×10^3ha of inter-tidal marsh flats has been reclaimed since 1956 by the Shanghai Government by the construction of dikes (CHEN *et al.*, 1999). These dikes are likely to have a profound impact on the natural succession of these virgin lands and the pioneer marsh biotic communities. Once enclosed, the wetland dries up and the grasses on which the shorebirds depend die out. Therefore, the role of land-use change and its relation to biodiversity conservation have become more and more critical. Previous reports have concentrated mainly on vegetation, birds and fauna (MA *et al.*, 2002; WU *et al.*, 2002; MA *et al.*, 2003), and few studies have yet been carried out on the impact of the reclamation process on LUCC. It is a challenge to make efficient exploitation and wise utilization of the newly growing land resources carried by the Changjiang River.

2 METHODS

2. 1 Study Area

The study area is the East Beach (Dongtan), which is a typical marshy land located in the east of Chongming Island (Fig. 1). The site is a staging and wintering site for millions of birds, as well as a spawning and feeding ground for 63 species of fish, including the protected Chinese sturgeon (*Acipenser sinensis*).

Mudflat wetland on this area is a resting ground for migratory birds and host more than a hundred species, including rare cranes and geese. It has reached the criteria of international importance set by Ramsar Convention on Wetland. The records show that Dongtan has 109 bird species and nearly one million birds. Shanghai municipal government established a wetland sanctuary "Chongming Dongtan Nature Reserve" (31°38′N, 121°58′E) on this area to better protect the habitat of rare birds and biodiversity. This is an extensive area of fresh and salt water marshes, tidal creeks, and inter-tidal mudflats at the eastern end of Chongming Island, a low-lying alluvial island in the mouth of the Changjiang River, which supports farmland, fish and crab ponds, and extensive reed beds. This reserve was established in November 1998 with a total area of 32.6×10^3ha, in which wetland takes 14.5×10^3ha. In 1999 the reserve became a member of the East Asian-Australasian Shorebird Site Network. It is also listed in the National Wetland Conservation Action Plan for China as a wetland of national importance in 2001.

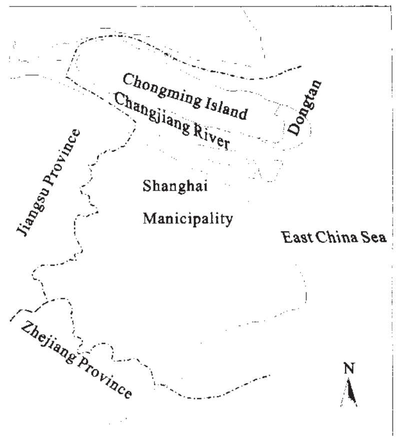


Fig. 1 The sketch of study area

2. 2 Data Collection and Preparation

The data used here were extracted from cloud-free LANDSAT Thematic Mapper (TM) imageries of three periods: December 1990, February 1997, and June 2000 (ETM). First, the orthocorrected ETM panchromatic image of 2000 was geo-rectified and registered to a Universal Transverse Mercator (UTM) coordinate system, by using road intersections and other prominent visible features on the existing topographic map of Shanghai at the scale of 1∶100 000 (provided by Shanghai Municipal Institute of Surveying and Mapping) in IDRISI Release 2 (Clark Labs., http://www.clarklabs.org). Then, the imageries of 2000 were used as the master dataset to rectify the TM RAW images of 1990 and 1997. Average RMS error of less than 0. 5 was achieved for all the imageries, and the pixel size was kept as 30m × 30m.

2. 3 Land-use Classification

With remotely sensed data of 3 different seasons, the differences between time periods might have resulted from the difference in data collection rather than from actual change taking place on the ground. We minimized this danger in three ways. First, we standardized the atmospheric conditions of the 3 years' imageries. Second, we selected 5 LUCC types that could be clearly distinguished by using a specific 3-band composite of the TM images (4, 3, 2). Third, we conducted 3 intensive ground truthing for the 3 imageries at corresponding periods between autumn of 2001 and summer of 2002. The classification approach was a combination of unsupervised and supervised classification techniques using a high degree of human interpretation and expert knowledge about the location. More than 30 training sites were collected through extensive fieldwork. Fourteen ground control points were collected by using GARMIN-12 Global Position System (GPS).

