Food flow and agricultural landscape changes towards a sustainable city region in Tianjin, China

（中国天津市における持続的都市圏形成に向けた食料フローと農業ランドスケープの変化に関する研究）

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Abstract

No matter where it is, cities must find a way to grow sustainably. Food security should not be ignored when assessing the future of our cities. Food for cities will either have to be sourced from remote locations, or they will have to incorporate their own food-production. However, it is criticized that transportation of food from remote areas contributes to a variety of environmental impacts, e.g. increased use of energy, CO2 emission. It is approved that an increase in food self-sufficiency rate can be an effective option to increase food security and reduce CO2 emission. Recently, localized food production–consumption system strategies have received considerable attention in Europe, North America and Japan as a means of improving sustainability.

A scientific question is how cities and the land areas needed to feed them scale in relation to city population density. Agricultural activities in the city play a vital role in provision the food, e.g. urban/peri-urban agriculture. But their products are still not enough for city need. The concept of ‘city region’ is necessary to consider ‘sustainable city’ because it integrates city and its hinterland where exist huge agricultural areas. Chinese city based on administrative boundary is an exact example of ‘city region’ which includes urban, suburban, and rural areas.

Most Asian megacity regions are located in rich alluvial deltas that have long served as the “rice-baskets” of their respective regions. The largest Asian megacity regions are in China because of large boundary, so Chinese megacity regions make a vital contribution to Asian (and global) social and economic sustainable development. Among the Chinese megacity regions, Tianjin not only has a large territory, but a relevant large portion of agricultural areas. So the aim of this study is taken Tianjin city region as an example, to search for the ‘sustainable city region’ from the view point of food production. It hypnotizes that Tianjin city region will highly depend upon the local for its food provision generated from suburban and rural. Food self-sufficiency (SSR) and land areas are two indicators of localization of food production in city region.

The study was carried out in China’s national capital region, Tianjin, which is in the northeast part of the North China Plain and located on a low-lying alluvial plain along the mouth of the Hai River (38°34'N–40°15'N and 116°43'E–118°04'E). This area has not only experienced rapid industrialization and urbanization (including the famous Jing-Jin-Tang Industrial Belt), but it also has played a pioneering role as an urban development model for other Chinese cities. The main objectives of the study were (1) to identify the extent to which the region's food consumption depends on local production (*Chapter 2*); (2) to examine spatial-temporal and functional changes from 1993 to 2009 in terms of agricultural land use and food production in both suburban and rural areas of the city (*Chapter 3*); and (3) to explore whether the dependence of local consumption on local production could be improved based on the current trend of agricultural land use changes, in particular changes in paddy fields (*Chapter 4*). Furthermore, suggestions for how to promote a sustainable city region in Asia are discussed in Chapter 5. The main approaches were food flow analysis, landscape analysis by satellite image interpretation, and semi-structured and key informant interviews with local people.

Chapter 2 examines the calculated food self-sufficiency ratio (CSSR) and observed food flow in Tianjin, divided into three areas (urban, suburban, and rural), as a case study to gain a better understanding of the extent to which a region's food consumption depends on its local production. The main objectives were to estimate the self-sufficiency within its administrative boundary by calculating a self-sufficiency ratio by the formula which is commonly used in China using statistical data at both the city region and local scales, to explore food flow at the regional scale from the information provided by local government authorities, and to observe real flows of the two primary types of arable crops (cereals and vegetables) from semi-structured household interviews at the local scale. The results show that Tianjin has experienced a rapid increase in CSSR since the 1980s, and it appears to have the capacity to support the citizens within its borders. By 2007, the CSSR of major foods were relevant high; cereals were the lowest category which was below 100%. Even with these high ratios, wholesalers, retailers and consumers have chosen to use and exchange products from distant areas, utilizing regional food flow. Local fresh vegetables can meet the demand in peak harvest season, farmers could still export some to other Chinese areas to increase revenue; however in off season, local fresh vegetables accounted for only 30% of the vegetable market because of seasonality, whereas the other 70% is supplied by other regions of China. Government imported around 70% of total cereals consumption, not only for citizens, and also for others, e.g. stock in case of emergency. All cereal products consumed by the urban population are supplied by other regions. At the local scale, rural areas have had a surplus in all food categories studied since the 1980s, and suburban areas have a history of high self-sufficiency for vegetables, poultry, and fish. However, a low degree of locally sourced product flow was observed. Most local cereal crops were consumed in agricultural production areas, but 50% of vegetables produced in rural areas flowed outside of the region and did not support local consumption in Tianjin.

Local agricultural production is the main driver of self-sufficiency and food flow. An accurate understanding of changes in land areas and the driving factors, especially the cereals and where the CSSRs changed dramatically, has important implications for the future of localization of food production and policy making. In Chapter 3, Landsat images are used to evaluate agricultural land use changes at the landscape scale in suburban and rural areas in Tianjin from 1993 to 2009, based on two case studies where experienced a dramatic decreasing CSSR of cereals. The main driving factors of the changes were investigated at the farm scale through a survey of local farmers. The image classification results showed an obvious loss of agricultural land since the early 1990s in suburban areas, similar to what has occurred in other peri-urban areas in developing countries. Two other notable trends in land use, which differ from those of other peri-urban areas, were observed: (1) land was converted from the production of traditional perishable food to cereals, in this case, from vegetables to maize; and (2) there was a shift from cereals to non-food production, in this case, from paddy rice and maize to cotton. Areas for cereals production was decreased by 53%. In rural areas, a similar shift from cereals to non-food production was noted during the study period, in this case, from rice and maize to cotton. Two other results, which differ from those of suburban areas, were found: (1) a relatively small amount of land had been converted from the production of cereals to fresh food, in this case, from maize to vegetables; and (2) recently, some land has shifted back from non-food production to the production of cereals, in this case, from cotton to rice. Areas for cereals production was decreased by 60%. Through semi-structured household interviews, a scarcity of water was noted as an important problem for agriculture in Tianjin—this was found to be a primary factor for agricultural land use change both in suburban and rural areas. Beyond the limitation of clean water, suburban farmers had to adjust their agricultural activities by adapting to an insufficient amount of labor and the use of treated wastewater from urban areas for irrigation. Rural farmers' activities, however, were still driven by market mechanisms and government policies. Changes in local production have accounted for the trend of food self-sufficiency levels and contributed to the current regional and local pattern of food flow. Specialized vegetable production in rural areas generated an active flow from the rural areas of Tianjin to other Chinese regions, whereas the decreased production of paddy rice was only able to support consumption in the production areas themselves, so there was no local surplus to flow locally.

Rice is the principle staple crop in Tianjin, and any deterioration of rice production systems would seriously impair food security. Increasing land area is one option to solve food deficit. Given some paddy fields in suburban were converted into developed areas, the possible to enlarge the production area for local consumption will be only in rural areas. Chapter 4 conducted a further study in rural areas to explore whether it would be possible to enlarge the production area for local consumption, in this case of paddy rice, to enhance food security and develop a more sustainable urban–rural system. Further understanding of the dynamics of the traditional rice-dominated agriculture area was undertaken both at the county and village level in rural areas through a comparative study of the planting area of recent annual crops, precipitation variability, and water flow. The manner in which the involved stakeholders attempt to cope with and adapt to a constantly changing environment was also determined through semi-structured and key informant interviews. With limited water flow from the outside and in response to recent historic precipitation variability, local people adjusted to both year-to-year variability and extreme events through collective and individual actions in the short term by changing planting areas and switching crops. Annual rainfall and water flow records show that a serious and continuous drought occurred during 1999–2003. The drought compelled farmers to shift paddy fields to field crops, and some irrigation and drainage systems were also destroyed. As they switched to less water-intensive crops (e.g. cotton), the farmers appeared to be making a relatively permanent adaptation to water stress, but in so doing, many have become more vulnerable through worsening pest and disease management and a low level of self-sufficiency. Although most villagers were willing to replant paddy rice, shifting land use back to paddy cropping to adapt to the more recent increased precipitation has not been common because of damaged irrigation and drainage systems and a lack of willingness of community leaders to maintain the systems as they previously did. Only farmers in a few villages, which maintained their properties well and had leaders who seemed aware of the importance of traditional crops, succeeded in switching back to paddy cropping again. Resilience building is important for local agricultural communities to improve the self-sufficiency. The possibility of enlarging the paddy rice production area will most likely be highly dependent on local institutions in initiating and supporting adaptations and participating in collective irrigation regimes. It was suggested that new institutional arrangements including collective irrigation regimes for rice production is necessary in order to establish localization of food production.

From this study, in order to apply the localization of food production, the priority should be given to the production of rice which is the principal staple food for security. To improve rice production in Asian city region, it is important to consider both the climate fluctuation and collective irrigation regime. Urban, suburban, and rural linkage need to be re-structuralized, so that food production in suburban and rural can be fully used for urban dwellers closed by. To apply the results of this study, appropriate spatial boundary/size need to be considered to define the city region.

要　旨

都市の持続可能性を高めるうえで、食料フローのローカライゼーション（地産地消）による域内食料自給率の向上は、食料安全保障の観点のみならず、輸送等にかかるエネルギー・二酸化炭素排出の削減を通じた低炭素社会実現の観点からもきわめて重要である。都市を取りまく農村は、食料供給をはじめとして、さまざまな生態系サービスを都市に対して提供することから、都市の後背地としての農村は都市環境の健全化をはかるうえで重要な役割を果たすことが期待されている。とりわけ、拡大を続けるアジアの大都市においては、周辺農村との食料・資源・エネルギー循環系の再構築を通じた、持続可能な都市圏形成と都市環境の健全化が喫緊の課題となっている。

本研究は、中国・天津市を対象として、都市における食料消費の域内依存度および、農業的土地利用と食料生産の時間的・空間的変化を明らかにしたうえで、食料フローのローカライゼーションを促進するための方策を提示することを目的とする。研究対象である天津市は渤海湾に面する沖積低地に位置し、水田耕作の卓越する広大な農業地域を後背地に有する一方で、沿岸部の経済拠点として近年急速な都市化・工業化が進行していることから、食料フローの観点からアジア型の持続的都市圏形成のあり方を検討するうえで最適な事例都市といえる。研究は、天津市を「都市」、「郊外」、「農村」の３区域に区分したうえで、以下の手順によって進めた。(1)食料自給率および食料フロー解析により、食料の域内依存度を把握した。(2)農業的土地利用変化の空間解析により、域内依存度変化の要因を明らかにした。(3)基幹作物である米に着目し、域内依存度向上にかかる制限要因を抽出するとともに、改善の方策を検討した。

統計資料に基づき天津市における推定食料自給率を算出した結果、1980 年代以降、統計データの入手できた 2007 年まで、穀物以外の農産物の食料自給率は急速に向上していることが確認された。一方、食料生産区域（「郊外」および「農村」）において半構造化面接による農家調査を行い、実際の食料フローを解析した結果、生産された食料は食料生産区域内で消費される割合が高く、穀物でその傾向が顕著であった。とくに米については、生産量の 96%が食料生産区域内で消費されており、「都市」へのフローはきわめて低いことが明らかになった。また、推定食料自給率の比較的高かった野菜についても、域内でのフローは低く、域外へのフローも一部で確認されたが、これは、生産量の季節変動が大きいこと、生産品目が限られていること等が原因として考えられた。以上から、天津市の「都市」における食料消費は域外からの供給によって維持されており、域内の「郊外」「農村」との関係が脆弱であることが示唆された。

「郊外」および「農村」において、推定食料自給率が顕著に変化した地域を対象に、複数時期の衛星画像（LANDSAT TM/ETM 画像：1993 年、2001 年、2009 年）を用いて過去約 20 年間の農業的土地利用の変化を解析した結果、特徴的な作目の変化が抽出された。「郊外」では、都市的土地利用への変化が顕著であったほか、作目については野菜→穀物、穀物→

繊維作物（綿花）への変化が特徴的であった。「農村」ではとくに穀物→繊維作物への変化が大きく、穀物の栽培面積は約 60%減少したことが分かった。半構造化面接による農家調査の結果、上記の作目変化の動機としては、収益の向上よりもむしろ水資源の枯渇であることが明らかになった。この傾向は、基幹作物である米から耐乾性・耐塩性の強い綿花への作目変化においてとくに明瞭であったことから、天津市においては水資源の安定供給が、食料自給と食料フローの改善に向けた重要課題であることが示唆された。

過去 20 年間の降水量変動と作目変化の関係を解析した結果、1999 年～2002 年に生じた干ばつ期を契機として米から綿花への転換が進んだことが明らかになり、農家は短期間の降水量変動に対応して作目選択を行っていることが確認された。半構造面接による農家調査およびキーインフォーマントインタビューの結果、自家消費用食料の確保や病害虫・土壌劣化の防止等の理由から、農家は綿花から米への再転換を強く望んでいるものの、米栽培に不可欠な灌漑設備がすでに破壊されており、修復には多額の費用と共同管理が必要なため、米への転換が進んでいないことが分かった。これに対し、干ばつ後に綿花から米への再転換が成功した一部の集落では、集落のリーダーが基幹作物の重要性を強く認識しており、干ばつ期間も灌漑施設が適切に維持管理されていたことが明らかになった。以上から、天津市において、基幹作物である米の生産を回復させるためには、灌漑施設の修復と共同管理に代表されるような、ローカルな農地管理制度の再構築が不可欠であることが示唆された。

以上、本研究の結果、天津市においては推定食料自給率は向上しているものの、食料フローからみた「都市」「郊外」「農村」の関係は脆弱であること、作目の変化は市場メカニズムや農業政策よりもむしろ降水量変動にもともなう水資源の枯渇によって引き起こされていること、食料の域内依存度向上のためには、ローカルな農地管理制度の再編を通じたレジリエンス強化が必要であることを明らかにした。

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Chapter 1 Introduction

1.1 Background

1.1.1 Sustainable city

No matter where it is, cities must find a way to grow sustainably (Nature 467, 899; 2010). In fact, there is no agreed definition of a sustainable city (Satterthwaite, 1997). The efforts to measure the level of sustainability of city are infinitely complex because city systems are interrelated and are constantly changing (Choon et al., 2011). Haughton and Hunter (1994) described a sustainable city as 'one in which its people and businesses continuously endeavor to improve their natural, built and cultural environments at neighborhood and regional levels, whilst working in two ways which always support the goal of global sustainable development' (p. 27). Their definition means that the concept of a sustainable city is a multidimensional one and also related to higher geographical levels. On the other hand, emphasizing the outcome of the use of local resources, both for consumption and for production purposes, viz. the level of welfare or per-capita income, Nijkamp and Opschoor (1995) stated that urban sustainable development (USD) is 'a development which ensures that the local population can attain and maintain an acceptable and non-declining level of welfare, without jeopardizing the opportunities of people in adjacent areas'(Camagni et al., 1998).

A key component of the sustainable city is a 'circular metabolism' which assures the most efficient possible use of resources. From point of view of system ecology, cities are self-regulating systems and may be seen as super-organisms, created for the benefit of human beings and for sustaining their livelihood. Cities cannot be self-regulating without maintaining stable links with the surrounding areas from which they draw energy, food, and materials and into which they release their wastes (Huang and Hsu, 2003). The need for sustainable, or harmonious, urban development further requires cities to function with a circular, rather than a linear, metabolism (UN-Habitat, 2008). City can be developed more sustainable by increasing the ability of systems and societies to absorb and adapt to multiple stresses, including population growth, urban sprawl, climate change/variability and disaster (Hay and Mimura, 2006).

1.1.2 Food for the cities

Each city's "food system" is conceptualized as nested system of production, distribution, marketing and consumption of goof demanded by that city. Relevant system boundaries for useful analysis are set respectively at the city's metropolitan limits, at its geographical hinterland, at the national border and then with the rest of the world (Deutsch et al., 2009). The areas produce surplus foods can supply other areas, and whereas in food deficit need to get food from other areas to meet consumption (Deutsch et al., 2009). Food in this context is taken to mean grains, vegetables, fruit, meat, milk and fish.

Food for cities will either have to be sourced from remote locations across the globe, or cities will have to incorporate their own food-production facilities by such developments as peri-urban farming (Porter et al., 2011). Currently, most societies are dependent on distant food flows through national and international markets and are no longer directly dependent on local production for food supply (Sundkvist *et al.*, 2005). Most basically, the geographical scaling-up of agriculture is achieved through the intensification and centralization of agricultural production in regions favourable to capital accumulation through industrial agriculture, and the simultaneous marginalization of agriculture in areas less fertile to reaping profits (Kurita et al., 2009). Residents of any given region are no longer connected with traditional food, mainly harvested from the local environment, and instead utilize products and services of ecosystems located far outside their local borders. The large distance, both geographically and institutionally, impedes the flow of information in the food system and blocks ecological feedback along the whole chain from extraction to consumer decision (Princen, 1997). It is important to tighten the feedback loop between production and consumption to achieve sustainability (Sundkvist *et al.*, 2001).

Recently, an "alternative food network" (food supply chain) strategy has received considerable attention in Europe and North America as a means of improving sustainability (Ilbery et al., 2006; Jarosz, 2008; Renting et al., 2003; Weatherell et al., 2003). It is argued that in order to make food systems more sustainable, it is important to avoid a trade-off between chain links (Gerbens-Leenes *et al.*, 2003). A central notion in this literature is the idea that food consumed closer to its point of production has the potential to provide economic, environmental, and social benefits in relation to sustainable development at the local scale (Chambers et al., 2007; Guptill and Wilkins, 2002). In Japan, there are also some calls for the re-localization of agricultural production and food consumption (Kurita et al., 2009). Many studies have addressed the benefits of local food chains, such as the union of both social and ecological aspects of resource use, the linkages between rural and urban producers and consumers and the inclusion of farmers' ecological knowledge (Duram and

Oberholtzer, 2010), an increase of local heterogeneity in the agricultural landscape (Hinrichs, 2003; Stephens et al., 2003), maintenance of physical infrastructure and public health (Desjardins et al., 2010), and the potential for reducing the use of energy and water as well as greenhouse gas emissions (Coley et al., 2009; Cowell and Parkinson, 2003; Sundkvist et al., 2001). Some studies have also shown that the consumption of imported goods and services has environmental impacts in other places around the world (Deutsch and Folke, 2005; Wiedmann *et al.*, 2007). Food localization can also contribute to a low carbon society and a green economy due to shorter transportation rotes (Coley et al., 2009; Cowell and Parkinson, 2003; Sundkvist et al., 2001).

1.1.3 Agricultural in the city regions

An increase in food self-sufficiency rate can be an effective option to increase food security and reduce CO_2 emission (Miyawaki et al., 2005). But, a scientific question is how cities and the land areas needed to feed them scale in relation to city population density(Porter et al., 2011). Agriculture in the city is an important way to provide the food needed. But it is still insufficient by the limited agricultural areas. The concept of “city region” is necessary to consider “sustainable city” because it integrates city and its hinterland. Since the advent of the automobile, the regional city has been the emerging urban form organizing human activities and settlement patterns in the Anglo New World countries. Today, a more appropriate term is regional city as city and region are increasingly integrated (Russwurm, 1987). The city region is a series of concentric zones with a cluster of settlements of varying size and administrative allegiance whose inhabitants perform different roles, composed by municipality and rural (Victor, 1988).

Few sectors in society have had such profound impacts on ecological systems as the food industry, ranging from problems of soil erosion and depletion of groundwater in agricultural areas to emission of greenhouse gases from food processing and transportation (Sundkvist et al., 2001). Agriculture and food provision for cities population is the key function of cities’ areas. Food security should not be ignored when assessing the future of our cities (Nature 467, issue 7318; 2010). What can agriculture add to a city’s sustainability? There is a strand in the urban agriculture literature that is high on advocacy, and has become associated in recent times with ideas of food self-sufficiency in cities at both household and city-wide levels, of poverty reduction addressed solely within urban boundaries, and of futuristic waste recycling systems that can maximize city food output in an ecologically friendly and sustainable way (Ellis and Sumberg, 1998).

Agriculture also supports other values that have become increasingly important in our urbanized society: it supports landscapes in which part of our historic and cultural heritage is embedded; it modifies, contains and is supported by the biophysical environment; and it is associated with open spaces around our cities, contributing to the provision of out door recreational opportunities for the urban population (Bryant and Johnston, 1992).

Beyond the immediate benefits of providing freshness, dietary variety and landscape diversity to urban dwellers, are longer term gains possible from growing food in and around cities? Agriculture in the cities is concerned with human-environment interactions and rural-urban relations in seeking a sustainable way for development. Agricultural activities play a vital role in maintaining the sustainability and conservation of urban and rural environments. Agriculture sustains both rural and urban populations (UN-Habitat, 2008). Urban agriculture is increasingly practiced by the poor to supplement declining incomes and to mitigate food and income insecurities (UN-Habitat, 2008). The sustainability can be achieved at the scale of city region compared with city.

1.1.4 Urban-rural linkage

Sustainable development of regional cities calls for viable regional-spatial strategies that strengthen the network of cities and their hinterlands (Kidokoro et al., 2008). At present, the significance of urban–rural interactions has been well established for sustainable city development (Gutman, 2007; Lin, 2001).

Generally people living within the hinterland of a city no longer think of the city as a strange world occasionally visited but as a world that is part of their regular lives. Numerous flows of people, good, money and information integrate the population and activities of the regional city. Integration of cities and their immediate hinterlands is a response to rising incomes, increased mobility and increased leisure time associated with population and employment growth in urban areas. Technological accessibility in transportation and communications along with personal choice has made easily possible the dispersal of population and economic activities into surrounding settlement nodes and the open countryside (Russwurm, 1987).

