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Comparing vulnerability of coastal communities to land use change: Analytical framework and a case study in China

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ABSTRACT

Coastal regions in China are undergoing rapid land use change, but little attention is paid to the implications of this change to local community. Assessment of vulnerability of coastal community to land use change is an important step for enhancing the understanding and decision-making to reduce such vulnerability. This article presents an analytical framework and associated indicator system to assess and compare vulnerability of communities to land use change in coastal areas, and present a case study in China applying this framework. The study includes quantification of *Exposure Index* (*EI*), *Sensitivity Index* (*SI*) and *Adaptive Capacity Index* (*AI*). *EI* is to measure intensity of land use. *SI* and *AI* are based on some socio-economic attributes of the native residents, as well as their view on environmental change and management. Based on the quantification of *SI* and *AI*, *Vulnerability Index* (*VI*) can be assessed and compared among different communities. This framework was applied in a case study in Maluan Bay, Xiamen, China. The area consists of four administrative, as rural communities in the 1980s, evolving into four distinctive communities with different policies and development modes. Comparison of *EI* and *VI* reveals large disparity among communities. Analysis demonstrated that vulnerability was not evenly distributed across communities, which might be linked to the different stage of transformation the community was undergoing. For the case areas, vulnerability tends to increase with the increase of exposure to land use change, but can peak off once the community start to benefit socio-economically from development. The most vulnerable community is the one where native residents lost their livelihood, but benefited a little from economic development. This may suggest the need for tailor-made policy responses to help them to benefit from development and aid their smooth integration into the city, only in this way can enhance adaptive capacity of coastal communities to use change of land and sea.

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1. Introduction

As densely populated and highly productive regions, coasts are also among the most exploited areas, experiencing various environmental impacts associated with the local, regional and global issues, and are highly vulnerable to threats from both natural processes and socioeconomic activities (Nicholls et al., 2008; Andrade et al., 2010). Many papers about coastal vulnerability focus on climate change related impacts such as sea-level rise, hurricanes, typhoons, and other cyclonic disturbances (Thieler et al., 1999; Kasperson, 2001; Dwarakish et al., 2009; Locantore et al., 2004; Lozoya et al., 2011; Moreno and Becken, 2009; Wood et al., 2010; Chazal et al., 2008; Metzger et al., 2006; Snoussi et al., 2008; Lankao, 2010), but the influence of non-climatic environmental change or socio-economic change is less considered (Berry et al., 2006; Nicholls et al., 2008). One of the possible reasons might be that vulnerability studies are often conducted at the continental or national scale. At smaller scales, local factors along with human activities, such as land use change and pollution (Ceia et al., 2010), might have more profound impacts than global climate change. This understanding has led to an increasing number of studies involve vulnerability assessment at small scales, such as household (Paavola, 2008) and community (Fazey et al., 2010; Nelson et al., 2010; Romon, 2009; Wood et al., 2010; Krishnamurthy et al., 2011). Lahsen et al. (2010) suggested that research should center on understanding the broad range of underlying causes of vulnerabilities, focusing analysis and policy efforts on social and environmental stresses in general, not only on those associated with climate change. Others shared similar views (Metzger et al., 2006; Schröter et al., 2005).

Land use change presents unique challenges to local community, especially for those who depends their livelihood on the land. In China for example, after a rapid economic growth in coastal regions during the past three decades, losses of farmers and poor people were finally considered. A large amount of farmlands were turned into built up area. Recent study shows there is a positive feedback between landscape urbanization and economic growth in China, indicating the existence of a strong driver for land use conversion from agriculture to urban use (Bai et al., 2012). Agriculture environment now faces the threats of pollution. For the farmers, those who live close to cities were deprived of lands, turning into vulnerable groups. Poverty and unemployment in turn drives these communities into excessive exploitation for natural resources, such as overfishing, overcut of woodlands and excess reclamation. Resulting in land use/cover change and ecological damage, these actions would transfer social vulnerability into ecological vulnerability. Therefore, we assert that land use change due to urbanization and industrialization deserve much attention in coastal vulnerability research in China.

Vulnerability, as a concept, was applied to examine the combination of physical, social, economic, and political components that influence the degree to which an individual, community, or system is threatened by a particular event, as well as their ability to mitigate these threats and recover if the event was to occur (Cutter et al., 2003). The purpose of this paper is to develop an analytical framework and an indicator system for comparing vulnerability of coastal communities which are exposed to land use change, using the concepts of exposure, sensitivity and adaptive capacity. The following section explains the analytical framework and methodology. The framework and indicator system is then applied to analyze a case study region in southeast China, which is presented in Section 3. Section 4 presents discussion and concluding remarks. The results will reveal the relationship between vulnerability of coastal communities and exposure.