According to the characteristics of LUCC in Dongtan of Chongming Island, five main land-use categories were classified, including aquaculture pond, farmland, orchard & plant nursery, settlement, and wetland.

2.4 LUCC Modeling and Detection

Transition probabilities have been used extensively for analysis and modeling of LUCC (BURNHAM, 1973; TURNER, 1987; AAVIKSOO, 1995; COUSINS, 2001; LóPEZ *et al.*, 2001). The approach treats state transitions as Markov random processes that are conditional on the initial state only. The 1st-order Markov process is based on the probability that the system will be in a given state (land class) at some time $t+1$, deduced from the knowledge of its state at time t. Therefore, the probability does not depend on the history of the system before time t. When a Markov process moves from one time step to the next, the transition from one state to the next only depends on that given state and not on how the process has arrived in that state. Transition model can be expressed in matrix form:

$$n_{t+1} = Pn_t \quad (1)$$

where n_t is a vector of land-area fractions in each of m cover or use types at time t, n_{t+1} is the vector of land-area fractions for the same types at time $t+1$, and P is an $m \times m$ matrix which expresses the probability that a site in state i at time t will be transferred to state j at time $t+1$. Because of some limitations of Markov transition probability-based model for LUCC analysis, BAKER (1989) suggested setting state transition probabilities as a function of exogenous or endogenous variables, which varies in space and time. The above equation then becomes:

$$n_{t-1} = P[f(t, x)]\, n_t \quad (2)$$

$$P_{ij} = f(t, x) = b_1X_1 + b_2X_2 + \ldots + b_kX_k \quad (3)$$

where p_{ij} is the element in the matrix of transition probabilities P, and the parameters b_k describes the functional relationship between some set of predictor variables X_k, which can vary in both time (t) and space (x), and p_{ij}.

In this study, LUCC was assessed using first-and second-order Markov chains for the periods 1990 – 1997 and 1997 – 2000. LUCC data were then analyzed in IDRISI GIS using function CROSSTAB, MARKOV and STCHOICE.

2.5 Spatial Pattern Analysis of Land-use Patches

In order to reveal the patterns of overall land-use patches, as well as each land-use patch, an analysis was performed at two levels. One was at the level of the overall land-use patches (landscape level); the other was at the level of each type of land-use patch (class level). In the past years, more than 60 landscape indices have been proposed, and were used to characterize landscape spatial structure (TURNER, 1990; TURNER and GARDNER, 1990; HUNSAKER *et al.*, 1994; MOODY and WOODCOCK, 1994; SIMPSON *et al.*, 1994; RIITTERS *et al.*, 1995). However, many of the available metrics are correlated (TISCHENDORF, 2001), so we just need to use several relative metrics in a specific study. Here, seven indices were selected in this study and the various landscape indices used were grouped into three classes. The seven indices include four structural indices: 1) number of patches of each land-use type (N), 2) total area of each land-use type (A), 3) proportion of each land-use type (P), and 4) mean patch size of each land-use type (MPS); one shape index: mean shape index (MSI) (GARDNER *et al.*, 1987; BURROUGH, 1986); two pattern indices: 1) Shannon's diversity index (SDI) (MCGARIGAL and MARKS, 1995), 2) Shannon's evenness index (SEI) (O'NEILL *et al.*, 1988; TURNER, 1990)

All the landscape indices employed were calculated using the software Patch Analyst Extension 2.0 for Arcview (MCGARIGAL and MARKS, 1995).