According to Overbeek (2009), the term ‘rural-urban relationship’ may refer to three different relations between rurality and urbanity. Firstly, they are based on the flows between different places such as between the rural fringe or rural hinterland and the town or urban area; secondly, based on the different territorial bounds of the actors living inside or outside the rural area. Thirdly, it also points to the different functional relations between actors mainly living and working in rural areas and the actors living in the rural areas, but working in urban places(Overbeek, 2009).

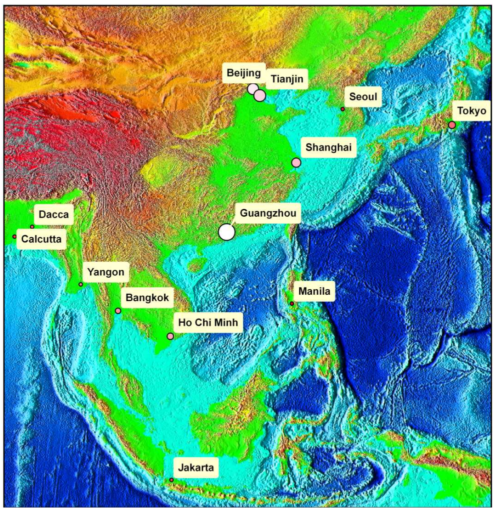
Urban, peri-urban and rural food production interacts through both resource and output markets. In classic accounts of the economics of location, these markets are mediated especially by transport costs and the value of land as a resource (Ellis and Sumberg, 1998; Grigg, 1995). Several classical models anticipate the structure and adaptation of agricultural land use near the edge of urban areas. In the 19th century, Von Thünen stated that the most perishable commodities and items that are difficult to transport should be located nearest to the urban edge because of transportation limitations (Grigg, 1995; Sharp and Smith, 2004). In 1967, Sinclair proposed that high-value, urban-oriented production (e.g., vegetables and fruits) will exist closest to the urban edge where land values are higher (Sharp and Smith, 2004).

1.1.5 Chinese mega-city and its agriculture

In recent decades, the number and size of mega-cities (cities of over 10 million inhabitants) in Asia has grown tremendously. The growth of these cities significantly raises their caloric requirements while, at the same time, reducing the amount of available agricultural land through sprawling development. The disappearance of potential agricultural production is exacerbated by the fact that most Asian megacities are located in rich alluvial deltas that have long served as the “rice-baskets” of their respective regions (Kurita et al., 2009; McGee, 2008). In-line with the rapid urbanization, cities in Asia are now at a crossroads: will they decline or get better under the impacts of globalization?

In response to population growth, urbanization, and climate change, Asian megacities and agricultural producers are facing complex challenges; bio-resources management has become a prominent area of research as well as an important policy in agricultural areas near large cities (Hara et al., 2005; Midmore and Jansen, 2003; Vagneron, 2007). In such areas, agricultural land management in rural-urban fringe is particularly important. The changing nature of the relationship between rural and urban land uses has deep consequences both for human quality of life and for the environment (Kidokoro et al., 2008).

Chinese megacity regions are larger but with low population density on the continent because of large boundary (Figure 1-1). Chinese megacity regions make a vital contribution to Asian (and global) social and economic sustainable development.



Share of agricultural land in total area (2008)

	Area (km2)	Agricultural land	Pop. (mil.)
Beijing	16410	19%	17.8
Tianjin	11920	**36%**	12.3
Shanghai	8240	20%	19.2
Guangzhou	7434	14%	10.2

Source from China Statistical Yearbook (2009), Guangzhou Statistical Yearbook (2009)

○ Size of city
● Population density *Source from Hara (2007)*

Figure 1-1 Mega-city regions in Asia and profile of four Chinese mega-city regions

The spatial organization of the city region allowed the Chinese city to achieve the goals of self-sufficiency through the flow of resources between the urban and the surrounding rural under its administration. Traditional Chinese city was used to highly depend upon local ecosystem for its food through the flow of resources between the urban and the surrounding rural areas. Suburban areas produced vegetables and other non-staple foods to supply the daily needs of the population of the central city, and farms in rural areas in the outer ring, sometimes known as the outer suburbs, where most of the farmland of the city region was located, produced the bulk of the cities' staple foods and cereals grains (Victor, 1988) (Figure 1-2).

In order to guarantee food security, the Chinese government has promoted self-sufficiency in food production at the city and provincial levels since the 1949, and until recently, most provincial governments set a declared goal of cereal grain self-sufficiency in their long-term plan (Lichtenberg and Ding, 2008). The accelerated industrialization and urbanization following the economic reforms of 1978 as well as the population increase have greatly affected agricultural production and trade (Fan and Zhang, 2002; Huang et al., 2009). China's cities continue to expand rapidly. Vast tracts of agri-cultural land and their associated villages have already been absorbed into the urban areas (Yang et al., 2010). The adoption of market principles has resulted in an ongoing international restructuring of agriculture from traditional concept of self-sufficiency in cereal crop production to more commercialized and diversified activities such as cash crops, fruits and aquaculture. A shift from local self-sufficiency towards a domestic and global commodity market is ongoing. The terms of exchange between the countryside and the city have been going against the former.

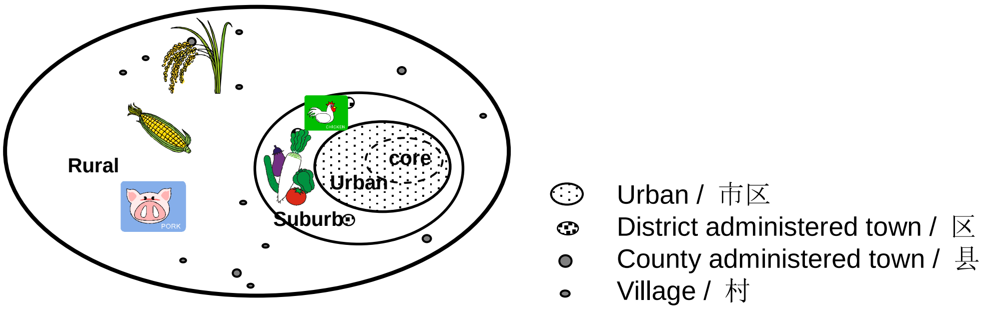


Figure 1-2 The traditional spatial organization of the agriculture in city region, China

During these four Chinese mega-city regions, Tianjin remains much agricultural land (36%) than others which indicates that Tianjin owns the high potential of self-sufficiency (Figure 1-1).

1.2 Objectives

This study hypnotizes that Tianjin city region will highly depend upon the local for its food provision generated from suburban and rural, uses Food self-sufficiency ratio (SSR) and land areas as indicators of localization of food production in city region, takes Tianjin city region as an example of the search for the "sustainable city region" from the view point of food production.

This study attempts to identify and analyze the emerging form of the urban–rural relationship through examining the role of agriculture in one of the Asian metropolitan regions in China, Tianjin. The main objectives of the study were:

(1) to identify the local and regional food flow and the extent to which the region's food consumption depends on local production and to assess the relationships between urban, suburban, and rural areas in the region (*Chapter 2*);

(2) to examine spatial-temporal and functional changes from 1993 to 2009 in terms of agricultural land use and food production in both suburban and rural areas of the city (*Chapter 3*);

(3) to explore whether the dependence of local consumption on local production could be improved based on the current trend of agricultural land use changes, in particular changes in paddy fields (*Chapter 4*).

Furthermore, suggestions on how to promote a sustainable city region are discussed in *Chapter 5*. The detailed research framework is shown as Figure 1-3.

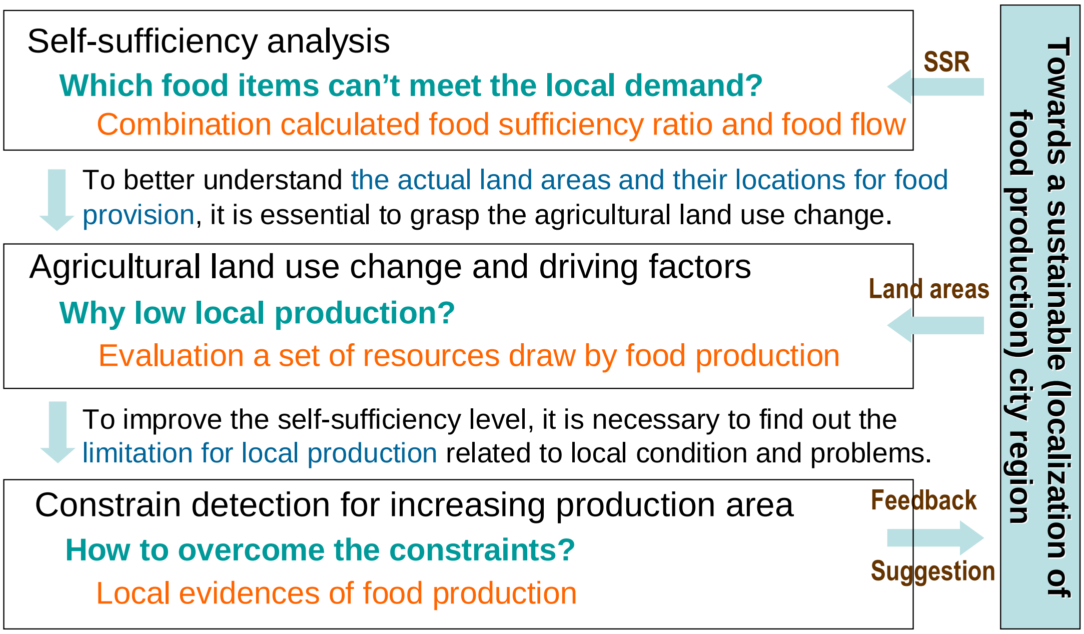


Figure 1-3 Study flow

1.3 Definition of terms

1.3.1 City and city region

On the basis of the Merriam-Webster's Dictionary, international Edition, city is defined as an inhabited place larger or more important than a town. Although there is no agreement on how a city is distinguished from a town within general English language meanings, many cities have a particular administrative, legal, or history status based on local law. Generally speaking, in west sense, city refers to the areas where is all developed; however, in Asian sense, city usually contains continues settlement, including urban, suburban and rural areas.

For example, in the United State, a city is a municipality in the U.S. governed under a charter granted by the state; also, in Canada, it means an incorporated municipal unit of the highest class (Merriam-Webster, 2004). Historically, in Europe, a city was understood to be an urban settlement with a cathedral (from Wikipedia).

In Mainland China, a city is an administrative division. There are three types of cities: a municipality of a provincial-level division (e.g. Shanghai or Beijing); a prefecture-level city is governed by provinces or autonomous regions; and a county-level city is a sub-unit of a prefecture-level administrative division. No matter which type, a city usually has associated urban, suburban and rural. In this study, the division of urban, suburban and rural is on a basis of local administrative boundary. So, Chinese city based on administrative boundary is an exact example of "city region" including suburban and rural areas where exist huge agricultural areas.

In this study, a sustainable city region is a city designed with consideration of environmental impact, inhabited by people dedicated to minimization of required inputs of energy, water and food, and waste output of heat, air pollution - CO^2, methane, and water pollution.

1.3.2 Urban agriculture

Peri-urban regions are the transitional zones between urban and rural areas. Many peri-urban agricultural areas have been rapidly transformed as urban sprawl has caused decreases in the area under cultivation (Thapa and Murayama, 2008). The peri-urban area in this study was defined as the suburban areas shown in Figure 1-2.

Global attention for the phenomenon of urban agriculture has been increasing since the 1990s. Usually, urban agriculture is located within or on the fringe of a city or peri-urban area, and comprises of a variety of production systems, ranging from subsistence production and processing at household level to fully commercialized agriculture (Veenhuizen M. van, 2006; Yang et al. 2010). This definition is particularly based on experiences in countries where UA (i.e. horticulture, aquaculture, livestock production, and forestry) maybe part of livelihood strategies of the urban and peri-urban poor and in which many food production activities are still based on relatively small-scale farming practices by relatively low income farmers. Such a focus is very much evident for example in sub-Saharan Africa and the countries of Latin America (De Bon et al., 2011; Yang et al., 2010).

In this study, urban agriculture is defined as the growing of plants and the raising of animals for food and other uses under the city administration (city region), and related activities such as the production and delivery of inputs, and the processing and marketing of products, including peri-urban areas and its countryside, in China.

1.4 Methodology

The main approaches were food flow analysis, landscape analysis by satellite image interpretation, and semi-structured and key informant interviews with local people.

1.4.1 Food flow analysis

- Flows of local agricultural production

In order to develop a self-regulating relationship with the biosphere, cities will need to adopt circular metabolic systems that ensure the continuing viability of the environment on which they depend. Adopting circular metabolic flows will help cities to reduce their footprint, and thus, their impact on the biosphere (Huang and Hsu, 2003). It is vitally important to recognize the pattern of resource flow from the perspective of sustainable development. The materials flow approach has important implications for evaluating the sustainability of city region development.

The areas produce surplus foods can supply other areas, and whereas in food deficit need to get food from other areas to meet consumption (Deutsch et al., 2009). Food production carried out within regions draw on a set of existing resources (land, water, labor, waste, energy, etc.) and generates food and non-food flows (Vagneron, 2007). Such this flow directly influences environmental change, regional ecosystem, agricultural structures in future and rural-urban sustainability (Prändl-Zika, 2008; Sundkvist et al., 2001; Sundkvist et al., 2005). In related to the agricultural land use, this study focused on the flow of agricultural products, food.

Food provision is a vital function of agriculture ecosystem services for consumption needs. Food production relies on the ecosystem, but it also impacts the environment. Food flow analyses can show the ecosystem dependence and environmental impacts embodied in the production process, regardless of where they are generated. A better understanding of food flows and the extent to which a region’s food consumption depends on the local ecosystem is important to understand what is sustainable both for the food system and the ecosystem. In this study, food flow refers to the movement of agricultural commodities from the point of production to the point of final consumption; it includes the flow from rural to urban areas as well as that between regions and countries (Hubacek and Sun, 2001; Swinton et al., 2007).

1.4.2 Landscape approach

- Identify the food production and agricultural land use/cover change

Accurate and comprehensive land use change statistics are useful for devising sustainable urban and environmental planning strategies. It is therefore very important to estimate the rate, pattern and type of LULC change in order to predict future change in urban development (Dewan and Yamaguchi, 2009). Some studies have identified agricultural land loss and urban expansion in Tianjin (Gondhalekar, 2007; Hara *et al*., 2010), but the dynamics of the internal restructuring of agricultural land use for production and its driving factors in the past decade remain unknown. An accurate understanding of this restructuring and its driving factors is of critical importance to assess food security and encourage sustainable development in the region.

Land cover in this study was captured by analysis of remotely sensed imagery. An analysis of the pattern of agricultural land cover change undertaken by the entire population of local farmers will indicate changes in the agricultural structure and land use in the study area. Because annual cropping is the main cropping system used in this area and crop rotation is not common, land cover can represent land use on the landscape scale.

1.4.3 Resilience-based approach

- Explore whether the local production could be improved

The resilience-based approach is one of several methods (the other methods include vulnerability research, ecological economics and sustainability science) used to understand the adaption process in systems thinking; this approach was designed to understand the changing dynamics of the integrated social-ecological systems (SES), and it can provide insights into potential management options during conditions of uncertainty and change (Allison and Hobbs, 2004; Cutter et al., 2008; Folke, 2006; ResilienceAlliance, 2010).

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1.5 Study areas

The Beijing-Tianjin metropolitan region, China's national capital region, has not only experienced rapid industrialization and urbanization (including the famous Jing-Jin-Tang Industrial Belt), but also has played a pioneering role for as urban development model for other Chinese cities. Tianjin is one of four province-level municipalities under the direct control of the central government of China, and it is the gateway to Beijing and northern China.

The study was carried out in Tianjin, which is in the northeast part of the North China

Plain (NCP) and located on a low-lying alluvial plain along the mouth of the Hai River (38°34'N–40°15'N and 116°43'E–118°04'E). With a total permanent resident population was 12.28 million in 2007 (40.4% live in the urban area), Tianjin is the third largest city in China and the second largest port city. In economic terms, the role of agriculture in Tianjin is modest. The share of agriculture in the area’s GDP has decreased from 6.1% in 1978 to 2.2% in 2007. Among the permanent population, the number of people employed in agriculture, including in fisheries and animal husbandry, fell by 8% from 1980 to 2007. Agricultural land accounted for 58.7% of all land in 2007, and cereal crops, vegetables, and cotton are the predominant crops in both suburban and rural areas (Tianjin Statistics Bureau, 1991, 2008). No agricultural land exists in the urban centre, which is entirely dependent on outside sources for food. Because Tianjin functions as the economic centre of northern China and is an international shipping centre and a designated eco-city, the local government has not made food self-sufficiency a key policy objective. Food flows and trade are much greater in this area than in other Chinese cities. The whole areas are divided based on local government: urban; suburban, 7 districts; rural, 5 counties (Figure1-4).

The terrain is generally flat and swampy near the coast, but it is hilly in the far north and covers an area of 11,760 km^2. It has a semi-arid monsoon climate, with an average precipitation of about 544 mm/year, about three-fifths of which occurs in July and August (Figure 1-5). Precipitation is also extremely varied from year to year, typically in cycle of several consecutive wet years followed by several consecutive dry years (Song et al., 2011). The city of Tianjin has an available per capita volume of water resources of only 1/15 the national average and 1/50 the world average (Bai and Imura, 2001; Song et al., 2011). Due to the rising demand for water caused by industrial and urban development and upstream irrigation construction, water has become a pronounced factor limiting development of the city. As is true with peri-urban agriculture in many other countries, the Tianjin region has suffered a shortage of freshwater in semi-arid and arid zones, and treated wastewater from urban areas has become an important source of irrigation water for agriculture in suburban areas over the past 45 years in Tianjin (Cao et al., 2005; Shi et al., 2005; Tao et al., 2004).

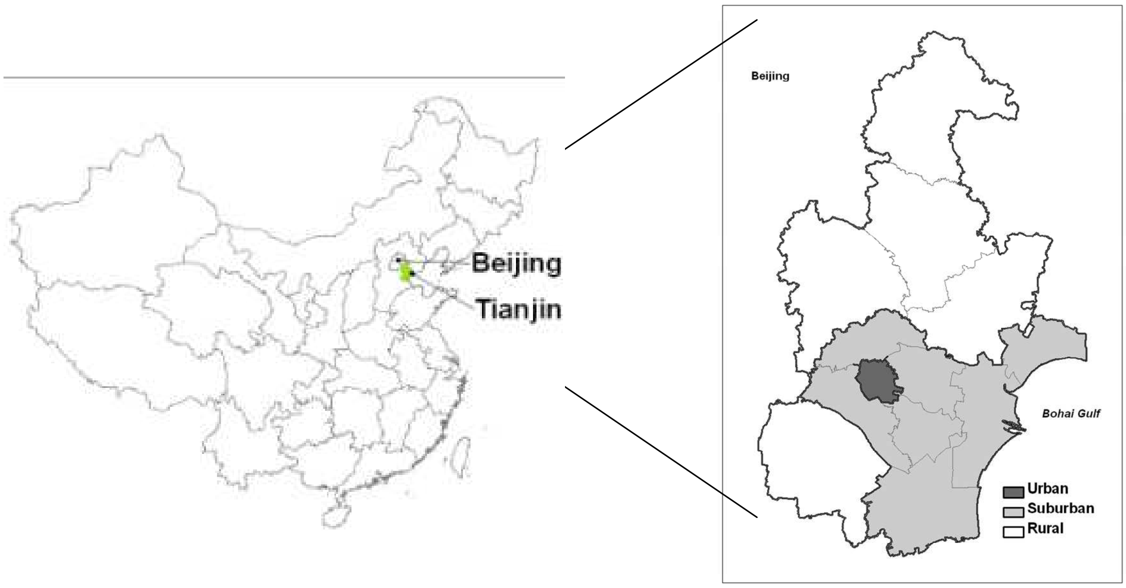


Figure 1-4 The location of Tianjin

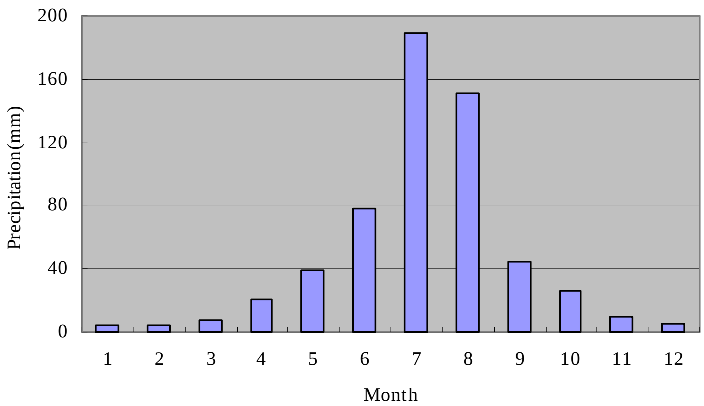


Figure 1-5 Average monthly precipitation in Tianjin

Chapter 2 Food self-sufficiency and observed food flows

A better understanding of food flows and the extent to which a region's food consumption depends on its local area's production is important to understand future sustainable cities. However the recent rapid development of transportation and specialized production has generated an active flow of food, we simple must be clear about the degree of dependence that exists today with respect to our use of ecosystem areas and services.

This chapter examined the food self-sufficiency and food flow in Tianjin, divided into three areas (urban, suburban, and rural), as a case study to gain a better understanding of local and regional food flow and of ecosystem performance. The main objectives were to evaluate the city's capacity for self-sufficiency within its administrative boundary by calculating a self-sufficiency ratio using statistical data at both the city and local scales, to estimate potential food flow at the city scale from data derived from field surveys of local markets and statistics provided by local government authorities, and to observe real flows of the two primary types of arable crops (cereal grains and vegetables) from semi-structured household interviews at the local scale.