2. Framework and methodology

2.1. Framework of vulnerability

As a starting point, definition of vulnerability by the Intergovernmental Panel on Climate Change (IPCC, 2001) is the extent to which a natural or social system is susceptible to sustaining damage from climate change, which is a function of the sensitivity of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), adaptive capacity (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of exposure of the system to climate hazards. This function is well accepted and applied in many studies (Chazal et al., 2008; Turner et al., 2003b; De Lange et al., 2009). Other typical definitions on vulnerability include exposure to contingencies and stress, and the difficulty in coping with them (MEA, 2005), a vector represented by a position on a three-dimensional surface: exposure, sensitivity and state (Luers, 2005), or a function relative to cognition of the subject (Acosta-Michlik and Espaldon, 2008). In this paper, vulnerability is defined as the negative effects of environmental change on a system, in proportion to sensitivity of the system, and in contrast to its adaptive capacity.

A framework was built on to assess and compare vulnerability of coastal communities to land use change based on the definition (Fig. 1). It demonstrates the relationship between exposure and vulnerability, and the relationship between sensitivity and adaptive capacity. Exposure is a trigger of vulnerability, instead of one part of vulnerability. Sensitivity and adaptive capacity is the core of vulnerability. It is a little different from the framework of Chazal's research (2008), in which vulnerability of socio-ecological systems to land use changes contained analysis of exposure, sensitivity and adaptive capacity. The objects of assessment here were native communities of coastal areas, exclusive of immigrant workers. The essential difference between them is that the immigrants can easily migrate to other places or go back to their hometown, while the natives do not have such choices. In some papers (Gallopin, 1991; Chazal et al., 2008; Turner et al., 2003a; Tyler et al., 2007; Gallopin, 2006), social–ecological system was regarded as a target of assessment, while ecosystem (Metzger et al., 2005; MEA, 2005) or society (Morrow, 1999) in others.

2.2. Methods to quantify vulnerability

To apply the concept of vulnerability in policy-driven assessments, researchers need to be able to measure it (Luers et al.,

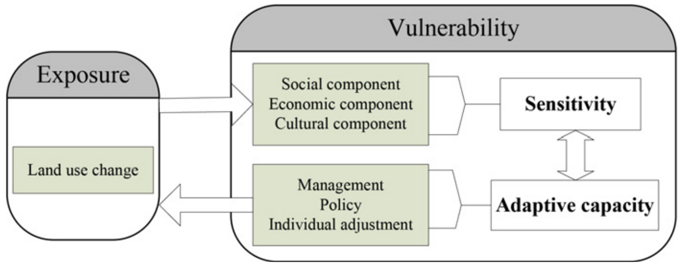

Fig. 1 – Vulnerability framework of coastal communities to land use change. A community is composed of social, economic, and cultural components. Sensitivity in the framework is the impact of land use change on the three components. However, if the community has advantages in management, policies and individual adjustment, its adaptive capacity will play a key role when facing the exposure. The vulnerability consists of sensitivity and adaptive capacity. We focus on the interaction between exposure and vulnerability in this paper.

2003). One possible approach for assessing vulnerability is quantifying an index, which is constructed with several indicators (Andrade et al., 2010; Cutter, 1996; Luers et al., 2003). The most important feature of index is that it can be used to compare vulnerability among different systems. Using county-level census data, Cutter et al. (2003) placed multiple indicators of vulnerability into a principal components analysis, including race, age, gender and income of individuals. The extracted factors were used to derive an overall Social Vulnerability Index score (SoVI) for each county. Boruffa et al. (2005) used the Coastal Vulnerability Index (CVI) to assess physical vulnerability, and borrowed the SoVI outlined in Cutter et al. (2003) to assess social vulnerability, then added the physical and social scores together to determine which counties in the U.S. were most vulnerable to coastal erosion. The socio-economic vulnerability score was generated by aggregating individual-level indicators of vulnerability, which had become a widely adopted method in social vulnerability assessment. The World Food Programme (Haan et al., 2001) used indicators representing some variables to assess vulnerability to food insecurity in Kenya at the district level and the community level, such as life expectancy, adult literacy, access to safe water, non-agricultural income, proximity to markets, and so on. Hahn et al. (2009) constructed a Livelihood Vulnerability Index (LVI) through IPCC's three contributing factors to vulnerability. The LVI was designed to provide development organizations, policy makers, and public health practitioners with a practical tool to understand demographic, social and health factors contributing to climate vulnerability at the district or community level.