3 RESULTS

3.1 Change Detection and Description

The quantification of LUCC for the analyzed categories is given in Fig. 2 and Table 1. Within the study area, the most variable class was wetland, which shrinked most from 1990 to 2000. The second highly dynamic class was orchard and plant nursery, which almost increased 12 times during the former 7 years and more

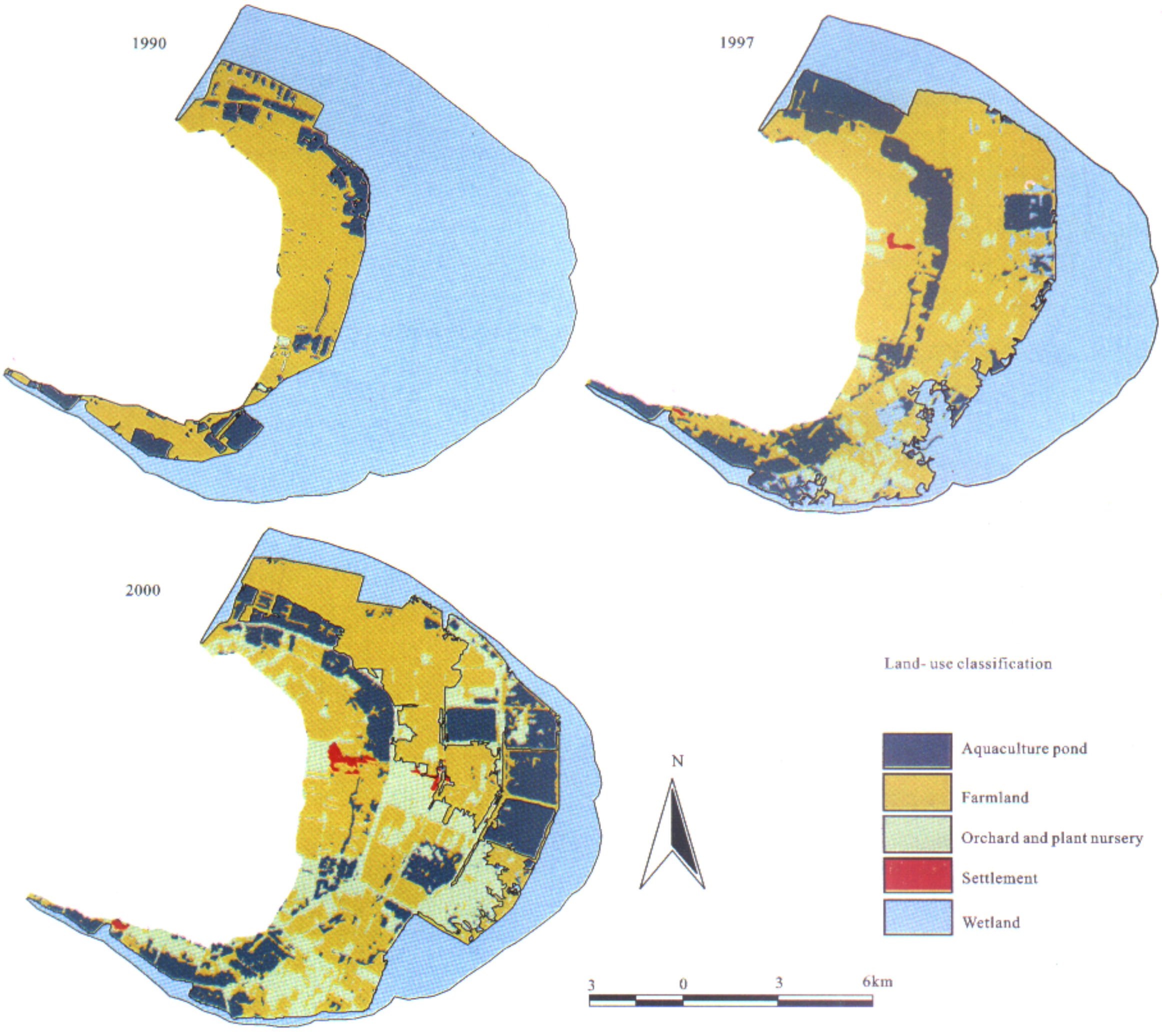


Fig. 2 The dynamic change of land-use types in Dongtan, Chongming Island in 1990, 1997 and 2000

Table 1 Land-use types in Dongtan, Chongming Island in 1990, 1997 and 2000

Land-use type	1990		1997		2000	
	Area(ha)	Cover(%)	Area(ha)	Cover(%)	Area(ha)	Cover(%)
1 Aquaculture pond	1140.75	6.29	2633.76	14.53	3291.57	18.16
2 Farmland	3470.58	19.15	6596.55	36.39	7008.75	38.66
3 Orchard and plant nursery	80.01	0.44	953.64	5.26	3863.16	21.31
4 Settlement	3.51	0.02	27.81	0.15	107.64	0.59
5 Wetland	13432.14	74.10	7915.23	43.67	3855.87	21.27
Total	18126.99	100.00	18126.99	100.00	18126.99	100.00

than 4 times during the later 3 years.