2.1 Introduction

Food flow refers to the movement of agricultural commodities from the point of production to the point of final consumption; it includes the flow from rural to urban areas as well as that between regions and countries (Hubacek and Sun, 2001; Swinton et al., 2007). Different food production structures and consumption patterns in different regions may accelerate the trade of agricultural commodities (Seabrook *et al.*, 2006), and a significant change in the flow of food implies that regional agriculture and agricultural land use may change (Seabrook *et al.*, 2006). A dramatic transformation of regional agricultural production and land use can also be a main driver leading to a shift in the flow of food.

Food production carried out within region draws on a set of existing resources (land, water, labour, waste, energy, etc.) and generates food and non-food flows (Vagneron, 2007). Such flows directly influence environmental change, regional ecosystems, future agricultural structures, and rural-urban sustainability (Prändl-Zika, 2008; Sundkvist et al., 2001; Sundkvist et al., 2005), and food provision is a vital function of agriculture ecosystem services for consumption needs (Metzger *et al.*, 2006; Swinton *et al.*, 2007; Verburg *et al.*, 2009). The flow of food also influences the use of resources and energy and generates pollution, thereby impacting the environment (Deutsch and Folke, 2005; Gadda and Gasparatos, 2009; Sundkvist et al., 2001). Therefore, food flow analyses can be useful in studying ecosystems and associated environmental impacts, taking into account where the food was consumed and produced (Deutsch and Folke, 2005; Sundkvist et al., 2001; Turner et al., 2007). The recent rapid development of transportation and specialized production has generated an active flow of food. It is now clear that patterns of production, consumption, and well-being not only develop from economic and social relations within and between regions but also depend on the capacity of other regions' ecosystems to sustain these patterns (Arrow et al., 1995; Folke et al., 1998; Folke, 2006).

Few studies have examined the characteristics of food flows. The most relevant comprehensive studies have been of food distribution (Osvald and Stirn, 2008), food miles (Coley et al., 2009; Kemp et al., 2010; Sundkvist et al., 2005), the food web (Rossberg, 2008; Sakka Hlaili et al., 2008), food networks (Jarosz, 2008; Seyfang, 2006), and alternative food supply chains (Ilbery and Maye, 2005; Renting et al., 2003) in Europe and North America. Studies on the degree of dependence on internal ecosystems have been conducted at a national or regional scale (Deutsch et al., 2009; Deutsch and Folke, 2005), but studies at the local scale are few. The spatial route of regional food transportation is not known with certainty in emerging countries. Therefore, understanding food flows and the extent to which a city's food consumption depends on the local ecosystem is important to understand what is sustainable both for the food system and the ecosystem.

In this study we examined the food self-sufficiency and food flow in Tianjin city, divided into three areas (urban, suburban, and rural), as a case study to gain a better understanding of local and regional food flow and of ecosystem performance. The main objectives were to evaluate the city's self-sufficiency capacity within its administrative boundary by estimating a self-sufficiency ratio using statistical data at both the city and local scales, to estimate potential food flow at the city scale from data derived from field surveys of local markets and statistics provided by local government authorities, and to observe real flows of the two primary types of arable crops (cereal grains and vegetables) from semi-structured household interviews at the local scale. Finally, the differences between the theoretical self-sufficiency capacity and the observed local food flows as well as the ecosystem impacts were considered.

2.2 Methods and data sources

2.2.1 Calculated self-sufficiency capacity

Self-sufficiency depends upon trends in production and consumption which in turn are affected by the individual country's political environment. The self-sufficiency ratio (SSR) measures the extent to which a broad commodity group (e.g. cereal crops, meat, or vegetables) produced within a given region meets the consumption needs of that region (Cowell and Parkinson, 2003; Deutsch et al., 2009). In this study, SSR was defined as the ratio of local food production to local food consumption for each year in the period from 1980 to 2007 for the suburban and rural regions of Tianjin as well as for the entire area for each major food category. Given the historical net imports data were not available, SSR was estimated on a amount basis using the following equation:

$$SSR_{(a,i,y)} = \frac{Pd_{(a,i,y)}}{Cp_{(a,i,y)}} \times 100 ,$$

where $SSR_{(i,y)}$ is the SSR of agricultural commodity i in area a in year y; $Pd_{(a,i,y)}$ is the total production (ton) of agricultural commodity i in area a in year y, and $Cp_{(a,i,y)}$ is the total consumption (ton) of agricultural commodity i in area a in year y. SSR was calculated within the whole city area, suburban and rural areas, and each county, respectively.

To account for differences in consumption by area, food consumption for the entire area was calculated as follows: $Cp_{(i,y)} = \sum_a P_{(a,y)} c_{(a,i,y)}$, where $P_{(a,y)}$ is the resident population in area a in year y, and $c_{(a,i,y)}$ is the per capita consumption of product i in area a in year y. SSRs were calculated for the following major agricultural commodities: cereal crops, vegetables, eggs, meat (pork, beef and mutton), poultry, fish, and milk. The total consumption of cereal crops is the sum of human food and animal feed, where the feed consumption is calculated as meat production multiplied by the following feed/meat ratios on the basis of Feng (2007): pork, 1.08; milk, 0.5; poultry, 1.6; eggs, 1.9; beef and mutton, 2; fish, 1. These ratios were assumed to be stable during the study period. All data were collected from annual Tianjin Statistical Yearbooks. Per capita food consumption was taken from household survey data of the Tianjin Statistics Bureau. Given Chinese official data, including production and population statistics, are commonly perceived to be inaccurate, although data quality has improved since the 2000. The "calculated SSR" in this study was paid more attention to its trend and its relative value, not absolute values.

2.2.2 Potential food flow at the city scale

In order to explore the actual flow of food in Tianjin, four researchers from the Tianjin Academy of Agricultural Sciences conducted qualitative interviews with researchers, government officers, food sellers in open markets, and managers of wholesale markets in August 2009. Seven government officials were interviewed, including two from the Commercial Committee, one from the Bureau of Cereals, three from the Bureau of

Agriculture, and one from the Agriculture Committee. No one official agency tracks the flow of food. Rather, each of these agencies works with different aspects related to agricultural production, local sales, and food trading both within and outside of the region.

The two largest wholesale markets in the central city (the Hongqi and Jinzhong wholesale markets) were also visited and interviews were conducted. According to the market mangers and local government authorities, these two markets supply almost 50% of all foodstuffs to the central city. The other 50% is supplied by two other, smaller wholesale markets, supermarkets that have their own procurement and distribution systems, and local retail markets. Trade data for most fresh vegetables sold in the Hongqi wholesale market from December 2008 to June 2009 were obtained from market staff for each type of vegetable. Data included the daily amount sold (kg) and origin of the product (either local or from outside of Tianjin), as well as the average, lowest, and highest price per unit (CNY/kg).

2.2.3 Observation of local food flows at the local scale

Food flows at the local scale were estimated from statistical data reported by the Tianjin Statistics Bureau and a qualitative semi-structured survey undertaken from 23 December 2009 to 29 January 2010 with farm families in the Xiqing district and Ninghe county, which represent areas of typical agricultural production in suburban and rural areas, respectively (Figure 1-5). Several major raw products (wheat, rice, corn and vegetables) were examined in terms of both food consumption and production.

In each area, the villages to be surveyed were selected according to their distance from the urban centre, main production patterns, and changes that occurred in the past two decades. A maximum of three households were randomly selected to be interviewed in the sample villages. A total of 40 interviews were conducted in 17 villages in suburban areas, and 27 interviews were carried out in 17 villages in rural areas. For each selected crop, farmers were first asked if the purpose of planting was commercial or for subsistence. If the farmer replied both commercial and subsistence, the response was classified as the one the farmer thought of greater importance. If the farmer replied commercial, the following questions were asked: “who is the buyer?” and “where will the commodities go?” We then divided the number of “commercial” responses by the total number of responses (%) for rice, wheat, corn, and vegetable farmers, respectively, and took that proportion as the rate of commercial flow. We also calculated the share of each type of food produced as compared to total production of each crop in each area in Tianjin. The total amount of flow was estimated for each selected product, as were the flow routes (Figure 2-1).

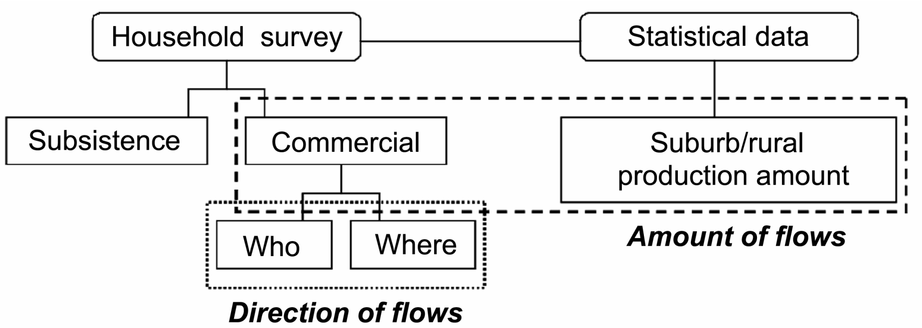


Figure 2-1 Approach used to observe local food flows at the local scale

2.3 Results

2.3.1The changes in food consumption patterns

Growing economies and individual incomes have contributed to growing demand and a shift in food consumption patterns. Meanwhile, consumption patterns were strongly influenced by the local availability of commodities, resulting in large regional and inter-generational differences (Gerbens-Leenes and Nonhebel, 2005).

According to the household survey data from the survey by statistic department, which can figure out the consumption habit of household in the form of expenditure, per capita food consumption showed the changes and large differences between rural and urban areas (Figure 2-1).

In the past three decades, both rural and urban areas spurred a rapid increase in per capita consumption for animal products, notably poultry and pigs, and other high-value food, such as fish, and oils, whereas a stabile decrease in demand for grain. Per capita vegetable consumption is special, which is always increasing in rural, but in urban area, it decreased from 148.0kg in 1980 to 123.4kg in 2007 per year. In urban, per capita consumption on each food item is higher than it in rural except the grain. By growing population either in urban and rural, the total consumption of food is decreasing, including vegetable, poultry, fish, dairy and eggs, except grain.

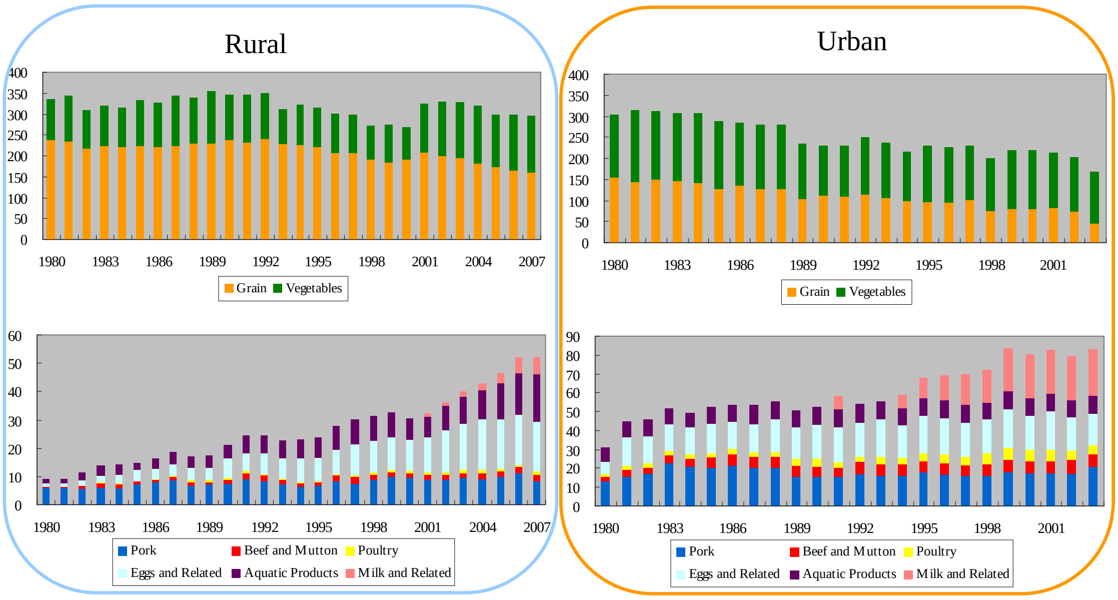


Figure 2-2 Per capita consumption pattern change from 1980 to 2007 (Unit: kg)

2.3.2 Calculated self-sufficiency capacity

The agricultural sector in Tianjin was not self-sufficient in 1980, particularly in terms of beef and mutton. By the 1990s, however, Tianjin overall had achieved self-sufficiency in most categories. By 2007, there was a surplus of vegetables, meat, and fish, and the only category in which the agricultural sector did not meet demand was cereal crops (Table 2-1; Figure 2-3).

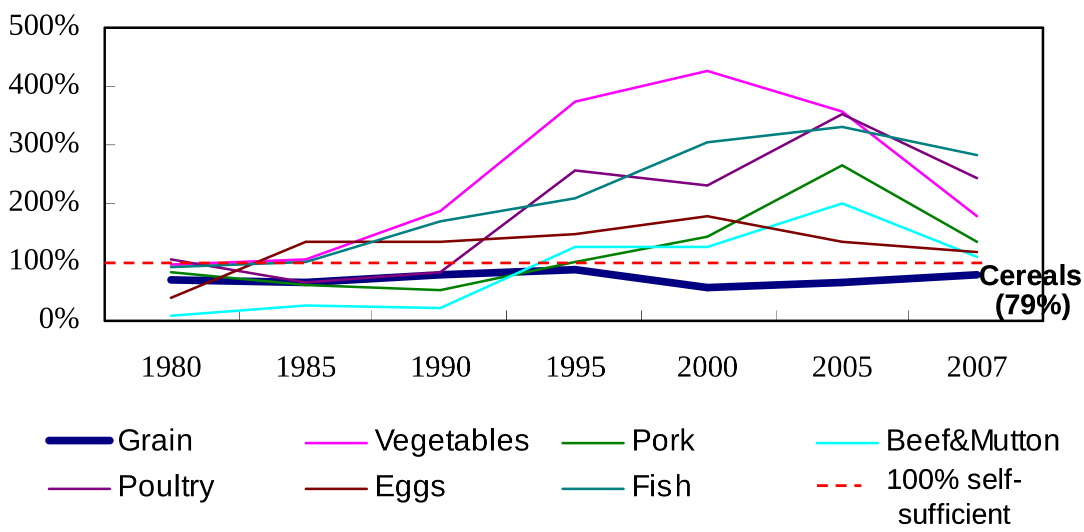


Figure 2-3 Ratio of local production to consumption

In Figure 2-3, the 100% line indicates the level at which the city can meet its demand from local production. Commodities shown above the line indicate local surpluses available for export elsewhere in China and then to the rest of the world. Commodities below the line indicate a local deficit and the need for imports to meet local consumption.

Not surprisingly, rural areas have had a surplus in all categories since the 1980s. Suburban areas have generally had high SSRs for vegetables, poultry, and fish, but SSRs for the other categories were generally below 50%.

Table 2-1 SSRs (%) for various agricultural products produced in Tianjin from 1980 to 2007

Area	Periods	Cereals	Vegetables	Poultry	Fish	Pork	Beef & Mutton	Eggs
Suburban	1980~1989	29	95	-	-	11	-	41
	1990~1999	28	129	123	167	27	26	78
	2000~2007	13	119	157	227	56	33	40
Rural	1980~1989	163	134	-	-	262	-	709
	1990~1999	222	655	2518	286	407	1052	556
	2000~2007	211	833	3576	387	989	957	428
Total	1980~1989	69	100	86	97	72	17	88
	1990~1999	84	280	170	188	78	74	141
	2000~2007	67	321	277	305	181	145	144

Note: - indicated no production data available

Given the cereal crops was the only commodity which the city can meet its demand from local production, SSR of cereal crops was calculated within each district of Tianjin to indentify the area in cereal deficit. The results showed in the rural areas, Ninghe county enjoyed a highest SSR in 1980, whilst its SSR became the lowest among the rural areas; Xiqing district was the only self-sufficient area in suburban areas, which experienced a decreasing SSR along with the other suburban districts during the study period (Figure 2-4).

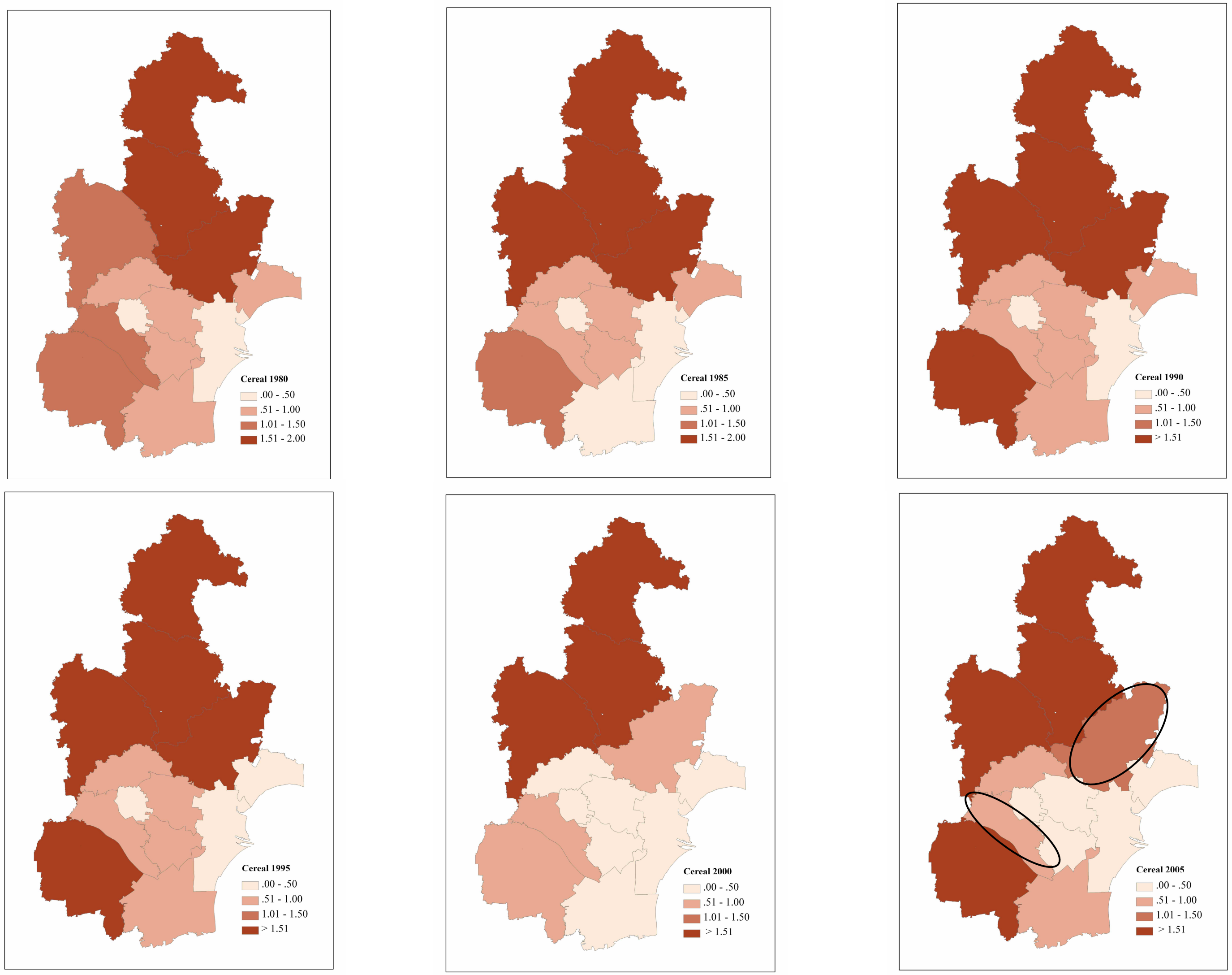


Figure 2-4 The trend of SSR spatial pattern of cereal crops from 1980 to 2007

2.3.3 Potential food flow at the city scale

Local government authorities stated that, after the price of pork was deregulated in 1992, the increased local demand was met by the rapid expansion of local commercial feedlot production, not by the traditional practice of grazing. This change in the method of meat production allowed Tianjin to change from a net importer of meat (primarily from Sichuan Province) to a net exporter to surrounding areas (primarily Beijing and Hebei Provinces). Almost all large national milk producers have factories in Tianjin that mainly produce milk powder and fresh milk, which are sold in Beijing and surrounding areas. The aquatic food industry supports the entire city primarily because of its geographic location near Bohai Bay. As for the vegetables, the self-sufficiency and flow depend on the species and seasons. During the off seasons, the self-sufficient ratio for vegetables only reached to 30%, the remaining 70% was supported by the south China; during the peak seasons, they can feed by themselves and export to the north China (Table2-2).

Table 2-2 Local vegetable harvest and flow calendar

Month	12	1	2	3	4	5	6	7	8	9	10	11
Harvest	Off season			Peak Season				Off Season			Peak season	
Weather	Cold							Hot, rainy				
SSRs	Leafy veg. 30% Fruit veg. 10%			> 100%				30%			>100%	
Regional flow	Import (South) Export (North)			Export (North)				Import (North) Export (South)			Export (North)	

According to interviews with managers of the two largest wholesale markets, most vegetables produced locally are from individual farmers, but they do not produce enough for urban consumption and trading. The managers stated it is more convenient and cheaper to import vegetables from outside the region (Figure 2-6). The trade data obtained from the Hongqi wholesale market from December 2008 to June 2009 showed that local fresh vegetable products account for a small share of the vegetable market in Tianjin, averaging only 33% of all vegetables sold during that time period (Figure 2-5). The other 67% was usually transported from other Chinese regions through trade in domestic markets.