It is very general to compare current condition of society with the past (Liu et al., 2008) or the future in a simulative scene (Nicholls, 2004; Schröter et al., 2004). Others compare adaptive capacity and vulnerability in different regions to indicate the most vulnerable one (Romon, 2009; Vanessa et al., 2010). However, it is difficult to make a thorough investigation of historic states or changing process in some areas because the records were missing. Therefore, we need an efficient method and current data to reflect spatial variation of vulnerability.

Index construction based on scale is crucial in increasing user confidence in metric designed to represent the extremely complex phenomenon of social vulnerability. Published studies provided good references for that at the community level (Brooks et al., 2005; Posey, 2009; Schmidtlein et al., 2008). To explore variation of communities' vulnerability, Eq. (1) was constructed based on the framework, in which *Vulnerability Index* (*VI*) is in proportion to *Sensitivity Index* (*SI*), and in contrast to *Adaptive Capacity Index* (*AI*). So indicators of *SI* in this study should indicate negative effects of land use change in communities, while indicators of *AI* correspond to positive effects. Exposure is not included in the equation, but the relationship between exposure and vulnerability will be the core of the study.

$$VI = \frac{SI}{AI} \quad (1)$$

where *VI* is *Vulnerability Index*, *SI* is *Sensitivity Index*, and *AI* is *Adaptive Capacity Index*. In the following sections we present in detail how to construct *SI* and *AI*.

2.3. *Assessing exposure based on land use change*

Land use (the purpose for and manner in which biophysical attributes of the earth's surface and immediate subsurface are manipulated) as distinct from land cover (the biophysical state of the earth's surface and immediate subsurface) change (Turner et al., 1995) represents a wide range of conversions including to and from forest, grassland, cultivated or urban land. Other important aspects of land use change include habitat fragmentation (Fahrig, 2003), and management differences within the same land use (Chazal and Rounsevell, 2009). The scales and spatial patterns of human land use were demonstrated as ecosystem disturbances (Petrosillo et al., 2010). Since land use change was defined as the exposure of communities in this study, we constructed *Exposure Index* (*EI*) based on land use intensity, which reflects the degree of human impact on natural land, containing information on patterns and their proportions of land use (Liu, 1996).

$$EI = 100 \times \sum_{i=1}^{n} i \times C_i \quad (2)$$

where *EI* is the *Exposure Index*, *i* is the rank of land use; C_i is the area percentage of land use of rank *i*. *EI* can be calculated according to Eq. (2) and Table 1. We make $n = 4$ in Table 1.

Table 1 – Correspondence between types and ranks of land use.

Type of land use	Rank (i)	Example
Limited used	1	Forest, sea
Low-impact used	2	Agricultural land
Middle-impact used	3	Land for living and tourism
High-impact used	4	Land for industry and transport

Based on Liu (1996).

2.4. *Method to quantify sensitivity and adaptive capacity*

Following the framework, assessing and comparing vulnerability of coastal communities to land use change is based on the quantification of sensitivity and adaptive capacity. There are various indicators to define and measure sensitivity and adaptive capacity, each with different focus and thus varying results. Social sensitivity analysis as a focus largely encompasses of those related to security, job opportunities, and adequacy of freshwater and food. And adaptive capacity typically involves the features of management, deposits, education, skills, and pattern of social relation. According to the report of IPCC (2001), factors that determine adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital. In Advanced Terrestrial Ecosystem Analysis and Modeling (ATEAM) (Schröter et al., 2004), a generic index of macro-scale adaptive capacity was developed, which was based on a conceptual framework of socio-economic indicators, determinants and components of adaptive capacity, such as GDP per capita, female activity rate, income inequality, number of patents, and age dependency ratio (Schröter et al., 2003). In our study, adaptive capacity of community is defined as the ability of the natives to adapt to a changing environment caused by land use change, which depends on factors such as the skill to find a job, property of household, management of community, and so on.

Land use change is a spatial manifestation of human activities, associated with regional planning, land management and economic development. High intensity of land use may present a potential threat to local ecosystem or community. Land use change may impact on geomorphology and water surface, lead to water quality deterioration, threaten the delicate balance of ecosystems and reduce ecosystem services supply (Xue et al., 2004), all of which can influence the well-being of coastal residents (MEA, 2005; Schröter et al., 2005). The native residents of coasts might lose their farmlands, wetlands, and opportunities to fish, and suffer contamination when the ecosystem services are damaged, all of which are considered as important aspects of sensitivity to land use change in coastal regions. Sensitivity of a community was reflected in the following 5 aspects: (1) the extent of natives' discontent with contaminated living environment. Along with the progress of land use change, natural vegetations around villages were destroyed, but population and industry increased a lot, making sewage and garbage beyond the purification capacity of ecosystem. So the natives would be dissatisfied and suffer psychological and economic losses. (2) The percentage of occupied farmlands with the expansion of industrial and residential areas. (3) The percentage of lack of fresh water resource by the reason of flow reduction and pollution. While flow reduction is the result of occupation of catchment areas and river ways by waterproof buildings, and pollution is the result of excessive industrial waste. Since aquiculture and agriculture both depended on fresh water, farmers have been severely affected. (4) The degree of unemployment. It is much serious in farmers because of farmland loss. (5) The rate of loss of traditional culture. In a changing environment, the traditional culture always fades away to exchange for economic opportunity, such as traditional architecture.