The first-order Markov matrix of 1990 – 1997 (Table 2) indicated that the settlement, orchard and plant nursery and aquaculture pond were the most stable classes with transition probabilities of 1.000, 0.994 and 0.979, respectively. The highly variable class was wetland, with transition probability of only 0.772.

From 1997 – 2000, the main settlement area and orchard and plant nursery also acted as the most stable classes depicted by the Markov matrix(Table 3), with transition probabilities of 1.000 and 0.999, respectively. The transition probabilities of other three land-use classes decreased compared to the period 1990 – 1997, indicating that these classes were highly dynamic.

When we integrated the two-time interval (1990 – 1997 and 1997 – 2000) to one time step (1990 – 2000), a new Markov transition probability was recalculated in Table 4. Table 4 shows that settlement area and orchard and plant nursery still were stable, while the other 3 classes were dynamic. The trends were essentially the same as in Tables 2 and 3.

Table 2 1990 – 1997 Markov transition matrix of land-use change

	Land-use type in 1997				
	1	2	3	4	5
Land-use type in 1990					
1 Aquaculture pond	0.979	0.021	0	0	0
2 Farmland	0.131	0.838	0.028	0.003	0
3 Orchard and plant nursery	0	0	0.994	0.006	0
4 Settlement	0	0	0	1.000	0
5 Wetland	0	0.208	0.020	0	0.772

Table 3 1997 – 2000 Markov transition matrix of land-use change

	Land-use type in 2000				
	1	2	3	4	5
Land-use type in 1997					
1 Aquaculture pond	0.673	0.225	0.102	0	0
2 Farmland	0.050	0.679	0.259	0.012	0
3 Orchard and plant nursery	0	0	0.999	0.001	0
4 Settlement	0	0	0	1.000	0
5 Wetland	0.151	0.245	0.118	0	0.487

Table 4 1990 – 2000 Markov transition matrix of land-use change

	Land-use type in 2000				
	1	2	3	4	5
Land-use type in 1990					
1 Aquaculture pond	0.863	0.089	0.048	0	0
2 Farmland	0.144	0.555	0.280	0.022	0
3 Orchard and plant nursery	0	0	0.985	0.015	0
4 Settlement	0	0	0	1.000	0
5 Wetland	0.135	0.371	0.205	0.002	0.287

3.2 Change Prediction Using Markov Matrices

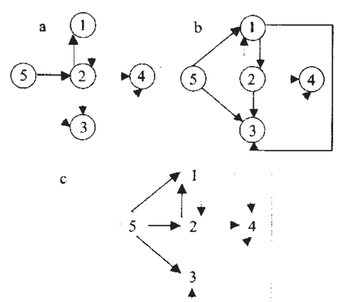
Second-order Markov matrices were tested for goodness of prediction of land-use transition. The model was calibrated by predicting the situation in 2000 using the 1990 – 1997 matrix. According to the model, wetlands tended to decrease, while other classes tended to increase(Table 1). Measured versus predicted values for 2000 are given in Table 5.

Table 5 Observed and predicted area of land use types in 2000(ha)

Land-use type	Predicted	Measured
1 Aquaculture pond	3462.21	3291.57
2 Farmland	7207.47	7008.75
3 Orchard and plant nursery	1294.38	3863.16
4 Settlement	51.39	107.64
5 Wetland	6111.54	3855.84

To quantitatively assess the overall performance of the prediction, a χ^2 test was used. Results revealed that the second-degree Markov matrix was not a successful predictor of LUCC patterns in Dongtan ($P > 0.01$). The result suggested that the two-time interval (1990 – 1997 and 1997 – 2000) had some different transition mechanisms. Thus, to demonstrate exemplary wide variety of possible uses, three scenario types were distinguished based on above 3 periods: scenario 1990 – 1997, scenario 1997 – 2000 and scenario 1990 – 2000.