Using the self-sufficiency capacity data and the responses from local government authorities, researchers and managers of wholesale markets, we mapped the potential food flows at the city scale as shown in Figure 2-7. Cereal products were supplied by Northeast China (e.g. rice from Heilongjiang Province). Vegetables, meat, dairy and fish produced locally flowed to the surrounding area outside of Tianjin, whereas vegetables were imported from outside of Tianjin's administrative boundary.

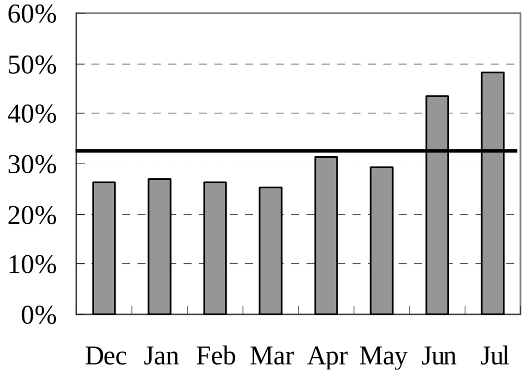


Figure 2-5 Average market share of locally produced vegetables at the largest wholesale market in Tianjin from December 2008 to July 2009

Note: the black line indicate the average share

Figure 2-6 Interviewed largest wholesale and retail markets in August, 2009

Figure 2-7 Local food items which were found in the local market; eggs produced today from Xiqing (left); local grape (middle)

Note: the only local rice grown in Ninghe, others were imported from the Northeast China (right). The red marks indicated that the item was from the local.

Figure 2-8 Potential food flows at city scale in Tianjin

2.3.4 Local food flows within the city

As can be seen in Table 2-3 and Figure 2-8, there was a limited flow of locally produced cereal grains between rural, suburban, and urban areas. Most rice was consumed where it was produced, whether in terms of own or other local consumption or by being processed in local factories. Almost all of the wheat produced was consumed by the farmers. In contrast, 81% of corn produced in rural areas was sold to local feed factories to be processed into manufactured feed, or to individual pig farmers in neighbouring villages. The remaining 19% was consumed by producers.

The flow of vegetables was more active than that of cereal grains. Rural vegetables flowed within the rural area and out of the region, whereas suburban vegetables flowed from suburban areas to the urban centre. Almost 70% of vegetables produced in rural areas, accounting for 50% of total vegetable production in Tianjin, went to other Chinese regions. Because of monocultural planting practices in rural areas, a surplus of specific types of vegetables is produced and traders from outside of Tianjin buy the vegetables directly from the farmers and transport them by truck or train, primarily to regions in the north. The other 30% of vegetables produced in rural areas were consumed by rural residents. All of the vegetables produced in suburban areas (30% of total production) were consumed in the urban centre.

Table 2-3 Share (%) of local production and product flows

	Suburb			Rural		
	Share of Production	Commercial	Subsistence	Share of Production	Commercial	Subsistence
Wheat	2	30	70	98	0	100
Rice	4	20	80	96	0	100
Corn	9	20	80	91	90	10
Vegetables	30	100	0	70	100	0

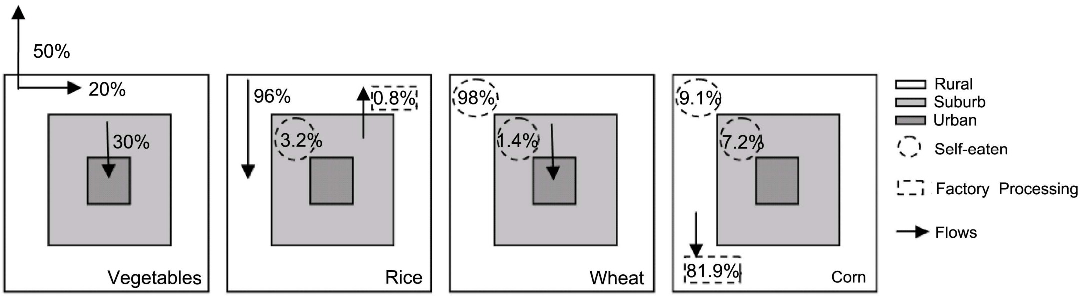


Figure 2-9 Agricultural products flows within the city

2.4 Discussion

2.4.1 Calculated self-sufficiency capacity and observed real local food flows

The analyses of calculated self-sufficiency capacity and potential flow at the city scale show Tianjin was a net importer of food in 1980, whereas, theoretically at least, the only inflow was cereal grains in 2007. Rural areas have also experienced surpluses since the 1980s, and suburban areas have a history of high calculated self-sufficiency for vegetables, poultry, and fish. The flows of two major local food items were observed at the local scale: (1) most cereal grains were consumed in agricultural production areas, and there was little flow from either rural or suburban areas to the urban centre, with the result that the bulk of cereal grain consumption by the 40% of the population living in the urban centre was supplied from other areas of China; and (2) 70% of vegetables produced in rural areas flowed outside of the region and did not support Tianjin local consumption, whereas almost all of the fresh vegetables produced in suburban areas were sold in the urban centre, but they only accounted for about 33% of total local consumption.

Despite the predicted surplus in vegetable production, Tianjin is highly dependent on vegetables supplied from other areas of China. Meanwhile, many other Chinese areas remain highly dependent upon selling their products to Tianjin. Currently, many agricultural products are imported from other localities, most likely because of a greater availability of a wider variety of products and to take advantage of lower prices in the national market.

Tianjin is a major consumer of cereal grains, and it liberally trades cereal grains with other major cereal-producing provinces. Local government authorities face little pressure to produce sufficient cereal crops and seldom consider how to raise food self-sufficiency or promote local food production and consumption. Instead, the focus is on helping farmers be more profitable and produce food with high value and quality, or special varieties to capture market share in terms of both domestic sales and exports. A focus is also on guaranteeing stable food provision, especially of rice, as a food security issue, and on providing special foods, for example, off-season vegetables and fruits, to enrich consumer choice. Government authorities want to create a friendly political environment for food distribution and trade in a free market. Farmers generally do not care as much about where their food ends up, but they are concerned about whether it will sell at a high price. Moreover, it is also difficult for local consumers to discern the source of products.

2.4.2 Local food flows and urban-rural linkage

A low proportion of locally sourced products and flows was observed in this study. The urban centre clearly depended on areas outside the region's borders for almost 100% of cereal grains and 67% of its vegetable consumption. Instead of using the local ecosystem, the population in urban and suburban areas used distant ecosystems. The food flow between the local areas in the region seems separate, and, moreover, there is a general lack of communication about food flow.

Figure 2-10 Local farmer with cargo trike in the market (left); retailers with car (right)

Approx. 20 years ago, the face-to face interaction between the producers and consumers in farm market still occupied the major terms of food market; now it became not officially recognized in the urban area, even forbidden, only exists in the suburban and rural areas. During the survey, the author found that it was interesting to distinguish the local farmers in the local markets. The feature of local farmers includes food items in seasons, few amounts, various types, and transported by cargo trike/bike and so on (Figure 2-10).

Fortunately, during the field survey, we observed that, although cereal grains and vegetables seldom flowed from rural to suburban areas, much paddy rice straw flowed from rural to suburban areas to be used as a covering to keep greenhouses at a constant temperature for vegetable production.

2.5 Conclusions

Tianjin has experienced a rapid increase of calculated self-sufficiency capacity since the 1980s, and it appears to have the capacity to support the citizens within its borders. By 2007, the self-sufficiency ratio of major foods reached more than 140%, and in the case of milk, the ratio was 360%; the only category in which the agricultural sector did not meet demand was cereal crops. Even with these high ratios, the city has chosen to use and exchange services from distant areas, utilizing regional food flow. In the urban area, local fresh vegetables currently account for only 33% of the vegetable market, whereas the other 67% is supplied by other regions of China. The situation is even worse for cereal grains. All cereal products consumed by the urban population are supplied by other regions. At the local scale, rural areas have had a surplus in all of the food categories studied since the 1980s, and suburban areas have a history of high self-sufficiency for vegetables, poultry, and fish. However, a low degree of locally sourced product flow was observed. Most local cereal crops were consumed in agricultural production areas, but 70% of vegetables produced in rural areas flowed outside of the region and did not support local consumption in Tianjin.

Owing to the limited access to historical data for comparative purpose, it was not possible to estimate changes over time in the size and routes of local food flows. But it is possible to explore the main drive, local food production, which will contribute to the food flow. Next chapter will be focused on food production and agricultural land use changes, and how this may contribute to the current food flow.

Chapter 3 Agricultural land spatial temporal dynamics and their function change

As discussed in *Chapter 2*, local agricultural production is the main driver of self-sufficiency and food flow. Different food production structures and consumption patterns in different regions may accelerate the trade of agricultural commodities, and a significant change in the flow of food implies that regional agriculture and agricultural land use may change. A dramatic transformation of regional agricultural production and land use can be a main driver leading to a shift in the flow of food. This chapter tried to understand the food production structure first, then to evaluate recent structural changes in agricultural land use at the landscape scale in suburban and rural areas in Tianjin from 1993 to 2009, based on two case studies where experienced the dramatic decreasing SSR during the study period, and to understand farmers' decision-making behavior of these changes at the farm scale.

3.1 Introduction

In response to population growth and urban development, agriculture in peri-urban regions has become an increasingly important policy concern, particularly in light of the rapid growth of cities and other urban centers in developing countries (Huang et al., 2006; Sharp and Smith, 2003; Thapa and Murayama, 2008; Vagneron, 2007; Yang et al., 2010). Agricultural land use changes in peri-urban areas have important food security implications for neighboring urban populations, as well as for designing sound environmental planning and management programs and for creating sustainable livelihoods for local communities in urban-rural fringe areas (Liu et al., 2005; Torres-Lima and Rodriguez-Sanchez, 2008). Although a number of researchers have described the conversion of agricultural land to nonagricultural uses in urban fringe areas (Dewan and Yamaguchi, 2009; Tan et al., 2005; Xiao et al., 2006), few have distinguished spatial structural changes and the driving forces for the changes within the agricultural landscape (Li and Yeh, 2004), both in urban fringe areas and in city's countryside.

Some academics have acknowledged that agricultural landscape components and the magnitude of change should be related to the farming systems' structural influences on the regional landscape (Mander and Jongman, 1998; Torres-Lima and Rodriguez-Sanchez, 2008). The examination of farmers' decisions has been recognized as a helpful way to understand agricultural changes at the rural-urban interface (Kizos et al., 2010; Sharp and

Smith, 2004). Decisions at the farm level include all management practices, including the type and intensity of inputs and the land cover. Land use decisions and landscape changes at the farm scale are driven by many different factors, which are often related to the economic efficiency of the specific land uses and other social issues (Kizos et al., 2010).

This chapter aimed to quantify recent structural changes in agriculture land use in the Tianjin's countryside and explore whether market mechanisms, land use policies, or other environmental factors have been the primary driving factors in farmers' decision making. We interpreted Landsat images from two periods to characterize temporal patterns of agricultural land cover from 1993 to 2009. The primary driving factor of the change was evaluating by interviewing local farmers. The use of crop inputs and treated water was also evaluated to better understand farmers' decision-making behavior. Two case studies were chosen where experienced the dramatic decreasing SSR during the study period (Fig. 3-1).

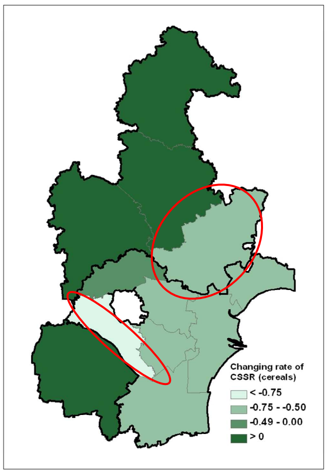


Figure 3-1 Study areas

3.2 Agricultural processes at the city scale

3.2.1 Profile of Tianjin agriculture development

In consequence of increased trading and the availability of natural resources, agriculture in Tianjin has experienced a profound structural change during the past three decades. This is reflected in the decreasing of share of plant cultivation, and increasing of share of fish and animal husbandry. Decreasing sown area of paddy rice together with increasing of corn, cotton and vegetable are notable in plant cultivation, especially cotton. Livestock, poultry and aquaculture are currently growing faster than the rest of agriculture. The area devoted to cropping has decreased from 431.5km^2 to 406.0km^2 (1990-2007), or nearly 6% in 17 years;

while, the planted area has decreased from 549.5 km^2 to 434.0 km^2 during the same period, more than 21%.

The most rapidly increasing crop in Tianjin is without doubt the cotton, whose cultivation areas have grown from 10.4 km^2 in 1990 to 67.5 km^2 in 2007, for an increase of 549%; the second one is vegetable raised by 25% from 50.8 km^2 to 63.4 km^2. The dramatically decreasing crops are rice, wheat (fallen by 63%, 28%, respectively).

The cereal production amount decreased 22.0% from 1.89 million ton in 1990 to 1.47 million ton in 2007(wheat, rice dropped by 21.9%, 51.8%, and corn raised by 15.0%). Vegetable grew by 2.3% which means there has been a decline of 18.0% in the yield per hector (although we doubt there are some statistic problems according to officer from Tianjin Agriculture Committee). Extraordinarily, statistic records have shown that the agricultural productivity of cereals (average yield per hector) has been growing, which are 1.2 times larger in 2007 than in 1990 (as wheat, rice, corn are 1.08, 1.32 and 1.09 times larger, respectively) (Tianjin Statistics, 1991, 2008).

3.2.2 Agriculture specialization index analysis

The specialization index (SI) is generalized to understand agricultural production specialization, which is calculated as follows:

$$SI = \left(X_{ij} \Big/ \sum_i X_{ij} \right) \Bigg/ \left(\sum_j X_{ij} \Big/ \sum_i \sum_j X_{ij} \right)$$

where X_{ij} is the amount of agriculture production j in county i. The range of index value lies between 0 and positive infinity. If the index equals unity, the share of the county i's production in product j is identical to its share of production j in total agriculture products. Accordingly, if the index value is greater than unity, it indicates a relative specialization of the country in product j. If it is less than unity, the respective specialization of each county in a given production is weak. The dynamics of agricultural products specialization are analyzed at the district level from 1990 to 2007. For each of the twelve districts, data for area and output are compiled for partial product-cereals and vegetables (as land), meat, poultry, milk and aquaculture (as output) (Figure 3-2).

The results showed the pattern of specialization differs according to their location and urbanized level. The pattern change of specialization implies that agriculture process is connected with urban regional development. Cereal planted became concentrative in specific counties; vegetables cropping expanded to rural area with a decline in urban-rural interface; the movement of poultry production out of suburban can be seen as well.

Tianjin has a long history of growing vegetables, most of which are in suburban (because it closed to the consumption area). Cucumber, celery, pepper, tomato and Chinese cabbage are the most four vegetables, each one grows more than 7000ha. Recently, in order to compete with other city, a complementary area of government support concerns investment aimed at increasing the off-season supply of vegetable, flattening price and species seasonality. Main areas for cropping cereal are north rural counties; cotton are grown the same area as cereal except mountainous area.

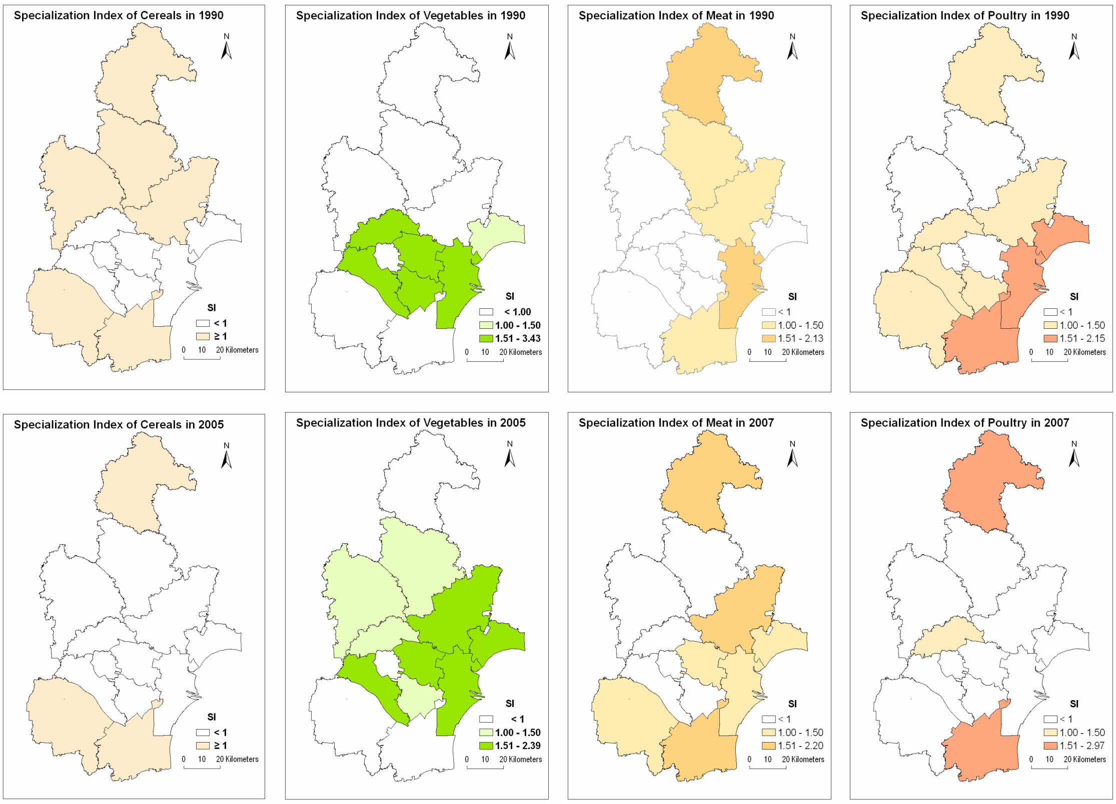


Figure 3-2 The pattern of specialization from 1990 to 2007/2005

3.3 Methodology

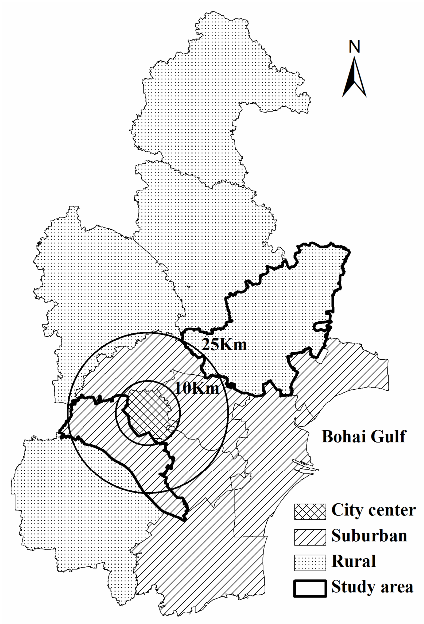
3.3.1 Two study cases

Tianjin consists of six inner urban districts without agricultural activities, five surrounding suburban districts with agricultural activities, and four rural districts. For the purpose of the study, the area was divided into urban, suburban, and rural areas (Figure 3-3).

Two areas were selected as case studies to stand for the suburban areas (Xiqing district) and rural areas (Ninghe county) in Tianjin. Annual cropping is predominant in both two case areas, although multiple cropping of vegetables is common.

Xiqing is a typical suburban district southwest of Tianjin with a population of about 336,200 people; almost 30% of the population does not engage in agricultural activities. Several canals, drainage channels, and natural rivers run through Xiqing.

Ninghe is typical rural area, the major land use in this county is agriculture, and agricultural land accounts for more than 55.6% of the area. Irrigated paddy rice, corn and cotton are the primary crops, particular planting a local traditional brand of rice named “Xiaozhan”. Given its chewy texture and nutty flavor, it has been known as a geographical indication in China. There are two main rivers run through Ninghe, Ji Cancle and Chaobai River.



(Indicated by bold lines)

Figure 3-3 Two study areas

3.3.2 Definitions and research structure

Farmers are important agents in urban-rural landscape management because they modify the land cover to suit their needs. Therefore, farmers’ activities represent some of the most significant contributions to land cover changes at the landscape level (Kristensen et al., 2001). Land use on the farmer scale was obtained by a survey of farmers, which included questions on crop arrangements and farm inputs. The farm survey should allow us to gain a better understanding of factors that influence farmers’ decision-making about cropping activities.

In the first stage of the analysis, we investigated land cover changes during the study period (1993-2009) to quantify cropping pattern changes at the landscape scale. We then analyzed the main factors farmers considered when changing crops. In the third stage, we applied the standard economic assumptions of rational behavior and profit maximization to farmers and their land use decisions. We investigated variable inputs, costs, and profit of each crop (or land use type) at the farm scale to estimate and assess the factors that influenced farmer activities as well as current conditions and historical changes. Because agriculture is strongly influenced by the availability of water(Olesen and Bindi, 2002), we also analyzed the use of irrigation water.

3.3.3 Detecting agricultural land cover changes

Remote sensing provides an efficient tool to map peri-urban agriculture and monitor long-term land cover changes. At a medium resolution of 30 m, Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) data enable mapping of important crops and primary cover types (Gao et al., 2006). A single satellite image from Landsat was inadequate to identify all of the required land use and crop categories (Birnie et al., 1982); some researchers have noted that mixed pixels may be a problem in pixel-based classification if land cover variation occurs within 5-15 m, which can be the case with small-scale peri-urban agriculture(Forster et al., 2010). A segmentation algorithm is a bottom-up region-merging technique that takes shape, texture, and spectral information into account to attempt to overcome the problems associated with pixel-based methods (Bock et al., 2005; Munyati et al.)Yu *et al.*, 2006; Munyati *et al.*, in press). Limited data were available because land cover and peri-urban agriculture mapping of large areas using a large number of images and high spatial resolution was not a cost-efficient approach for our study. Instead, we applied an approach that combined both human interpretation and machine-based segmentation to ensure mapping accuracy. The detailed processes are described in the following sections.

(1) Image collection and preprocessing

Three Landsat images (Path 122, Row 33; cloud-free) were selected to classify the study area, one from 15 June 1993 (TM), the other from 4 September (ETM) and the third one from 30 August 2009 (TM). Ancillary data layers, including a Japan Earth Resources Satellite-1 Very Near Infrared Radiometer image from 8 September 1992, an IKONOS image from 20 November 2000, a Quickbird image from 12 January 2004, and Google Earth images were also used to aid in Landsat image interpretation and quality control. The

June 1993 Landsat5 TM image was taken when the paddy rice had been planted and the soil was saturated by water; the other summer crops had also been planted. In the September 2001 image and August 2009 image, most of the crops were near harvest.

Landsat images were received from the U.S. Geological Survey with geographic coordinates WGS_1984. High-resolution images were obtained from DigitalGlobe. Because there was no ground control point or relief geo-referenced map, image-to- image correlation was conducted in terms of relative geometrical accuracy. ERDAS Imagine 9.3 was used to create image subsets. The preprocessing did not include either atmospheric correction or topographic normalization.

(2) Segmentation

In this study, eCognition 4.0 was used to segment images into disjoint, spatially continuous, and homogeneous regions that refer to meaningful objects in the real world (Bock et al., 2005; Pekkarinen et al., 2009). Multi-resolution segmentation was applied because it generates objects that very closely resemble ground features. The segmentation parameters were defined as follows: layer weights were set to 1, scale to 8, shape factor to 0.3, and compactness to 0.8. Finally, the image of Xiqing was divided into 15,048 objects with consistent shapes in 2009, 15479 objects in 2001 and 14,175 objects in 1993, the image of Ninghe was 23760 divided into objects with consistent shapes in 2009, 33019 objects in 2001 and 27194 objects in 1993.

(3) Classification

Classification of segmented objects was performed visually to ensure the highest accuracy. To support the visual interpretation, ground truth data were collected in August 2009 and January 2010. A PhotoTracker (GiSTEQ) was used in the field that integrated photographs with precise location information for future reference in Google Earth. During the field survey, large parcels or plots corresponding to different land cover types or crops were selected for identification and recorded in the printed images. A total of 177 ground truth sites in Xiqing and 241 in Ninghe were collected to reduce the uncertainty. Interviews with local residents were conducted as well to confirm past land covers in 1993.

A hierarchical classification system of four major land cover categories was distinguished from Landsat TM/ETM+ data: agricultural areas, built-up areas, water bodies, and others. The land cover class of primary interest in this study was agricultural land, which was further subdivided into six classes: paddy rice, maize, cotton, vegetable fields, orchards, and fish ponds. Built-up land included urban areas, rural settlements, and other similar areas (e.g., roads). Water bodies included rivers, canals, and reservoirs. Other areas included areas with bare soil and reeds. A crop rotation of winter wheat-summer maize is still practiced in some plots, but given the small area affected, we omitted it in the land cover mapping and included those areas in the annual maize cropping category (Table 3-1).

ArcGIS 9.3 was used to interpret the data at a spatial scale of 1:100,000, displayed with bands 4 (near infrared), 5 (shortwave infrared), and 3 (red) shown as red, green, and blue, respectively. To facilitate assigning attributions to segmented objects, a point was manually added inside each segmented object in a new point layer. The points and segmented polygon layer were spatially joined where the polygon feature completely contained the selected points with the same category by using the program’s select feature by location tool. A value was then assigned to the selected polygons in the attribute table. If there was a mix of crop types on one object, the object was classified as the dominant land cover in all cases. All land cover patches smaller than 0.4 ha were merged with surrounding dominant land cover patches. Thus, spatial features consisting of less than approximately four Landsat pixels (corresponding to a 60-m-wide square) were not mapped.

(4) Change detection

Post-classification comparison was used to determine changes in land cover from 1993 to 2009. An overlay of two classified polygon layers was done in ArcGIS 9.3, in which all polygons from both classified layers were split at their intersections and preserved. A transition matrix analysis was then conducted to analyze the spatial distribution of land cover changes from 1993 to 2009. The rate of change was also calculated.

3.3.4 The farming survey

A quantitative semi-structured survey was undertaken from 23 December 2009 to 29 January 2010 in Xiqing and Ninghe, additional one was carried out from 6 December 2010 to 29 December 2010. The survey focused on farm characteristics, reasons for land cover (crop) change, and types of inputs used. The surveyed villages were selected according to the distance from the city center, main production patterns, and changes that occurred between the two study periods. A maximum of three households were randomly selected to be interviewed in the sample villages.

Agricultural inputs include materials, labor, technology, and other resources (Shriar, 2000). The amount of inputs used per hectare was determined at the farm level on the basis of the interview. Three inputs were quantified: operating expenses (CNY $ha^{-1}y^{-1}$), labor (days $ha^{-1}y^{-1}$), and water (m^3 $ha^{-1}y^{-1}$). Operating expenses included seeds, organic materials, chemical fertilizers, pesticides, rent payments, machinery and fuel costs, irrigation, and hired labor. Labor inputs were unpaid work days from family members or others. For each type of input, we determined both the amounts used and the cost incurred by farmers. Finally, we estimated and ranked the average annual cost of each crop.

Farmers were asked whether land use (crops planted) had changed since the early 1990s. If the response was yes, the farmer was asked the main reason for the change. If the answer was no, the farmer was asked the main reason for planting the current crop. We totaled the responses to determine the main driving force for past changes as well as the reasons for current land use. Farmers were also asked whether they faced water shortages or water pollution problems.

Table 3-1 Land cover interpretation key

Land cover class		**Texture**	**Tone**	**Descriptions**	**Example**
	Paddy field	Medium fine	Dark red		
	Maize	Coarse	Brown	Texture varies with regions	
Agricultural land	Cotton	Fine	Yellow		
	Vegetable field	Coarse	Blue and brown	Mixed; located along with the canal or rural settlement areas	
	Fish pond	Fine	Blue to purple	With rectangular shape	
Built-up areas		Mottled	Highlight blue		
Water surface		Fine	Dark blue	Smoother texture than fish pond	
Others		Medium fine	Green		

Image acquired on September displayed with band 4 (near infrared; NIR), 5 (shortwave infrared; SWIR) and 3 (Red) as R, G, B

3.4 The suburban areas: a case study of Xiqing district

3.4.1 Agricultural land cover changes

Land cover changes and transition rates are presented in Fig. 3-4 and 3-5, respectively. The area of land being used for agricultural purposes decreased by 17.3% during the period, although agriculture was still the dominant cover class in 2009, accounting for 50.8% of the total area. About 44.0% of newly built-up areas in 2009 had previously been used for agriculture.

Paddy rice cropping accounted for 11.0% of the study area in 1993. Paddy fields had declined by 89.2% in 2009, 38.0% of which was transformed to built-up areas, 20.1% to cotton, 19.5% to maize, and 11.8% to fish ponds. By 2009, paddy rice cropping was carried out only in four aggregated plots. In 2009, orchards had also decreased by 60%, vegetable fields by 49%, and maize by 38% as compared to 1993. Conversely, the area under cotton production grew rapidly, occupying 23.6% of the total agricultural land in 2009. Planting areas for cereals production decreased by 53%.

Some spatial shifts in agricultural land types are visible within the study area over the time frame of study (Fig. 3-6). The land cover distribution maps show that crop cover dominates in the western and southern parts of the study area, but agricultural use (particularly paddy rice fields) decreased in the eastern and central parts, which are closer to the city center. Agricultural land in the south is made up of large plots that were primarily occupied by paddy and maize fields in 1993, but these areas were largely converted to cotton by 2009.

Vegetable fields are more common in the western area along the south canal, which is part of the longest artificial canal in China, but plots that existed in 1993 near the city center were converted to urban uses. Seven industrial parks were built in this area during the last two decades, and they have expanded toward each other as part of the larger urban sprawl, leaving only parcels of agricultural land in this area. Most plots along the canal that were classified as maize in 2009 had been vegetable fields in 1993.

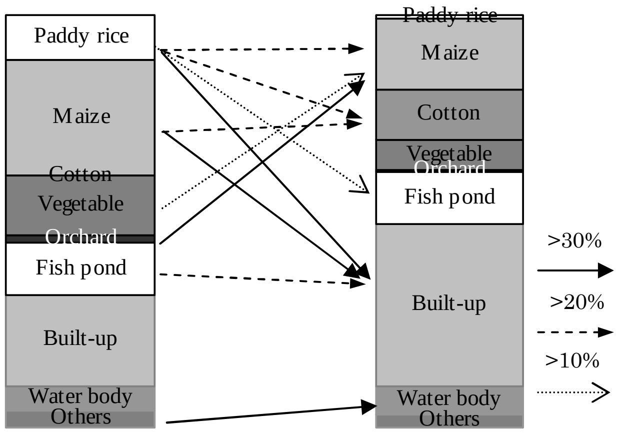


Figure 3-4 Land use changes from 1993 to 2009 in Xiqing

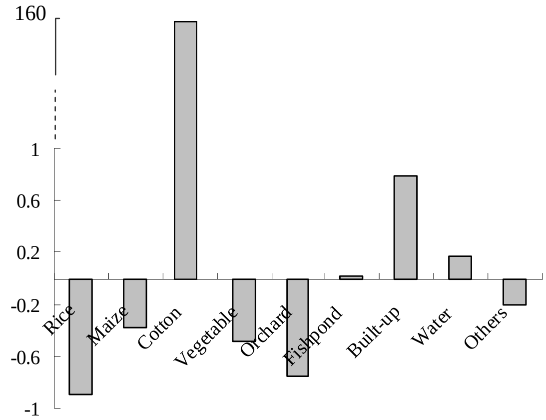


Figure 3-5 Transition rate of each land use type from 1993 to 2009

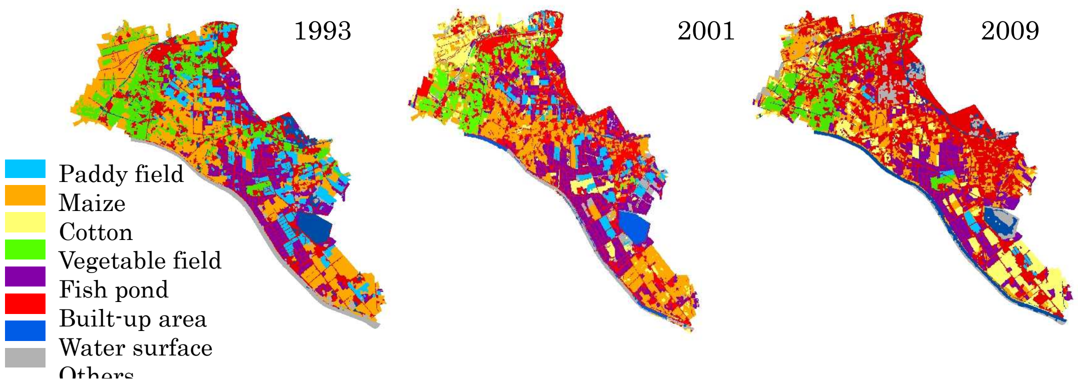


Figure 3-6 Land covers in Xiqing in 1993 (left), 2001(middle), and 2009 (right)

3.4.2 Household agricultural land use

A total of 40 interviews were conducted in 17 villages. The farmer characteristics in the study areas are presented in Table 3-2. The average age of interviewed farmers was 54 years, and 27% of the farmers interviewed were over 60 years old and still engaged in full-time farming. About 30% of interviewed farmers had other jobs to supplement their incomes. Per capita farming income in the study area was higher than the rural average (5310 vs. 4039 CNY y^{-1}), and per capita non-farming income was also higher than the rural average (7443 vs. 5768 CNY y^{-1}). The total per capita income was less than the urban average (14,753 vs. 21,402 CNY y^{-1}), however. The samples therefore seem to be representative of people living in urban-rural fringe areas.

Table 3-2 Farmer characteristics in Xiqing

	Mean
No. of villages	17
No. of interviewees	40
-Female	10
Average age(years)	54
Farming income (CHY y^{-1})	5310
Non-farming income(CHY y^{-1})	7443
Average property size (ha)	3.3
Average farm size (ha)	1.7
-Cost to land lease (CNY $ha^{-1}y^{-1}$)	4625

The current average planted area of rice and cotton by individual farmers is larger than 1ha in the study area, whereas the average planted area for vegetables, maize, and fruits are relatively small (Table 3-2). Vegetable farmers grew 3.5 different species on average and harvested 2.9 times annually.

The main reasons given for the current cropping pattern and crop choice at the farm level were local custom, self-consumption, crop profitability, available labor, and physical characteristics of the fields (e.g., soil type, field size, and available water; Table 3-3). Of the 40 farmers interviewed, 15 (37%) had not changed crops during the study period; 11 of those 15 are commercial vegetable farmers and the other 4 are subsistence farmers. The remaining 25 farmers (63%) changed their land use since the 1990s. The two most common reasons for the change were “preferred to reduce labor” (9) and “compelled to change from paddy rice due to water shortage” (8). Other reasons included water quality, profitability, and urban development (Table 3-3).

Table 3-3 Crop profiles in Xiqing in 2009

Crop	*N*	Yield ($t\ ha^{-1}y^{-1}$)	Plant area(ha)	Labor ($days\ ha^{-1}y^{-1}$)	Expenses ($CNYha^{-1}y^{-1}$)	Irrigation ($m^3ha^{-1}y^{-1}$)	Net income ($CNYha^{-1}y^{-1}$)	Reason for cropping
Rice	1	6.8	2.7	56.3	11,250	7,200	4,800	History and village consumption (1/1)
Maize	15	5.6	0.2	30.0	2,109	120	8,159	Home consumption(8/15),Extensive labor(7/15)
Cotton	2	2.9	1.3	97.5	11,250	0	6,803	Tolerant to saline soil and scarce water (1/2), Profitable (1/2)
Vegetables	18	56.7	0.2	2025.0	61,140	4,997	218,160	History (12/18), profitable (3/18)
Fruit	5	41.3	0.4	150.0	11,250	1,800	41,000	Profitable (5/5)

Table 3-4 Survey results in Xiqing

(1) Agricultural land use change in the past				N
a. No change				15
b. Changed and the main reason was:				25
-Developed				2
- Internal agricultural change				23
	Labor	Water scarcity	Water quality	Profitability
R→C		2	1	
R→M		6		
V→M	5		1	
F→M	4			
M→C				2
M→F				2
Total	9	8	2	4
(2) Current water quantity				
a. Water shortage				2
b. Satisfies basic irrigation needs				17
c. Completely satisfies irrigation needs				16
(3) Current water quality				
a. Irrigation water is clean				7
b. Irrigation water is polluted				26
c. Irrigation water is saline				2

Note: N, number of respondents; R→C planted by migrant farmers; R, rice; M, maize; C, cotton; V, vegetable; and F, fruit.

3.4.3 Profit, operating expenses, and labor input

The results of the economic analysis showed that vegetables were the most profitable crop, generating a net income of 218,160 CNY $ha^{-1}y^{-1}$. The second-most profitable crop, fruit, generated a net income of 41,000 CNY $ha^{-1}y^{-1}$, less than one-fifth that of vegetables. Rice farmers had the lowest net income (Table 3-3).

Vegetable farms also had the highest cost, and maize farms had the lowest. Rice, cotton, and fruit farms had roughly similar operating costs. The main cost of producing rice and cotton was the rent of land, whereas the main cost of growing fruit was the purchase of pesticides.

Vegetable farmers used the most family labor (2025 days $ha^{-1}y^{-1}$), and maize farmers used the least (30 days $ha^{-1}y^{-1}$). If the cost of family labor is included at the same payment as hired labor, the operating expenses rank order becomes vegetables, fruit, cotton, paddy rice, and maize. Figure 3-7 showed that elder vegetable farmers worked in their green house.

Figure 3-7 Elder vegetable farmers worked in their green house

3.4.4 Water use and pollution

Paddy rice consumed the largest amount of irrigation water, with an annual average of 7200 m^3 ha^{-1}. Vegetables were the second largest consumer of irrigated water (4997 m^3 ha^{-1}), whereas cotton did not require irrigation and maize had a fairly low demand for irrigated water (Table 3-3). According to the interviewees, both surface water and groundwater used for irrigation are free; farmers only need to pay a fee for electricity to pump the water in some cases.

When farmers were asked whether they currently faced a serious water shortage, only 5% (2/40) said they suffered from water scarcity and 40% (16/40) had direct access to as much irrigation water as they needed from a canal or river. The remaining farmers accessed water from drainage channels or wells. A majority (28/40) of farmers, however, noted a problem because of a lack of access to clean water (Table 3-4).

3.5 The rural areas: a case study of Ninghe county

3.5.1 Agricultural land cover changes

Land cover changes and transition rates are presented in Fig. 3-8 and 3-9, respectively. The area of land being used for agricultural purposes converted a little to un-agricultural land during the period, agriculture was the dominant cover class in 2009, accounting for 70.0% of the total area.

Paddy rice cropping accounted for 36.0% of the study area in 1993. Paddy fields had declined by 70.1% in 2009, 53.4% of which was transformed to cotton and 15.5% to maize. By 2009, paddy rice cropping was carried out only 9.7% of the study area. In 2009, maize had also decreased by 19.6% as compared to 1993. Conversely, the area under cotton production grew rapidly, occupying 44.2% of the total agricultural land in 2009. Vegetable had also increased by 47.6% during the period. Planting areas for cereals production decreased by 60%.

The land cover distribution maps show that the whole area is dotted with built-up areas consisted by towns and villages, vegetables dominated the northeast. Compared with 2001, the paddy field got increased until 2009(Fig. 3-10).

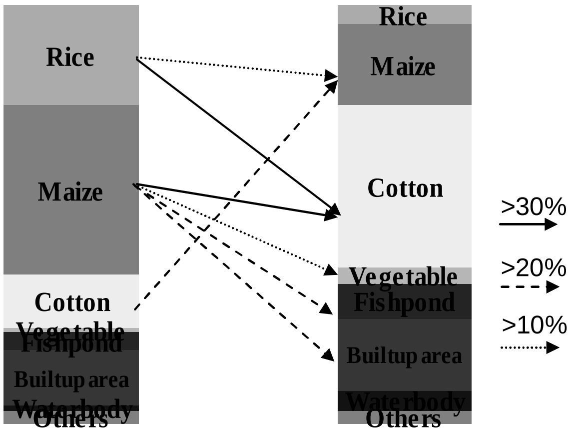


Figure 3-8 Land use changes from 1993 to 2009 in Ninghe

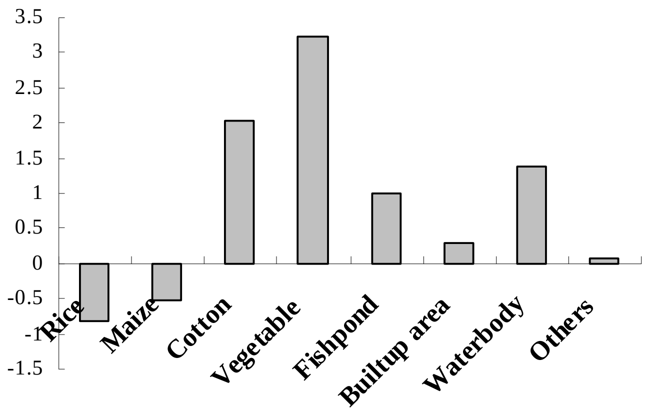


Figure 3-9 Transition rate of each land use type from 1993 to 2009 in Ninghe

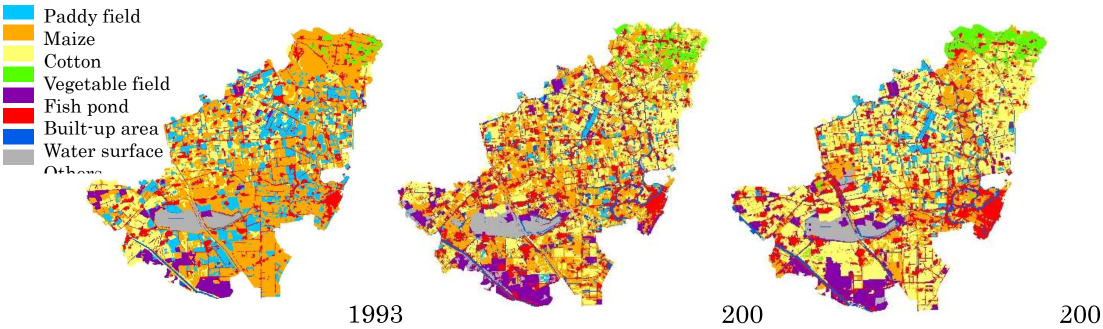


Figure 3-10 Land covers in Ninghe in 1993 (left), 2001(middle), and 2009 (right)

3.5.2 Household agricultural land use

A total of 78 interviews were conducted in 30 villages. The farmer characteristics in the study areas are presented in Table 3-5. The average age of interviewed farmers was 51 years, and 26% of the farmers interviewed were over 60 years old and still engaged in full-time farming. About 43% of interviewed farmers had other jobs to supplement their incomes.