In scenario 1990 – 1997 (Fig. 3a), a great deal of wetland changed to farmland, a little of them direct changed to orchard and plant nursery, but there were not direct transition from wetland to aquaculture pond at this period, and aquaculture pond land-use type was only transited from farmland. In scenario 1997 – 2000 (Fig. 3b), wetland was directly transited to other 3 land-use classes: aquaculture pond, farmland and orchard and plant nursery. At this term, orchard and plant nursery became a more important land development target. When we combined above two scenarios to one (1990 – 2000, Fig. 3c), we got an integrated result during the past 10 years. Wetlands were easily to be transferred to aquaculture pond, farmland, and orchard and plant nursery. Those transitions were unidirectional types. Aquaculture ponds were transferable to farmlands, and vice versa. However, the ttransition probability from farmland to aquaculture pond was more than that from aquaculture pond to farmland. Transition from farmland, and aquaculture pond to orchard and plant nursery also showed a unidirectional trend. The transition pattern from three land-use classes (farmland, orchard and plant nursery, and wetland) to settlement was also unidirectional.



Bold lines indicate high transition probabilities
① Aquaculture pond, ② Farmland, ③ Orchard and plant nursery, ④ Settlement, ⑤ Wetland

Fig. 3 1990 – 1997, 1997 – 2000, 1990 – 2000 land-cover transitions from the Markov martrix

It might be easy to find out two special LUCC types, wetlands and settlements, in our analysis. Transitions from wetland to other land-use classes and others to settlements were both unidirectional. We can define wetland land-use class as "raw" type (this type of land use can only transfer to others, and others will not rebound any more), while settlement class as "terminal" type (this type of land use can only be transferred from others, and it will not rebound to others any more).

The decrease of wetland area per year was calculated in Table 6. The mean decreasing rate of wetland area between 1997 and 2000 was 1353.12ha/a, greater than that of the possible mean increasing area in Dongtan (1200ha/a)(CHEN, 1999). If this condition continues, the wetland in Chongming Island will die out sooner or later.

Table 6 Decrease of wetland area

Item	1990	1997	2000
Area(ha)	13432.14	7915.23	3855.87
Absolute decrease rate(ha/a)		788.13	1353.12

3.3 Spatial Pattern Analysis Using Landscape Matrices

Mean patch size and number of patches were shown in Table 7. The two landscape metrics demonstrate following results: 1) The number of aquaculture pond patches and farmland patches increased, while *MPS* decreased. It could indicate that these two classes of land-use patches were increasingly fragmented, which was mainly due to the high frequency mutual transformation between the two land-use types. 2) Both mean patch size and patch number of orchard and plant nursery increased. This land-use class was a new development target in the study area. 3) Settlement patch was not a predominant land-use type in this area, but it was a terminal land-use pattern, which means other land-use classes can convert to settlement patch, but it will not convert to others. 4) Wetland patch had dramatic change from 1990 – 2000. We suppose that there was a vast wetland background or matrix (one patch with area 13435.01ha) in 1990, and it was fragmented because it was changed to other land-use classes in 1997 (patch number increased to 133 while *MSI* decreased to 59.51ha). At last, in 2000, other land-use patches swallowed many patches of fragmented wetlands. As a result, *MSI* increased to 113.47 and patch number decreased to 34. Wetland patches became more complex and fragmented.

Considering the whole study area, *MSI* was decreasing and patch number was increasing accordingly.