Compared with the case of Xiqing in peri-urban areas, the current average planted area of each crop by individual farmers is smaller than 1ha in Ninghe, whereas the average planted area for vegetables and Maize are larger than Xiqing (Table 3-6). Vegetable farmers grew 2.75 different species on average and harvested 2.0 times annually.

The main reasons given for the current cropping pattern and crop choice at the farm level were crop profitability, self-consumption, available labor, governmental promotion, and physical characteristics of the fields (e.g., low-lying; Table 3-6). Of the 78 farmers interviewed, 8 (10%) had not changed crops during the study period; all are subsistence rice farmers. The remaining 70 farmers (90%) changed their land use since the 1990s. The two most common reasons for the change were “compelled to change from paddy rice due to water shortage” (8) and “change to vegetables for purchase more profit”. Other reasons included government promotion, rotation, water quality, and available labors (Table 3-7).

Table 3-5 Farmer characteristics in Ninghe

	Mean
No. of villages	30
No. of interviewees	78
-Female	21
Average age(years)	51
Farming income (CHY y^{-1})	15318
Non-farming income(CHY y^{-1})	23904
Average property size (ha)	0.62
Average farm size (ha)	0.84
-Cost to land lease (CNY $ha^{-1}y^{-1}$)	4020

Table 3-6 Crop profiles in Ninghe in 2009

Crop	*N*	Yield (t $ha^{-1}y^{-1}$)	Plant area(ha)	Labor (days $ha^{-1}y^{-1}$)	Expenses (CNY$ha^{-1}y^{-1}$)	Irrigation ($m^3ha^{-1}y^{-1}$)	Net income (CNY$ha^{-1}y^{-1}$)	Reason for cropping
Rice	19	8.5	0.6	75	3,845	7,650	18,005	Home consumption (12/19); plots in low-lying area(4/19); rotation(3/19)
Maize	48	8	0.3	37	3,429	300	10,961	Extensive labor(27/48); stable profit(9/48); home consumption(10/48)
Cotton	46	3.4	0.7	150	4,974	480	16,801	Profitable(28/46); tolerant to scarce water (12/46); suitable to store(2/46)
Greenhouse vegetables	15	107.5	0.2	1350	83,490	4,770	111,510	Government promotion(9/15); Profitable (3/15)
Field vegetables	20	32.1	0.2	1170	10,866	3,150	36,804	Profitable(9/20); stable market(3/20)
Fruits	3	3.8	0.2	105	12,000	1,200	33,000	Profitable(3/3)

Table 3-7 Survey results in Ninghe

(1) Agricultural land use change in the past							N
a. No change							8
b. Changed and the main reason was:							70
-Developed							0
-Internal agricultural change							70
	Labor	Water quantity	Water quality	Profitability	Policy	Rotation	Self-consumption
R→C		30	3	5			
R→C→R		1				3	3
M→V				20	9		
M→C				8			
C→M	2					3	
Total	2	31	3	33	9	6	3
(2) Current water quantity							
a. Water shortage							10
b. Satisfies basic irrigation needs							46
c. Completely satisfies irrigation needs							22
(3) Current water quality							
a. Irrigation water is clean							48
b. Irrigation water is polluted							19
c. Irrigation water is saline							11

Note: N, number of respondents; R, rice; M, maize; C, cotton; and V, vegetable.

3.5.3 Profit, operating expenses, and labor input

The results of the economic analysis showed that vegetables were the most profitable crop, generating a net income of 111,510 CNY $ha^{-1}y^{-1}$. The second-most profitable crop, fruit, generated a net income of 41,000 CNY $ha^{-1}y^{-1}$, around one-third that of vegetables. However, Maize farmers had the lowest net income which was differ with that in suburban areas (Table 3-6).

As the same with suburban areas, vegetable farms also had the highest cost, and maize farms had the lowest. Rice, maize, and cotton farms had roughly similar operating costs. The main cost of producing rice and cotton was less than half of that in suburban because there was no rent fee, they almost crop on their own land. The main cost of growing fruit was the similar as suburban area, the purchase of pesticides.

Vegetable farmers used the most family labor (1350 days $ha^{-1}y^{-1}$), which is less than the suburban area, and maize farmers used the least (37 days $ha^{-1}y^{-1}$). If the cost of family labor is included at the same payment as hired labor, the operating expenses rank order becomes greenhouse vegetables, field vegetables, cotton, fruit, paddy rice, and maize. Figure 3-11 shows that rural farmers own relative large plots than farmers in suburban areas.

Figure 3-11 Farmer crop on their relative large plots

3.5.4 Water use and annual precipitation

Paddy rice consumed the largest amount of irrigation water, with an annual average of 7650 m^3 ha^{-1}. Greenhouse vegetables were the second largest consumer of irrigated water (4770 m^3 ha^{-1}), whereas cotton and maize had a fairly low demand for irrigated water (Table 3-6). As in the suburban, both surface water and groundwater used for irrigation are free; farmers only need to pay a fee for electricity to pump the water in some cases.

When farmers were asked whether they currently faced a serious water shortage, only 13% (10/78) said they suffered from water scarcity; most farmers (46/78) had direct access to irrigation water only for their basic need from a canal or river. According to the researcher in Tianjin Agricultural University, given the local government recently has initiated several new modern agriculture states, most vegetables produced in greenhouse now are irrigated by groundwater through drip or spray irrigation; other crops irrigate by surface water. A majority (48/78) of farmers can access to clean water (Table 3-7).

3.6 Discussion

3.6.1 Farm dynamics and adaptations

Peri-urban agriculture has been evaluated as a method of intensive production of highly perishable foods such as fruits, vegetables, meat and fish, and dairy products in both model and case studies (Mander and Jongman, 1998; Midmore and Jansen, 2003; Sharp and Smith, 2004; Thapa and Murayama, 2008; Vagneron, 2007). Our Landsat image classification analyses showed another trend in suburban area besides the conversion to development areas: a notable conversion of land use from the production of perishable food to staple foods, for example, from vegetables and fruits to maize. We also found a shift from the production of food to the production of fiber, in this case, from paddy rice and maize to cotton.

While in cities countryside little agricultural land conversion was found, one same finding as in suburban area is a shift from stable food to fiber production was significant (from Rice & Maize to Cotton). We also found two different results are: some small land had been converted from the production of staple foods to fresh food, from Maize to vegetable; and recently, there was a trend that some land under fiber production had been converted to the production of staple foods again, from cotton to rice.

Choices about which crops to plant and which inputs to use are made by producers within some technological, economic, organizational, and legal limitations, and at the farm level, within the limitations of the particular farming system in use (Primdahl, 1999). Our interviewees stated that in suburban area, they considered available labor and water as the main factors when they made decisions, rather than market mechanisms and government policies, as has been discussed in previous studies (Gao et al., 2006; Li and Yeh, 2004; Wu et al., 2009). Therefore, crops that require less water and less labor intensive crops, such as cotton and maize, are increasingly being farmed in this area. However, in the rural area, farmers considered crop profitability and available water as the main factors when they made decisions. Available water became the common both in suburban and rural areas.

In other areas in China, many paddy fields have been converted into other types of agricultural land use to increase revenue as a result of the influence of market mechanisms, such as conversion of paddy fields into aquaculture and mulberry fields for silk production in the Yangtze Delta (Wu et al., 2009) and the transformation to cash crops, fruits, and aquaculture in the Pearl River Delta (Li and Yeh, 2004). We also noted a large decrease in the area of paddy fields, but local farmers said the primary reason for changing crops was a shortage of water.

Our interview results indicated that the main reason for the shift from rice to cotton in suburban area was that farmers needed to adapt to water shortages and to the use of treated water from the city and industrial parks; in the rural areas, there are not so much treated water, farmers only faced the stress of water shortages caused by climate variability and high water demand for non-agriculture use.

Farmers also mentioned soil salinity. In the coastal area near the lower reaches of the Hai River, there is a large area of both saline-alkali and saline soils. Cotton is a major cash crop in this area and also quite tolerant of saline soils. Although rice is not tolerant of excess salinity, it can be grown in saline soils[1]. Local farmers planted paddy rice as a reclamation crop to reduce the salt in the upper soil successfully in the 1970s, but they stated that the rice tasted worse as a result of being irrigated with treated water. And soil salinity became a serious problem in some plots because of the salinity of treated water.

As mentioned above, more than one-third of farmers in Xiqing and around one-fourth of farmers in Ninghe interviewed changed their crops, primarily because of past problems with scarce water for irrigation. Only 5% of farmers in Xiqing and 13% in Ninghe currently suffer from water scarcity. However, this is not because irrigation water has become more available, but rather because farmers have already adapted to the situation and changed to less water intensive crops, such as cotton and maize, as was confirmed by the results of our image analysis.

The survey results in Xiqing case study also suggested that the conversion from the production of perishable to staple foods represents an adaptation to insufficient labor for labor-intensive crops, such as fruits and vegetables. The decline in the agricultural labor force is particularly strong on the edge of urban areas, and the amount of labor available may become insufficient for some labor- intensive crops (Grigg, 1995). Our analysis of inputs showed that the production of vegetable and fruit crops requires almost 70 and 5 times the amount of labor required by maize, respectively. Farmers who live near the city or industrial parks can find jobs in the nonagricultural sector more easily and are less likely to farm intensively. In addition, a substantial number of workers engaged in intensive cropping in the study area are facing old age, and some said they will give farming up in the future. Farmers can also get a direct subsidy for cereal crops from the central government, which is appropriately 1050 CNY ha^{-1} annually.

Although the annual profit from vegetable cropping was shown to be high, few farmers have recently converted to vegetable farming in Xiqing. By contrast, many farmers have

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1 FAO, Salt-Affected Soils and their Management, 1988. <http://www.fao.org/docrep/x5871e/x5871e04.htm> (verified 7 June 2011).

converted to vegetable farming in Ninghe, including greenhouse vegetables and field vegetables. The Tianjin city government has a subsidy for an initial investment in new plastic greenhouses for areas of no less than 3.3 ha, but it is difficult for individual farmers in suburban areas to take advantage of this subsidy because of size limitations, while it can be put into practice in the large rural areas. These farmers are also constrained by available water and labor. Fruit crops need less labor than vegetables (Table 3-3), and they are profitable as cash crops. Two farmers in Xiqing stated they changed from maize to fruits to increase their net income (Table 3-4).

3.6.2 Study limitations

Our sample of rice and cotton farmers in Xiqing was limited. Rice cropping is currently carried out by collective units (villages) sharing the irrigation system. The one rice farmer interviewed said that all of the paddy fields in his village were cultivated by 15 farmers who agree to give 215 kg of rice to other village members annually. Much of the land used for cotton farming is rented by migrant farmers from neighboring provinces who have experience growing cotton. The migrant farmers go back to their hometowns in the winter and return for farming the next spring. Therefore, we could not find many cotton farmers for our survey.

The lack of field verification after classification is partly the result of the difficulty of conducting field surveys so long after the acquisition of the image. Visual interpretation is regarded as a necessary tool for an accuracy assessment. Some studies conducted using visual interpretation have shown classification accuracy exceeding 85% using field truth sites(Liu et al., 2005; Jansen et al., 2008; Garedew et al., 2009), but other studies using visual interpretation did not assess accuracy (Gulgun et al., 2009; Gong et al., 2010; Niu et al., 2010). Interpretation errors are caused by uncertainties and regular mistakes (Gong et al., 2010). In this study, ground truth data and high resolution images were utilized to the extent possible to control quality and ensure high mapping accuracy, and we are confident that the overall accuracy is acceptable.

3.7 Conclusions

Agricultural processes are connected with the increased urbanization that accompanied the urban regional development in Tianjin. The image classification results showed an obvious loss of agricultural land since the early 1990s in suburban areas, similar to what has occurred in other peri-urban areas. Two other notable trends in land use, which differ from those of other peri-urban areas, were observed: (1) land was converted from the production of traditional perishable food to the production of staple foods, in this case, from vegetables and fruits to maize; and (2) there was a shift from staple production to fiber production, in this case, from paddy rice and maize to cotton. In rural areas, a similar shift from staple food to fiber production was noted during the study period, in this case, from rice and maize to cotton. Two other results, which differ from those of suburban areas, were found: (1) a relatively small amount of land had been converted from the production of staple foods to fresh food, from Maize to vegetables; and (2) recently, some land has shifted back from fiber production to the production of staple foods, in this case, from cotton to rice. Through semi-structured household interviews, a scarcity of water was noted as an important problem for agriculture in Tianjin—this was found to be a primary factor for agricultural land use change both in suburban and rural areas. Suburban farmers had to adjust their agricultural activities by adapting to an insufficient amount of labor and the use of treated wastewater for urban areas for irrigation. Rural farmers' activities, however, were still driven by market mechanisms and other government policies. To enhance food security and develop the region in a sustainable way, it is necessary to integrate agriculture into development and water management planning.

Rice is the principle staple crop in Tianjin (Figure 3-12), and any deterioration of rice production systems would seriously impair food security. Increasing land area is one option to solve food deficit. Given some paddy fields in suburban were converted into developed areas, the possible to enlarge the production area for local consumption will be only in total areas.

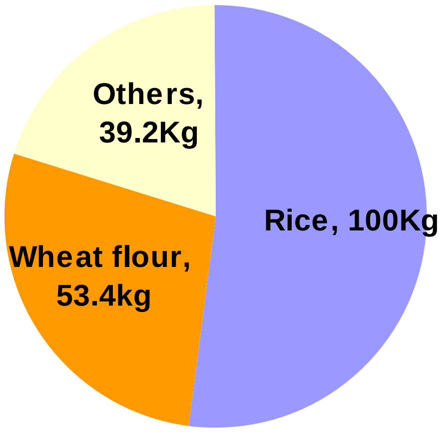


Figure 3-12 Annual per capita consumption of cereals in Ninghe (2006)

Chapter 4 Can local rice production be enlarged for local markets?

Changes in local production have accounted for the trend of food self-sufficiency levels and contribute the current regional and local pattern of food flow. Specialized vegetable production in rural areas generated an active flow from the rural areas of Tianjin to other Chinese regions, whereas the decreased production of paddy rice was only able to support consumption in the production areas themselves, so there was no local surplus to flow locally.

In *Chapter 3*, the primary reason for a large decrease in paddy fields area was a shortage of water. Attention to the link between food and water shortages continued from the 1980s. *Chapter 4* uses the concept of resilience as a framework to get the evidence from the local to explore whether it would be possible to enlarge the production area for local consumption, in this case of paddy rice, to enhance food security and develop a more sustainable urban–rural system.

4.1 Introduction

Climate change has emerged as one of the most multifaceted manifestations of global change (Dessai et al., 2007), and it is expected to affect many economic sectors, including forestry, energy consumption and tourism, but it particularly affects the agricultural sector (Moriondo et al., 2010). The current vulnerabilities to climate are strongly correlated with climate variability, in particular precipitation variability. These vulnerabilities are largest in arid and semi-arid low-income areas, where precipitation and stream flow are concentrated over a few months, and the year-to-year variation is high (Kundzewicz et al., 2007; Lenton, 2004). This year-to-year variation is of high concern in agricultural sectors (Thomas, 2008). Although humans and the natural ecosystems in many river basins suffer from a lack of water, in the water-scarce areas, the people and ecosystems are particularly vulnerable to the decreasing or variable precipitation that results from climate change (Kundzewicz et al., 2007).

Several recent studies have assessed the vulnerability to global environmental change and the adaptive capacity to cope with these changes on local and global scales (Acosta-Michlik and Espaldon, 2008; Dessai and Hulme, 2007; Kelkar et al., 2008;

Saldaña-Zorrilla, 2008). In recent years, the concept of resilience has been increasingly used in the research on the human dimension of global environmental change science (Cutter et al., 2008; Janssen et al., 2006; Vogel et al., 2007; Young, 2010). The resilience-based approach is particularly appropriate for managing the impacts of climate change because the future climate and climate predictions are inherently uncertain (Dessai et al., 2007; Marshall, 2010).

The agricultural system is an integrated system that contains an agricultural natural environment and a society engaged in agriculture. The development of resilient agricultural systems is an essential topic of study because many communities greatly depend on the provision services of such systems for their livelihood; these services include food, fodder, fuel and other bio-resources (Lin, 2011). On a year-to-year basis, agricultural systems on the community level are often highly resilient; in other words, the people are able to absorb the small disturbances, including droughts, floods, economic fluctuations and pest attacks, while the agricultural system retains its core structural features. In fact, this resilience reflects the history of the agricultural process in many agricultural areas throughout the world. However, severe disturbances, such as continuing drought or tsunamis, may provide the incentive to adopt new states of non-linear structural dynamics, thereby changing the reliable supply of provision services. Such alternate states may be desirable or undesirable for the continued production by sectors.

The factors that enable social systems to respond proactively to environmental change have emerged as a core domain of global change research (Conway and Schipper, 2011; Frank et al., 2011; Larsen et al., 2011; Marshall, 2010). A society's ability to manage resilience resides in the sectors, social networks and institutions (Lebel et al., 2006). Terms such as property regimes, population growth, family ties and social networks, community coping strategies, social learning, governance and institutional factors are all important aspects for the understanding of the resilience of agricultural communities that have the ability to respond to disturbances, including both individuals and collectives (Engle and Lemos, 2010; Fraser and Stringer, 2009; Larsen et al., 2011; Tompkins, 2005). Other aspects of maintaining the resilience of agriculture-based communities include the crop diversity and resilient environment (Fraser and Stringer, 2009; Lin, 2011).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change mentioned that the water and agricultural sectors are likely to be those that are the most sensitive to climate change-induced impacts in Asia (Cruz et al., 2007). Rice is the principle staple crop of Asia, and any deterioration of the rice production systems through climate change would severely impair the food security in this continent (Wassmann et al., 2009). Water availability is the primary factor that determines the success of rice cropping.

Although the production of rice has increased over time in the wake of the Green Revolution, the production of rice in the past few decades has declined in many parts of Asia due to the increasing water stress that arose partly from climate variability and change (Cruz et al., 2007). Therefore, the vulnerability of the rice-dominated agricultural system to water stress has become a key concern in Asia.

In China, rice is the largest cereal crop; it accounts for 25% of the cultivated land and is primarily grown in the southeast and is secondarily grown in the northeast. The combined impacts of climate change and socio-economic development have caused decreases in the future Chinese irrigation areas, especially in irrigated fields (Xiong et al. 2009). The North China Plain (NCP), which is a major agricultural production area in China, is one area that has suffered; its mean precipitation is 500-600 mm/yr, and the crop actual evapotranspiration is 800-900 mm/yr. The NCP includes three main river basins, which are the basins of the Yellow River, the Hai River and the Huai River. For many years, a shortage of water resources in the NCP has been a key concern of the sustainable crop production (Liu et al., 2008; Liu and Xia, 2004; Tao and Zhang, 2010). Rice cultivation in the NCP will be highly sensitive to the future climate change if no adaptation measures are implemented (Xiong et al., 2009). Extensive studies have used crop models and several climate change scenarios to simulate the impacts of climate change on rice production in Asia (Asada and Matsumoto, 2009; Masutomi et al., 2009; Matthews and Wassmann, 2003) and specifically in China (Chavas et al., 2009; Tao et al., 2008; Xiong et al., 2009). However, there have been limited local studies regarding the stakeholders’ responses to climate change and socio-economic development on rice production in the NCP or in other areas in China.

This study used the concept of resilience as a framework to understand the dynamics of the traditional rice-dominated agricultural areas in the NCP on the county, village and farm scales and the methods used by the involved stakeholders to cope with and adapt to the constantly dynamic and changing environment. In this context, in the agriculture-based communities, the resilience performance refers to the area and types of the dominant planted crops in terms of their food provision function. This study aimed to sustain the agriculture and enhance adaptive capacity and resilience in the context of climate change; the specific focus was on precipitation variability. First, we detailed the historical trajectories of the crop planting areas and precipitation variability using a comparative study on the county scale, and we posed research questions from the resilience perspective. Next, we assessed whether the current state was a desirable or undesirable state; this assessment involved the opinions of the stakeholders and the local communities’ resilience within the agricultural system to the precipitation variability and to any disturbances induced both on the village and farm scales. Finally, methods for enhancing the resilience of the local communities and their associated farmers to precipitation variability and for promoting sustainable agriculture are suggested.

4.2 The case study

4.2.1 Study area

The Hai River basin, northeast of the NCP, is one of the most developed regions in China and flows through Beijing (the Chinese capital), Tianjin (China's third largest city), and the primary Heibei province into the Bohai Gulf of the Yellow sea. This basin has the lowest annual precipitation in the Chinese east costal region and contains the lowest per capita water availability among all of the Chinese basins. Recently, due primarily to the rising water demand and competition for non-agricultural uses in the Hai River basin, the flow decreased greatly (Liu and Xia, 2004).

This study was conducted in a traditional rice-dominated agricultural area comprising two administrative counties of Tianjin, Ninghe and Baodi, which are located on a low-lying alluvial plain along the mouth of the Hai River (39°18'N-39°50'N, 117°08'E-117°56'E) (Fig. 4-1). The terrain is generally flat and swampy near the coast, and it covers an area of 1,414 km^2 in Ninghe and 1,509 km^2 in Baodi. This area has a semi-arid monsoon climate and an average precipitation of approximately 530 mm/yr. The precipitation is highly irregular between seasons and from year to year, and approximately 3/5 of the precipitation occurs in July and August. The city of Tianjin has an available per capita volume of water resources that is equal to only 1/15 of the national average and 1/50 of the world average (Song et al., 2011). The major land use in this area is agricultural, and the arable land accounts for more than 55.6% of the area. Annual cropping is predominant in the study area, and the multiple cropping of vegetables is common. Irrigated paddy rice, corn and cotton are the primary crops; specifically, a local traditional brand of rice named "Xiaozhan" is common. Given its chewy texture and nutty flavour, "Xiaozhan" has been regarded to be a geographical indicator in China. Historically and for a considerable length of time, wetland and paddy fields were widespread in study area. However, because of severe water shortages, the area encompassed by wetland and paddy fields has decreased over the past two decades (Li et al., 2007). In 2009, the paddy fields in these two counties accounted for approximately 12% of the whole area of paddy fields in the Hai River basin and 83% of all paddy fields in the Beijing-Tianjin capital region.