Mean shape index(*MSI*) for landscape level and class level was shown in Table 8. In general, most of *MSI*s ranged from 1.1 to 1.4, indicating that the shape of land-use class was simple in Dongtan. The *MSI* of land-use types in landscape level seems to increase over time, but there was no significant difference between different years ($p < 0.01$). But at class level, the wetland class had the highest *MSI* (1.825) in 1990, which might be attributable to the fact that this class was more natural and less disturbed. *MSI*s for aquaculture pond and orchard and plant nursery class increased over time, while *MSI* for farmland reached the lowest value in 1997 and *MSI* for settlement reached the highest one in this term. The results suggested that land-use development in Dongtan resulted in a tendency to increase spatial heterogeneity in aquaculture pond patches and orchard and plant nursery patches.

Shannon diversity index (*SDI*) and Shannon evenness index (*SEI*) for the landscapes were shown in Table 9. Landscape diversity depends on the number of patch and harmonious proportion of land-use and land-cover type, and finally affects the stability and productivity of the system. The larger the value of landscape patch diversity is, the more variable the landscape is. Large values of *SEI* indicate that different types of land use more equally share the landscape, while low values mean that one or a few types of land use dominate the landscape. Increase of *SDI* of landscape patches means landscape replacement by occupation of other elements.

On the whole, the change of *SDI* reached its highest value in 1997. The change of *SEI* had the same tendency as *SDI*. In general, the landscape is changed from simple to complex due to the natural and human disturbances (ZHOU, 2000). From 1990 to 1997, most of the wetlands were simply transferred to agricultural lands. But the pattern of transition changed after 1997, for example, some gardens, such as the best famous agriculture base Shangshi Agriculture Park, were setup at that period. The land-use patches became more and more regular gradually. Moreover, the island is ex-

Table 7 Mean size and number of patches

Land-use type	1990		1997		2000	
	MPS(ha)	*N*	*MPS*(ha)	*N*	*MPS*(ha)	*N*
1 Aquaculture pond	16.47	69	12.24	215	9.17	359
2 Farmland	56.97	61	19.27	343	8.82	795
3 Orchard and plant nursery	1.20	63	3.23	291	7.82	493
4 Settlement	0.83	4	13.68	2	9.81	11
5 Wetland	13435.01	1	59.51	133	113.47	34
Total	91.54	198	18.42	984	10.71	1692

Table 8 Mean shape indexes

Level	1990	1997	2000
Landscape level	1.207	1.206	1.230
Class level			
1. Aquaculture pond	1.209	1.227	1.260
2. Farmland	1.239	1.199	1.204
3. Orchard and plant nursery	1.165	1.186	1.246
4. Settlement	1.200	1.465	1.372
5. Wetland	1.825	1.229	1.254

Table 9 Shannon diversity index (*SDI*) and Shannon evenness index (*SEI*)

	1990	1997	2000
SDI	1.255	1.335	1.281
SEI	0.780	0.830	0.796

pected to become the city's largest leisure and tourism attraction and a prime green food production base over the next 10 years. In June of 2000, Shanghai kicked off a 3.79-billion-yuan (RMB) (US$456.6 million) project to set up a modern agricultural park in Chongming Island, which occupied an area of more than 84.7km^2.

4 CONCLUSIONS

This study demonstrates that using landscape indices and Markov models to assess landscape changes can provide useful information for detecting land-use dynamic. Landscape indices can be used to describe the structure of a landscape. While Markov models can be used to examine and predict distributional changes over time. The integration of landscape indices, Markov models, and spatial model will enable a more thorough analysis of landscape changes. The transition matrices were proved useful to describe quantitatively LUCC patterns. The main trend of land-use change in Dongtan area was transferring newly growing land, firstly as wetland, to aquaculture pond, farmland, and orchard and plant nursery.

The coastal zone of Chongming Island is a narrow fringe where the sea impinges on the land. Traditionally, this zone has provided valuable coastal fisheries for hundreds of years, and rich fish farming and marine cultivation for recent several decades. Chongming Island was one of the earliest places where land reclamation from tidal flat was practiced. It was as early as the 1960s when the government officially carried out reclamation on the island. The major purpose of reclamation in the early period was purely increasing agricultural land. There had not been any specific planning for mud-flat reclamation by the government prior to the early 1990s; it was after early 1990s when national economic growth was rapid and the national economy was improving that many of the projects by the public as well as private became large scale. Most of those tidal flat conversion projects were for agricultural purposes until 1997, but since then, some of the projects were built for multiple uses including orchard, fishery, eco-tourism, and transportation. In the long run, conservation of the tidal-flat and its rich ecosystem as natural resources must take precedence than its single-minded economic purpose. In the first 7 years (1990–1997), the main land-use types were aquaculture pond and farmland, while in the second 3 years (1997–2000), orchard and plant nursery land-use type developed fast. This was why the second-degree Markov matrix based on the first seven years can not be successfully predicted the second 3 years.