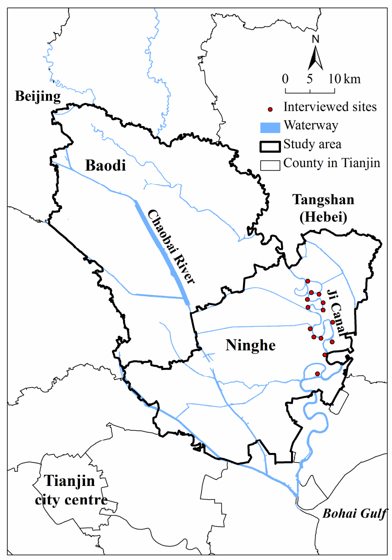
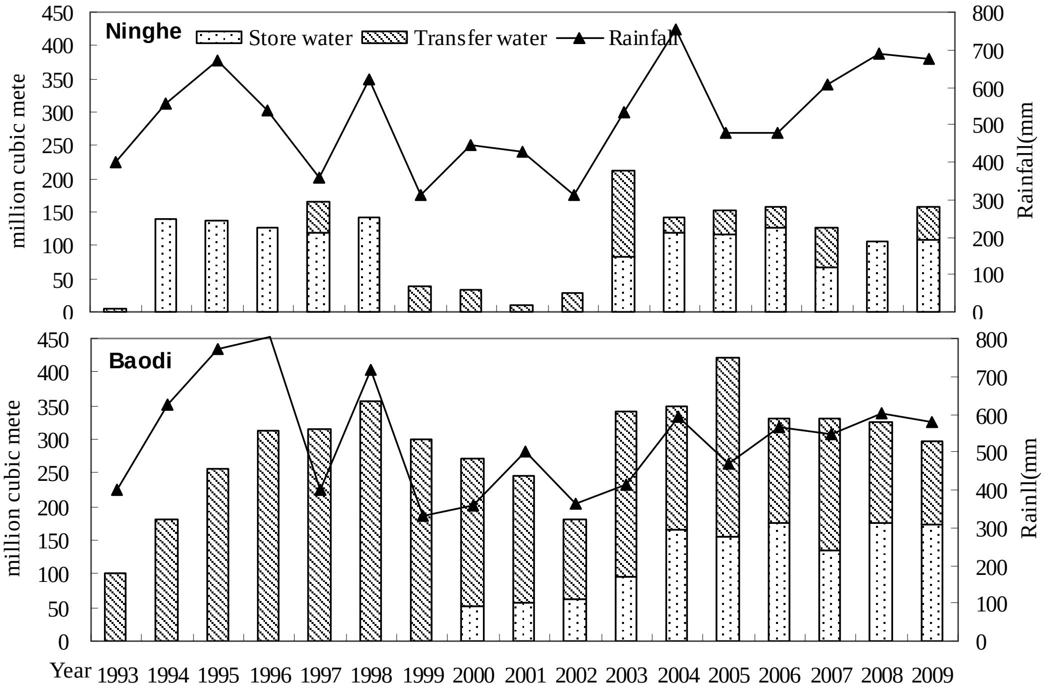


Figure 4-1 Study area

There are two main rivers in study area, the Ji Canal and the Chaobai River (Fig. 4-1). In the rainy season, the local farmers till, fertilise and irrigate their land by utilising rainfall. In the winter and spring, they bring water to their fields from the rivers, which are used for the collection and storage of the surface runoff during the rainy season; when the irrigation water is insufficient, they transfer water from other rivers. Based on the amount and composition of the available surface water resources, although two counties are geographically adjacent, Baodi County has more runoff water than Ninghe because Baodi County is located upstream, near the mouth of the Chaobai River. The agriculture in Baodi County is not as vulnerable to water stress as that in Ninghe. After Baodi County uses the water that they need from the rivers, they may release the dam so that the water may be used in Ninghe County. The water stored in the rivers is the primary water source in Ninghe after the rainy season. Thus, the water is more limited in Ninghe than in Baodi because of the geographical locations; as a result, the irrigation for agriculture relies heavily on precipitation (Fig. 4-2).



Note: the available surface water includes runoff water from upstream, local precipitation that was stored in the river and the water transferred from other rivers.

Figure 4-2 Composition of the annual available surface water resources and precipitation in the study area (1993-2009)

4.2.2 Statistic analysis and data collection

To understand the historical trajectories of the agricultural system and their responses to precipitation variability, it is assumed that the rice planting area (acreage) in the current year measures the farmers' cropping intentions and responses to their perspective perception, which is biased on the precipitation in the previous year. It is also reasonable to expect that when they suffer from the damage caused by extremely low precipitation, the famers may convert their paddy fields to crop fields. In the study area, several alternative crops were utilised by farmers to resist water stress, including cotton, maize and chilli pepper. Because cotton is the most common crop, occupying 45.6% of the total agricultural land in 2009, this study considered cotton planting to be the alternate state of the agricultural system, which shifted from a food- to a fibre-dominated provision. The planting areas of rice and cotton were analysed and related to a historical series of annual accumulated precipitation from 1990 to 2009 in both counties, as well as their associated differential responses.

The annual precipitation and acreage data were obtained from statistical yearbooks in the study area (Tianjin Municipal Bureau of Statistics, 1991-2010). Precipitation trend analysis was made using linear regression. The correlation between the system's response and variable precipitation was examined on the county scale by comparing the acreage of water-intensive rice or drought-tolerant cotton with the long-term variability in annual precipitation over the last two decades. To facilitate the observation, the study period was also separated into two time series (until drought and after drought) for the correlation analysis; the former series encompassed the years 1990-2001, and the latter series ranged from 2002-2009.

4.2.3 Responses to past year-to-year precipitation variability at county scale

It was determined that these two counties experienced the same annual precipitation patterns during the study period (Ninghe County: mean±S.E.=527.125±129.369; Baodi County: mean±S.E.=533.910±134.917); both counties encountered series of continuing drought from 1992-1993 and from 1999-2002 (Fig. 4-3). The second drought, with the duration of four years and was observed across much of the Northern Hemisphere's mid-latitude regions from 1998 to 2002 (Zeng et al., 2005), dramatically decreased the acreage of rice; the rice crops were maintained in a decreased area in both of the counties during that period. Increasing precipitation has been observed in both two counties since 2002 (Ninghe County: linear regression, y=34.2x-68106.0, R^2=0.341, p>0.05; Baodi County: linear regression, y=28.7x-57068.5, R^2=0.611, p<0.05), the precipitation levels were back to normal or above normal.

In Ninghe, rice cropping was the most popular agricultural practice and accounted for 33.4% of the agricultural area in 1990; this area declined by 67.8% in 2009. The area that was cropped with rice decreased dramatically, and this decrease was accompanied by the considerable increase in the area cropped with cotton during the period from 1990-2009. By 2009, rice cropping was carried out only in 10.3% of the agricultural area, while cotton cropping increased by 198.8% from 1990 to 2009. The agricultural practice in the study area transformed from a rice-dominated system to a cotton-dominated system.

The link between the precipitation variability and cropping over time in Ninghe is shown in Fig. 4-3. The acreage of rice production was significantly negatively correlated with the acreage of cotton during the last two decades (r=-0.894 at the P=0.01 level) (Table 1). No significant relationship was found between the acreage of rice production and precipitation with one-year lag over the whole study period (r=0.268). However, the lagged correlation was significant when the data after 2002 were removed (r=0.635 at the P=0.05 level).

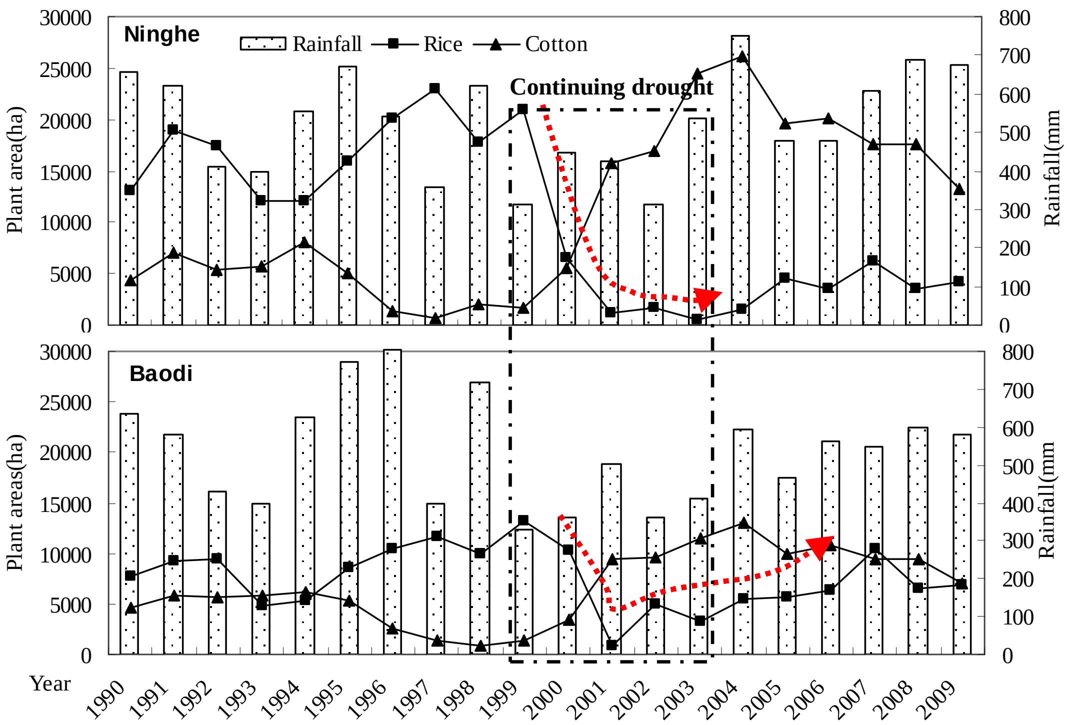
In Baodi County, the paddy fields declined by 9.9% during the study period, and the cotton fields increased by 52.2%. Similar to Ninghe County, the acreage of rice production was also significantly negatively correlated with the acreage of cotton during the last two decades (r=-0.730 at the P=0.01 level). A significant positive relationship was found between the acreage of rice production and precipitation with one-year lag over the whole study period (r=0.638 at the P=0.01 level) (Fig. 4-3 and Table 4-1).

The significant correlation between the rice and cotton cropping areas showed that the local people responded to the precipitation fluctuation by adjusting the planting area and switching crops. The different results of the correlation analyses of rice cropping and precipitation during different periods showed that precipitation is not currently perceived to be a limiting factor for rice cropping in Ninghe County, even when the precipitation levels were greater than normal. Although the rice cropping in Baodi County also experienced dramatic decreases during the continuous period of low precipitation from 1999-2002, its cropping state was recovered and its resilience was maintained after the extreme event occurred. The supplementary evidence from Baodi County helped us to exclude the possibility of any larger-scale external disturbances, such as consumption pattern or wider economic changes, exist in these two counties. We hypothesise that some internal disturbances may have occurred Ninghe County, and these disturbances may have caused the failure to recover to the previous state of rice cropping and loss of resilience. Therefore, two questions were asked. First, why did Ninghe County fail to recover to the previous planting state even when the precipitation became sufficient? Second, did this agricultural system lose its resilience? The aim of the next section was to answer these questions by examining the farmers' responses to the variable year-to-year precipitation on the village community scale and the farm scale in Ninghe County.

Table 4-1 Correlation coefficients between the paddy field areas and the annual precipitation (r1) or the cotton field areas (r2) in Ninghe and Baodi Counties

		Ninghe	Baodi
r_1	1990-2009 (N=20)	0.268	0.638**
	1990-2001(N=12)	0.635*	
	2002-2009 (N= 8)	0.572	
r_2	1990-2009 (N=20)	-0.894**	-0.730**

**,* Significant at the 0.01 and 0.05 level, respectively (2-tailed)



Note: red square dot arrows indicate the resilience performance

Figure 4-3 Precipitation variability and fluctuations in the cropped area with cotton and rice in Ninghe and Baodi Counties (1990-2009)

4.3 Farmers' coping strategies and adaptation capacity

4.3.1 Interview survey

The semi-structured interviews were performed in 14 village communities located along the Ji Canal of Ninghe County in December 2010 (Fig. 4-1). All of these villages have the same free access to the water in this canal. One village was considered as a community in the study. There are 30 km between the town and mouth of the river where the canal flows into the Bohai Gulf. The surveyed villages were selected according to the distance from the town along the Ji Canal, the main production patterns, and the changes that occurred during the study period. The survey focused on the farm characteristics, reasons for the current cropping state, crop changes, rationale for the lack of maintenance of the previous cropping state and their future willingness to continue cropping. An average of three to four households were randomly selected to be interviewed in each sample village. In total, 53 households were interviewed. Key informant interviews with 14 village leaders were conducted simultaneously to determine the community's contribution to adaptive measures. Additional in-depth interviews were conducted with the local officers of water and agriculture authorities to obtain information regarding the runoff and water consumption for the local agriculture production.

4.3.2 Coping strategies on extreme event

The interviews with the individual farmers and village committee leaders in 14 communities along the Ji Canal confirmed the above estimation of the implications of this variable precipitation for their production in each village. The majority of village committee leaders (12/14) reported that their conversion from paddy field to crop field started in 1998 and was concentrated on 2000 and 2001 due to the loss of harvest caused by the continuing extreme drought that was followed by a high water salinity level.

The extremely low precipitation caused dramatic shortages in surface water and ground water that was used for irrigation in Ninghe County (Fig. 4-2). The lack of freshwater runoff coupled with the intrusion of coastal sea water accelerated an extreme rise in the water salinity level. Without freshwater to rinse out the Ji Canal and its reaches, sea water encroached further up the Ji Canal through the broken sluice gate, which was distorted by the Great Tangshan Earthquake in 1976. Saline water entered as far inland as 100 km in Yutian county, Hebei province, according to the local officer of Water Authority. According to the local authority, the maximum water salinity level in the Ji Canal reached 15 ppm, with an average range from 5 to 8 ppm during 1998-2003. Although rice is a crop that favours saline soils, it is not tolerant to excess salinity. The high salt content threatened the agricultural water supplies that depend on freshwater from rivers, and it prevented the farmers in some areas from irrigating their crops.

Our interview results indicated that the farmers shifted from rice to cotton because they needed to adapt to less rainfall and the use of salt water. The farmers also mentioned the soil salinity as a reason for their conversion to cotton. In the coastal area near the lower reaches of the Hai River, there is a large area of both saline and saline-alkali soils. Cotton became the major cash crop in the study area; it was quite tolerant of saline soils and consumed less water than rice. The communities switched from a rice-dominated system to a cotton-dominated system to adapt to the extreme drought during that period.

4.3.3 Resilience lose and adaptive capacity in long term

<u>4.3.3.1 The responses of two involved stakeholders</u>

The interviews with the individual farmers and village committee leaders made it quite clear that two stakeholders were involved in this response, the individual farmers and the collective community committees. In rural areas of China, land was defined to be collectively owned, and the institutional units are the rural collective, e.g., villagers' committees, village economic cooperatives or township collective economic entities. In this study area, individual farmers were free to make decisions regarding the cropping pattern (which crop and how much to plant) they preferred to plant in their own crop fields; however, rice cropping was the exception to this practice (McGee, 2008). Only the villager's committee could plan and initiate rice cropping due to the collective irrigation scheme. The rice irrigation system is collectively owned, operated and maintained by the villagers' community and operated on a self-financed basis. The villagers' committee was formally in charge of these decisions through the ditch riders of water distribution when rice cropping. Typically, approximately four ditch riders were employed for one cropping season, and they contributed to the operation activities to ensure the delivery of water from the river to the secondary channels and finally to the paddy fields for the farmers of their village.

4.3.3.2 An undesirable alternate state

An increase in the supply of available irrigation water after 2002 was observed from both the meteorological data and the survey respondents. However, only a slight increase in rice cropping was observed in the study area. When asked about their plan for future agriculture adaptation, 49.1% (26/53) of respondents stated that they would let it remain as it was, 24.5% (13/53) desired to change their crops, and the remaining 5.7% (3/53) mentioned that it depended on the decision made by the village committee.

However, the local farmers have high intensions of shifting to the previous rice cropping state. Of the interviewed farmers, 62.3% (33/53) were willing to plant rice again. The most two common reasons for this contradiction were "self-production for family consumption" (13/33) and "rotation for preventing the pests and diseases and improving the soil" (18/33). However, this decision was made by the village committee leaders. One farmer explained, "*I would like to eat rice produced by myself. Yes, although I would buy it using the money I earn from cropping cotton… en, simply speaking, if I need to take one cup of rice per meal, I can eat two cups in the case that I plant by myself, but I may only eat half cup in the case that I buy from the market.*". And the other stated, "*I want to crop rice for family consumption, then I will be not afraid of the rice price rising.*"

However, most of the respondents considered the higher occurrence of pests and diseases, particularly fusarium and wilt of cotton, to be a major problem. Cotton was the most commonly grown crop when farmers changed from rice cropping. In addition, continuous cropping was practiced by 58.5% of the interviewed farmers (31/53), with an average of 4.5 years.

4.3.3.3 Social institutions and barriers to maintain the system's resilience

The results of interviews with village committee leaders indicate that there are considerable differences between each village community along the Ji Canal with respect to the current climatic situation (Table 4-2).

Within the 14 interviewed villages, two villages (GT and QM) continued cropping rice even during the extreme drought. All of the interviewed households in these two villages mentioned that because of their village's small agricultural land, it could not possibly be profitable to change their limited land per person into a cash crop. Therefore, both the village committee leaders and the village members preferred to crop rice. In 2005, these two villages dug wells as an alternative water resource, and when the surface water was insufficient or at a high salinity level, they mixed the underground water with surface water from the Ji Canal.

Two other interviewed villages (DW and XG) changed their rice cropping during the extreme drought periods, but they recently returned to the previous planting state. In 2007 (XG) or 2008 (DW), they resumed rice planting because of the more recent increased precipitation. The interviewed village members and committee leaders in these two villages all mentioned that they made this switch to improve the soil and enhance soil disease resistance. Another reason, which was mentioned by one farmer in XG, was that the price of rice was rising. Both of the committee leaders of the two villages recently stated that when the canal had sufficient water in the early spring of each year, they collected it and transported the surface water to the local agricultural technical support station to test the salt content. If the salinity level was below the regulation of 1.5 ppm, they decided whether to plant the rice for that year. The committee leader in DW still remembered that the test result in early 2010 was 0.8 ppm.

The remaining ten villages no longer cropped rice due to the extreme drought periods. Of the interviewed farmers in these four villages, 28.9 % (11/38) were not concerned about the change, but they mentioned that the decision was made by the village committee. Overall, 31.6% of the interviewed farmers (12/38) stated, "Our village can not crop rice any more" because the community members and leaders did not maintain their equipment, which now was rusty or was sold as an asset for money; the ditches were also full of weeds or occupied as the commons by surrounding farmers for the enlargement of their own land. As a result, the irrigation and drainage (I&D) system was disabled. Additionally, 23.7% (9/38) also complained that the village committee leaders did not want to concern themselves with or spend time initiating and managing rice cropping. Only 15.8% (6/38) of farmers mentioned the lack of irrigation water for rice cropping (Fig. 4-4). Overall 40% (4/10) of the village committee leaders stated that the committee did not have an adequate budget for rice cropping, and it was difficult to collect the cost for rice cropping from individual households. During the survey, the authors also interviewed three farmers who planted rice individually in three of the ten villages. All of the farmers cropped on the land leased from the villagers' committee, e.g., the land along the canal bank or a pervious fish pond. No crop other than rice can be grown well under the adverse conditions of unstable water levels during the rainy season.