Extensive tidal flats are in development along the eastern coast of Chongming Island. Reclamation in the shallow coastal zone provides valuable land resources. With limited agricultural land, Shanghai is in constant search for additional farmland based on Chinese land-use policy. But land-use conflicts occur between wildlife conservation and reclamation of tidal flats. Conservation supporters emphasize the importance of benefits and values deriving from the tidal flat ecosystem other than the immediate economic benefits. Of course, it is not suitable in this area to stop reclamation, but a controlled expansion is required, for example, leaving the grassy areas undisturbed for some years before the enclosure. Meanwhile, Chongming Island will focus on the construction of its East Beach (Dongtan) Reserve for migrant birds, the Dongping State Forest Park and the Wetland Park in the next five years, which will make the island become a back garden for Shanghai (China Daily, 2001).

As wetland area decreases, remaining wetlands may be less efficient at a variety of functions including sediment and nutrient control, floodwater retention, groundwater recharge, and so on. They may also not be able to meet minimum area requirements for some species and contain fewer habitat types/niches and therefore fewer species. As wetlands become increasingly fragmented, they may be less able to support viable populations of dependent flora and fauna, more susceptible to disturbance, and species interaction, for instance, those between predators and prey may be altered. As wetland patch edge-to-interior ratio increases, these wetlands may become more susceptible to edge effects, such as, altered microclimate, increased disturbance, increased herbivory, and the addition of more invasive species. Inter-patch dynamics, such as, dispersal and energy flow may also be altered.

REFERENCES

AAVIKSOO K, 1995. Simulation vegetation dynamics and land-use in a mire landscape using a Markov model[J]. *Landscape and Urban Planning*, 31(2): 129–142.

BAKER W, 1989. A review of models of landscape change [J]. *Landscape Ecology*, 2(2): 111–133.

BARDGETT R D, ANDERSON J M, BEHAN-PELLETIER V *et al.*, 2001. The influence of soil biodiversity on hydrological pathways and the transfer of materials between terrestrial and aquatic ecosystems [J]. *Ecosystems*, 4(5): 421–429.

BURNHAM B O, 1973. Markov intertemporal land-use simulation model[J]. *Southern Journal of Agricultural Economics*, 5(2): 253–258.

BURROUGH P A, 1986. *Principles of Geographical Information Systems for Land Resources Assessment* [M]. Oxford: Clarendon Press.

CHEN Ji-yu, LI Dao-ji, CHEN Bang-lin *et al.*, 1999. The processes of dynamic sedimentation in the Changjiang Estuary[J]. *Journal of Sea Research*, 41(2): 129–140.

COUSINS S A O, 2001. Analysis of land-cover transition based on 17th and 18th century cadastral maps and aerial photographs [J]. *Landscape Ecology*, 16(1): 41–54.

GARDNER R H, MILNE B T, TURNER M G *et al.*, 1987. Neutral models for analysis of broad-scale landscape pattern[J]. *Landscape Ecology*, 1(1): 19–28.

GSCCI (Group of Shanghai Coastal Comprehensive Investigation), 1988. *Report of Shanghai Coastal Comprehensive Investigation* [M]. Shanghai: Shanghai Scientific and Technological Press. (in Chinese)

GSICI (Group of Shanghai Island Comprehensive Investigation), 1996. *Report of Shanghai Island Comprehensive Investigation* [M]. Shanghai: Shanghai Scientific and Technological Press. (in Chinese)

HUNSAKER C T, O'NEILL R V, JACKSON B L *et al.*, 1994. Sampling to characterize landscape pattern [J]. *Landscape Ecology*, 9(3): 207–226.