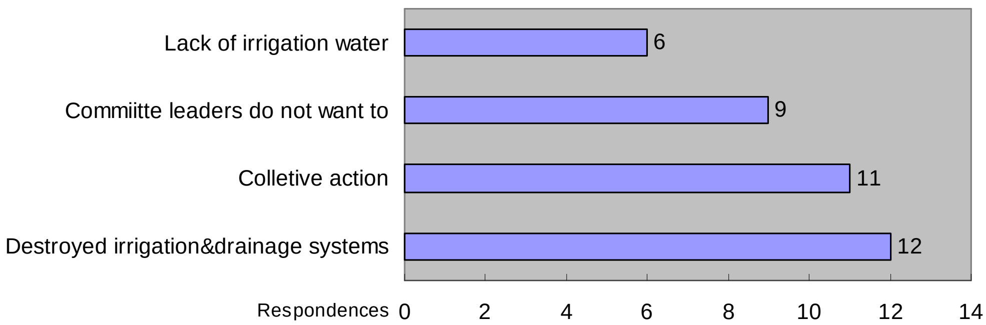


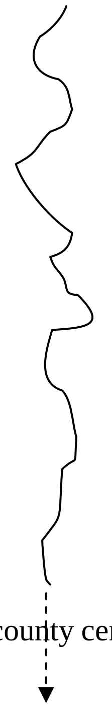
Fig. 4-4 Farmers' responses to the limitation of rice cropping

To determine the actual costs of cropping rice for a community, the costs and sources of payment were asked from the leaders of the four villages that currently crop rice (Table 4-3). On average, the cost of rice cropping paid by the village committee was 2445 CNY/ha; this was primarily used for electricity, labour payments and ditch cleaning; these costs accounted for nearly half of the whole operational cost and was equivalent to 10% of the revenue for the individual farmers if the farmers sold their rough rice at the average price for the autumn of 2009 (2.4 CNY/kg, 9000 kg/ha). This operational cost was paid from different sources among the four villages, but it was mainly derived from the money obtained from the leased fishpond or the lease of agricultural land to farmers. Despite this revenue, the leaders also mentioned that the lack of operational costs still restrains their rice practicing annually. The committee leader of the XG village mentioned "*we planned and succeeded to plant rice in 2007. The committee members collected the operation fee from most of the households (2250CNY/ha). Only three households did not pay but still planted and harvested. This situation let some other villagers felt unfair. When we planned to plant rice again in 2008, we failed to collect the money. So our committee has to find the other source of money if planting.*" The committee leader of the DW village said they do not plan to plant rice in 2011 because they have used up all their savings and need to save money for approximately two years to obtain the future rice operation costs.

All of the four villages that currently crop rice maintain a good irrigation infrastructure, which is now generally managed by a few farmers hired by the community committee. Commonly, due to the poor irrigation infrastructure and the limited budget, a loss of resilience followed. The local farmers are confident that rice is the most effective rotational crop to improve the soil and prevent pests and diseases. However, given the limitations mentioned above, they failed to maintain or return to the previous planting state. The short-term coping strategy may eventually result in long-term maladaptation. As a result, the agricultural systems continued their resilience even when the rainfall was sufficient.

Figure 4-4 The ditches used for irrigation before were filled of weed

Table 4-2 The profile of interviewed villages Unit: ha

	Village	Popu. /person	Total Ag. Land	Agr. land per person	Rice cropping	Reason for rice cropping
Upstream	NMZ	2102	280	0.107	I	fishpond; accumulated water easily
	BYZ	1760	246	0.100	NG	
	TZT	1210	199	0.107	NG	
	ZXZ	620	57	0.047	NG	
	DW	265	59	0.167	C; at intervals[1]	improve the soil and disease resistance
	XG	860	156	0.133	C; at intervals[2]	improve the soil; good price
	TC	454	109	0.200	NG	
	QJDG	299	43	0.133	NG	
	YBZ	1315	152	0.113	I	flooding easily
	GT	938	100	0.047	C; continuously	limited arable land; family consumption
	QM	814	54	0.047	C; continuously	limited arable land; family consumption
	DSW	2033	273	0.093	NG	
	DTZ	2074	169	0.053	I	low-lying plots; flooding easily
county centre	BH	1458	37	0.037	NG	
30 km Sluice gate						
Bohai Gulf						

I: Individually grown; C: Collectively grown; NG: Not grown

[1] in 2009 and 2010; [2] in 2007, 2009, and 2010

Table 4-3 Balance sheet of involved villages for rice cropping Unit:10^3CNY

Village	Area/ha (Person/ha)	Paid		Received	
		Items	Amount	Items	Amount
GT	26.7 (0.028)	electricity& payment of wages	70	leased Agr. land fee(35ha, 4800CNY/ha) leased fishpond fee(2ha)	156 20
QM	40.0 (0.049)	electricity& payment of wages	10	leased Agr. land fee(20ha, 6000CNY/ha) leased fishpond fee(2ha)	120 20
DW	40.0 (0.151)	electricity& payment of wages	90	accumulated profit brought forward leased Agr. land fee(10ha,1500CNY/ha) leased built-up land fee(village enterprise) rice subsidy(40ha, 1095CNY/ha)	10 15 20 45
XG	66.7 (0.078)	electricity& payment of wages ditch cleaning	150 10	leased Agr. land fee(13.3ha) leased fishpond fee(13.3ha) rice subsidy(67ha, 1095CNY/ha)	7 100 73

At the time of the survey, the exchange rate was roughly 1 US $=6.65 CNY.

4.4 Results and discussion

By focusing on the specific climate stress and comparing the communities on both the county and village scales, this study presents interesting and valuable evidence regarding the short-term adaptation and long-term resilience of the agricultural communities. The responses to recent historical precipitation variability and change in the case study demonstrated that local people were adjusting to both a year-to-year variability and extreme events through their collective and individual actions in a short-term fashion by adjusting the planting area and switching crops. The annual precipitation behaviour and water flow show that there was a serious, continuing drought that occurred during 1999-2002; this drought compelled the farmers to convert their paddies to field crops. By comparing two adjacent counties, it was observed that the upstream county had a high resilience of rice cropping, even to severe drought events; this resilience was a benefit of its geographical location. However, because of the limited water flow from the outside in the downstream county, the paddy fields faced high water stress and relied highly on precipitation, and they displayed a low resilience to precipitation variability; the possibility of external disturbances on a larger scale was excluded. By focusing on the county with a low resilience on the village scale, it was determined that farmers who switched to less water-intensive crops, e.g., cotton, appeared to make a more lasting adaptation to water stress; however, in making this change, many farmers are becoming more vulnerable on the long-term scale to a worsening pest and disease management and a low level of self-sufficiency. Most communities had a low resilience of traditional rice production to the current precipitation variability. The shift in land use to adapt to the increased precipitation in recent years was not commonly reversible because of the disabled I&D system and the farmers' unwillingness to maintain the previous state, although most villagers were willing to replant rice. Only a few villages, which maintained their properties well and possessed leaders who had the awareness to practice the traditional crop, had a high resilience and succeeded to recover from the variable precipitation to resume paddy cropping. The initiation and support by local institutions, such as the collective irrigation system and the role of village committees in participating, caused the local farmers to fail to replant rice even they had high intensions and a normal precipitation level.

Adaptations are often place- and context-specific (Adger et al., 2005; Conway, 2005). It has been assumed that traditional and subsistence farmers are the most vulnerable to the impacts of globalisation and climate change (Acosta-Michlik and Espaldon, 2008; Conway, 2005). The community-based rice production in the aforementioned study areas was mostly for the consumption by the farmer’s family or by farmers living in neighbour villages who did not grow rice. Only the cropping by individual farmers was for commercial use. This finding presents the following opposing evidence: given the limited amount of agricultural land per person in the GT and QM villages (0.028 and 0.049 ha/person, respectively), the marginal profit of shifting land use from subsistence rice cropping to the more valuable cash crops cropping, such as cotton, is not much higher due to the higher production inputs. Instead, they consistently crop paddy fields for family consumption to maintain their staple food sufficiency even in the presence of water stress.

The adaptation strategies of farmers to water stress vary with the crops and across different regions and levels of water availability. Common adaptation strategies among rice farmers to handle precipitation variability and water stress include minimal ponding periods for rice fields, growing shorter-season rice varieties, and increasing attendance at regular discussion groups with extension specialists concerning new techniques and best practices (Wei et al.). A key adaptation strategy is to increase water productivity by making more efficient use of the available water supplies. Local farmers have access to a range of irrigation technologies, but the majority of farmers in the study area usually use traditional flood/furrow irrigation systems for winter irrigation, which accounted for 20% of the agricultural water consumption each year according to the local authorities of Ninghe. Only the vegetable farmers applied efficient low-throw sprinkler and drip/trickle irrigation methods. It is critical to conserve water on the farmers’ scale and to make an effort to reduce losses from the distribution systems and improve irrigation technologies. Several case studies found that the improvement of rice technologies that help reduce the losses to drought can play an important role in long-term drought mitigation (Pandey et al., 2007), however, these technologies were not utilised by rice farmers in the study area.

The large fluctuation in annual precipitation has serious effects on the rice production in Tianjin. In the background of the community-managed irrigation scheme, the resilience of the agricultural system to the fluctuation, which was measured in terms of rice production in the study area, was controlled by the community committee and not individual farmers. Governance and institutions are critical determinants of adaptive capacity and resilience (Engle and Lemos, 2010). Institutions include the sets of working rules (Ostrom, 1990). A robust institution tends to enhance the capacity of individuals and communities to use resources in a sustainable way over long periods of time (Becker and Ostrom, 1995). There is growing interest in identifying public policies and institutional arrangements that currently impede the adaptation to environmental conditions; the goal is to remove such impediments to adaptation (Smithers and Smit, 1997). The original purpose of this local irrigation institution was to work together as a unit of village and effectively use water when rice cropping; however, collective action only on the village scale failed when the whole basin faced water scarcity. The village leaders' awareness and efforts to maintain the facility and operate traditional rice planting are a useful institution to enhance the resilience. To address these current water issues, governments and water managers also need to improve the existing managing organisations and institutions to promote more sustainable water use by involving a wider range of stakeholders and by redefining the scale of decision making to the city and basin levels. Although a water shortage may occur rather frequently in the future, these local communities could plant rice at least in turn by managing the water allocation and distribution.

Chapter 5 Conclusions

5.1 Discussions and Suggestions

5.1.1 Strengths of localizing food production and food consumption as a sustainability–building strategy

In Chapter 2, by 2007, the potential for increased food self-sufficiency, except grain cereals, is great. The studies of observed food flow in Tianjin have found that most cereal grains production is for household consumption rather than for sale; the vegetable case study showed that most vegetables production is for outside area of Tianjin rather than for the local. Population in urban core and suburban areas can not be blessed with their surrounding mosaic; large area of city's countryside seems to be isolated system because little local flows were found from either side. For urban-rural sustainability, it is necessary to re-establish a good relationship among the urban, suburban, and rural areas.

Recently, sustainable food and agriculture systems became important considerations in regional planning, using a mix of instruments including expanded local food marketing opportunities. First, a system-oriented approach to the study of food and agriculture, drawing inspiration from ecology, stresses the inter-relatedness of the entire domain, including the concept of the ‘ecological appetite’ of crops and foods, the union of both social and ecological aspects of resource use, the linkages between rural and urban producers and consumers and the inclusion of farmers’ ecological knowledge (Duram and Oberholtzer, 2010); secondly, more concrete economic and social linkages between urban and rural areas can be established through local food systems (Desjardins et al., 2010). For example, in Canada, a system named “a collaborative effort to build more locally based, self-reliant food economies—in which sustainable food production, processing, distribution and consumption are integrated to enhance the economics, environmental, and social health of a particular place” has been defined (Desjardins et al., 2010; Feenstra, 2002). In Europe, a cultural economy approach to rural development now highlights the instrumental and normative deployment of heterogeneous cultural markers, such as regional foods (Cowell and Parkinson, 2003; Ilbery and Maye, 2005).

Although Tianjin may have the capacity to feed the citizens within its borders, it has increasingly distanced resource users from the resource base and disconnected production from consumption through trade. In September 2010, the central government selected Tianjin as one of the first Chinese low carbon model cities. In order to build a low carbon city, government policy has to be more focused on industrial restructuring and developing new energy sources. Transportation contributes to a variety of environmental impacts, e.g. increased use of energy, CO2 emission. Until now, the government offers too little by failing to consider the role of rural-urban interactions. It is unsure whether such food localization movement will occur in China because of limited public awareness or academic concern about these issues in Tianjin and elsewhere in China. Localizing food production may seem a straightforward strategy for increasing sustainability in Tianjin.

It is necessary to facilitate the circulation of flows, active the interactions and flows, and promote the role of local authorities in partnership with other major groups to exchange information, build networks and create markets for small farmers.

While Tianjin actually increased in "calculated self-sufficiency ratio" for a wide range of food products in the period since 1980 to 2000 this has been begun to fall quite sharply in the period between 2000 and 2007. One reason was food for the city has been sourced from regional and national markets, which has been associated more generally in the coastal regions of China with the increase of chemical fertilizers and a growth of Chinese form of agri-business that can deliver cheaper food to urban consumers. At the same time Tianjin is being drawn into these wide regional food markets by exporting its products to these areas rather than the city. This is not a new story in the developed countries but it has important implications to the researchers who favor increases in local food production within urban regions in an attempt to preserve eco-systems and reduce carbon inputs.

Tianjin needs to recognize the high level of productivity of its local ecosystem and reduce its dependence on the capacity of other ecosystems to supply its food needs. A better relationship between urban and rural areas needs to be established. However the proportion of locally sourced food is related to structural difference in supply and consumption of agricultural products especially for vegetables. It may be reasonable for consumers to consume distance distributed food produced by other regions if there is no enough food supply to meet their needs at right time and right price and right quality. Food flow analysis alone, however, is insufficient to determine if production is truly ecologically sustainable. Further study need to consider how much extent of distance sourced products or how much proportion of locally sourced food is reasonable, and then to argue the unreasonable part in Tianjin.

5.1.2 Local production, food security and environmental management in urban fringe areas

There is growing concern about food safety and environmental contamination in the rapidly expanding peri-urban interface in Asia (Huang et al., 2006; Vagneron, 2007). Around the many quite large and fast-growing cities in China, and in particular the mega-cities, the current high levels of agricultural productivity have been achieved through the use of intensive agricultural practices, which are being adopted at an accelerated pace (Sundkvist et al., 2005; Wolf et al., 2003), a trend which is expected to continue in the future. Recent studies agree that intensification of agriculture by means of external inputs of fossil fuels, inorganic fertilizers, pesticides, and imported fodder has had significant and widespread impacts on ecosystem functioning, and much of this impact has been negative (Ericksen, 2008; Sundkvist et al., 2005). Modern intensive agricultural practices can pollute soil and water with agro-chemicals, reduce biodiversity, degrade the environment, increase desertification, cause soil erosion, and, in many cases, result in poorly structured, monotonic agricultural landscapes (Chen *et al.*, 2006; Huang *et al.*, 2006; Prändl-Zika, 2008). Few sectors in society have had such profound impacts on the ecosystem as the food industry (Sundkvist *et al.*, 2001).

In areas where there is a strong demand for food products, mainly for commercial purpose, are based on market with high-input intensive production, especially vegetable in suburban area. As a result of irrigation with treated wastewater in Tianjin, concentrations of polycyclic aromatic hydrocarbons (PAHs) in vegetables in suburban area were higher than those reported for other areas, and agricultural soils in some areas are also severely contaminated by PAHs (Tao et al., 2004). Consumption of vegetables produced in these areas could lead to health risks, especially for children (Wang et al., 2005).

Agriculture in urban fringe areas is part of the urban ecological system. The consequences of changes in agricultural land use and management have the potential to be both positive and negative (Wu *et al.*, 2009). The transition from paddy rice to rain-fed crops causes significant carbon loss from soils (Nishimura *et al.*, 2008), while at the same time substantially reducing methane emissions (Wu *et al.*, 2009). According to the farmers interviewed, the south canal, which is currently polluted run through Xiqing, is being treated and reclaimed for cultural heritage and tourism, and the traditional vegetable fields and villages along the canal may be converted to other uses. This may reduce health risks, but local famers could lose a reliable source of income from the loss of remaining agricultural land.

Because of the long history of paddy rice culture in the region, paddy fields in suburban area may have high educational value for the local urban population, while paddy fields in rural area may still have the production function, especially for local consumption. Also beyond the local precipitation, the irrigation water for paddy fields in suburban are mainly treated water from the industrial and residential areas in urban centre, whilst, in the rural, the irrigation highly depends on the inflow from the Beijing which is located on the upstream of Tianjin. Therefore, paddy fields may need special protection and consideration in their integration into a comprehensive land use plan and water management in the Beijing Tianjin region.

5.1.3 Adaptive capacity and resilience building for rice cropping

Most Asian megacities are located in rich alluvial deltas that have long served as the “rice-baskets” of their respective regions (McGee, 2008). Recently in China, many paddy fields have been converted into other types of agricultural land to increase revenue; this conversion is the result of the influence of market mechanisms, such as the conversion of paddy fields into aquaculture and mulberry fields for silk production in the Yangtze Delta (Wu et al., 2009) and the transformation to cash crops, fruits and aquaculture in the Pearl River Delta (Li and Yeh, 2004). However, in this study area, water shortages and unreliable rainfall compelled the farmers to shift their paddies to field crops. The conservation of the paddy field is important not only for the preservation of the traditional social culture, but it allows the local farmers to be flexible in their cropping activities and enhances the resilience to environmental change. Any fixed-cropping system will increase its vulnerability.

In order to apply the localization of food production, the priority should be given to the production of rice which is the principal staple food for security. In order to improve rice production in Asian city region, it is important to consider: the climate fluctuation, collective irrigation regime.

This study relays several lessons to other agricultural systems experiencing global environmental change. First, resilience-building must be integrated into the adaptation measures to climate and global environmental change for sustainable agricultural development strategies. Second, the local institution plays a vital role in building resilience. Although farmers continuously adapt to changes, these changes may impact both the current and future situations. The future climate is uncertain. Diminished resilience reduces the adaptive capacity, which is the ability of a social-ecological system to cope with novel situations without foreclosing future development options (Folke et al., 2002). Thus, the resilience and adaptive capacity of agricultural communities and their associated stakeholders must be enhanced to better cope with not only the constraints but the opportunities of the current climate variability; a fundamental shift in thinking is necessary for a community to move away from a short-term view of coping measures and profit gains to a long-term perspective that emphasises sustainable agriculture and vulnerability reduction. It is suggested that new institutional arrangements, including collective irrigation regimes for rice cropping, are necessary to build the social resilience and enhance the adaptive capacity. For rice production in the Asian “rice-basket”, it is important to consider both the climate fluctuation and collective irrigation regime.

During the preparation of our manuscript, the authors experienced the devastating 2011 Tōhoku earthquake and tsunami in Japan, which allowed us to recognise that in the face of uncertain environmental change and disaster in the future, it is important to build the resilience of social-ecological systems to respond proactively. An improved understanding of individual and societal resilience not only provides insights for estimating future adjustment, but it also helps to address the current problems of sustainable development in light of our variable and uncertain environment.

5.1.4 Public food consumption perception to food production and flow

Urban, suburban, and rural linkage need to be re-structuralized, food production in suburban and rural can be fully used for urban dwellers closed by. In this study, there is a lack of empirical information regarding consumer perceptions of local foods, which limits the extent to which alternative systems can be effectively theorized and developed. Although it was not recognized by this study, changing regional consumption pattern of food is the other driver of regional land use change as well as environmental change. Tianjin produces more food than they need for export. Local consumption for grain rations might have little impact on agriculture land use change; while local production for meat and dairy may respond for increasing crop of corn. Expanding food trading with other regions and countries may cause agriculture land use change in Tianjin. Agricultural income is perhaps able to be increased by exporting the products to other regions and countries. Agricultural land in Tianjin is also, perhaps, able to be kept or increase in that case. In another, expanding inflow of cheap and good quality food may let agricultural land in Tianjin decrease instead of food intake by local consumer or industrialization.

Trade in animal products as well as feed is strongly increasing worldwide, partly driven by the variable availability of natural resources. With trade in these products, natural resources and environmental impact are transferred, referred to as virtual trade in water and nutrients (Steinfeld and Wassenaar, 2007). Livestock's land use includes grazing land and cropland dedicated to the production of feed crops and fodder(Steinfeld and Wassenaar, 2007). Feedlot production relies on grain and legume crops to feed livestock (predominantly cattle) (McAlpine et al., 2009). Growing crops to feed animals requires high amounts of external inputs of nutrients, water and energy (Steinfeld and Wassenaar, 2007), and has substantial environmental impacts at the regional and global scales. At the regional scale, feedlots increase demand for agricultural land and hence generate added pressures for conversion of native ecosystems to agriculture. Feedlots are also a significant contributor to elevated greenhouse gases (McAlpine et al., 2009). The agriculture land for growing feedlot needed in Tianjin is nearly as much as the existing cultivated land.

5.2 Conclusion and new findings

This research took Tianjin, China as a case study area, used self-sufficiency and land areas for agriculture, especially for cropping, as two indicators to explore a sustainable city region in terms of localization of food production. Three new findings were got:

(1) Calculated SSR suggested that vegetables in Tianjin city region is high, but the real is still far from "the local production depended" because of seasonality and limited types; on the other side, Calculated SSR of cereals are relative low, however cereals are mostly consumed in production areas;

(2) Many paddy fields have been reported to convert into developed areas and other types of agricultural land use to increase revenue. But, a large decrease in paddy fields in Tianjin was due to a shortage of water;

(3) Large fluctuation in annual precipitation has serious effects on rice production in Tianjin. Local institutions play a vital role in rice production "recovery". Resilience building is important for local agricultural communities to improve the self-sufficiency.

It was suggested that new institutional arrangements including collective irrigation regimes for rice production is necessary in order to establish localization of food production.

In conclusion, the food flow and self-sufficiency analysis indicated that Tianjin needs to recognize the high level of productivity of its local area and reduce its dependence on the capacity of other regions to supply its food needs. A better relationship between urban and rural areas through local food production and consumption needs to be re-established. Water is currently the largest barrier to increasing food production in the city. In order to improve self-sufficiency and establish a localized food flow, it is necessary to enhance the resilience and adaptive capacity of local agricultural communities and associated stakeholders to cope better with not only the constraints but also the opportunities of climate variability and urbanization. From this study, in order to apply the localization of food production, the priority should be given to the production of rice which is the principal staple food for security. To improve rice production in Asian city region, it is important to consider both the climate fluctuation and collective irrigation regime. Urban, suburban, and rural linkage need to be re-structuralized, so that food production in suburban and rural can be fully used for urban dwellers closed by. To apply the results of this study, appropriate spatial boundary/size need to be considered to define the city region.

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