LEVIN L A, BOESCH D F, COVICH A *et al.*, 2001. The function of marine critical transition zones and the importance of sediment biodiversity [J]. *Ecosystems*, 4(5): 430–451

LóPEZ E, BOCCO G, MENDOZA M *et al.*, 2001. Predicitong land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico [J]. *Landscape and Urban Planning*, 55(4): 271–285.

MA Zhi-jun, JING Kai, TANG Shi-min *et al.*, 2002. Shorebirds in the east tidelands of Chongming Island during the 2001 northward migration[J]. *Stilt*, 42(1): 6–10.

MA Zhi-jun, LI Bo, JING Kai *et al.*, 2003. Effects of tidewater on the feeding ecology of hooded crane (*Grus monacha*) and conservation of their wintering habitats at Chongming Dongtan, China [J]. *Ecological Research*, 18(3): 325–333.

MCGARIGAL K, MARKS B J, 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure [R]. USDA Forest Service, Pacific Northwest Research Station, Portland, OR, USA. General Technical Report PNW-GTR-351.

MOODY A, WOODCOCK C E, 1994. Scale-dependent errors in the estimation of land-cover proportion: implications for global land-cover datasets[J]. *Photogrammetric Engineering & Remote Sensing*, 60(5): 585–594.

O'NEILL R V, KRUMMEL J R, GARDNER R H, 1988. Indices of landscape pattern[J]. *Landscape Ecology*, 1(2): 153–162.

REID R S, KRUSKA R L, MUTHUI N *et al.*, 2000. Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia [J]. *Landscape Ecology*, 15(4): 339–355.

RIITTERS K H, O'NEILL R V, HUNSAKER C T *et al.*, 1995. A factor analysis of landscape pattern and structure metrics[J]. *Landscape Ecology*, 10(1): 23–29.

SIMPSON J W, BOERNER R E J, DEMERS M N *et al.*, 1994. Forty-eight years of landscape change on two contiguous Ohio landscapes [J]. *Landscape Ecology*, 9(4): 261–270.

TISCHENDORF L, 2001. Can landscape indices predict ecological processes consistently[J]. *Landscape Ecology*, 16(3): 235–254.

TURNER M G, 1987. Spatial simulation of landscape changes in Georgia: A comparison of 3 transition models[J]. *Landscape Ecology*, 1(1): 29–36.

TURNER M G, 1990. Spatial and temporal analysis of landscape patterns [J]. *Landscape Ecology*, 4(1): 21–30.

TURNER M G, GARDNER R H, 1990. *Quantitative Methods in Landscape Ecology: The Analysis and Interpretation and Landscape Heterogeneity*[M]. New York: Springer-Verlag.

VITOUSEK P M, 1994. Beyond global warming: ecology and global change [J]. *Ecology*, 75(7): 1861–1876.

WU Ji-hua, FU Cui-chang, CHEN Shan-shan *et al.*, 2002. Soil faunal response to land-use: effect of estuarine tideland reclamation on nematode communities[J]. *Applied Soil Ecology*, 21(2): 131–147.

XIE Wen-hui, Yang Shi-lun, 1990. Evolution of Jiuduansha Shoal and its influence on adjacent channels in the Changjiang Estuary [J]. *China Ocean Engineering*, 13(2): 185–195. (in Chinese)

YANG Shi-lun, DING Ping-xing, Chen Shen-liang, 2001. Changes in progradation rate of the tidal flats at the mouth of the Changjiang (Yangtze) River, China [J]. *Geomorphology*, 38(2): 167–180.

ZEDLER J B, LEACH M K, 1998. Managing urban wetlands for multiple use: research, restoration, and recreation [J]. *Urban Ecosystem*, 2(4): 189–204.

ZHONG Yong-ling, CAI Xue-ru, 1997. Contracting via bidding: an effective form of land management[J]. *Chinese Rural Economy*, 2(1): 54–57. (in Chinese)

ZHOU Zai-zhi, 2000. Landscape changes in a rural area in China[J]. *Landscape and Urban Planning*, 47(1): 33–38.