Adaptive capacity is the ability of human sectors to handle change, which is determined by various factors such as economic development, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital (Lindner et al., 2010; McCarthy et al., 2001; Turner et al., 2003b). There are two types of human adaptive capacity: autonomous (or spontaneous) adaptation and planned (or societal) adaptation (IPCC, 2001; Posey, 2009). The former occurs at the level of individual, and the latter refers to the intervention of society through policy. Adaptive capacity of a community refers not only to the adaptive capacity of individuals living in a community but also to the capacity of leaders to effect collective action on behalf of the group. Previous studies have started with an assumption that adaptive capacity at the local level is associated with the socio-economic characteristics of local population (Metzger et al., 2005; Posey, 2009). In this article, adaptive capacity reflects potential capacity and implement of natives. Indicators of *AI* include natives' (1) education, (2) housing, (3) income, (4) management, and (5) expectancy and confidence about future. It is important to note that each designated indicator system is inevitably subjective. It presents only one possible result of vulnerability assessment. Therefore, it is more meaningful to use these indicators to compare relative values across communities as well as longitudinal comparison within the same community, rather than trying to make sense of the absolute values of indices. In view of different dimensions and magnitudes of the indicators, a standardization of the initial value is required. For indicators associated with the target index, make

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (i \in [1, m], j \in [1, n]) \tag{3}$$

where y_{ij} is the standardized value of indicator; x_{ij} is the initial value of indicator; i is the serial number of the study area, j is the serial number of the indicator; m is the number of study areas, n is the number of indicators.

After the standardization, *SI* and *AI* can be calculated based on Eq. (4), equal to the geometric mean of its standardized indicators. In this way the information of every indicator is contained by the target index, and each indicator is given the same weight, simple but clear. We choose the geometric mean algorithm because its result is eclectic and smoother than that of arithmetic mean, especially when some indicators of a object are unusually large or small.

$$SI_j \text{ or } AI_j = \left(\prod_{i=1}^{n} y_{ij} \right)^{1/n} \tag{4}$$

3. The case study

3.1. Description of study area

This study is an attempt to extend the research methods of vulnerability in small-scale systems, and provide a reference for development and wetlands protection in coastal cities. Xiamen is a coastal city of Fujian Province in China, with a coastline of nearly 226 km, awarded United Nations Habitat Award in 2004. The area belongs to subtropical marine monsoon climate, warm and rainy in summer. The mean daily temperature is 20.6 °C. The average annual rainfall is 1315 mm. In the process of rapid suburbanization, most of bays in Xiamen were transformed into residential or tourist areas, some of which were planned for the construction of new urban areas. Supporting the demands of urban population drives many types of land use change. It is not determined how the sea-level rise will impact the coastal wetland ecosystems, but the land use change around the city has damaged wetland ecosystems severely (Chen and Chen, 2006; Huang et al., 2010). Coastal area of Maluan Bay in Xiamen is regarded as an example. The area, made up of 12 villages and a state-owned farm, with 40 thousands of natives, and 100 thousands of immigrations, is selected as the case study area.

The Bay is located in the northwest of Xiamen City, lying between 24°32′13″ to 24°35′31″ north latitudes and 117°57′00″ to 118°03′00″ east longitudes (Fig. 2), forming a typical topographical feature of gulf, used to be important wetlands of Xiamen. There were nine streams in Maluan Bay watershed, with a total catchment area of 123.2 km^2. Half a century ago, there were extensive mangrove forests in the tidal zone at the edge of the estuary, with the area of 20 hm^2. Water quality and vegetation of this area was in good condition, which was a refuge of a variety of fish and birds. Hundreds of years, people around Maluan Bay lived on farming, fishing and shipping. There were rich cultural resources around Maluan Bay, such as a large number of Taiwanese traditional houses, ancestral shrines and temples in the villages.

The condition has changed a lot since 1957, when a seawall was constructed. It was used for blocking water exchange inside and outside the Bay, and became a road in 1958. The area suffered from anthropogenic stressors over the past 50 years. With the encouragement of government, a lot of wetlands in the Bay were reclaimed into salt pans. In 1988, the south of the Bay was designated as industrial estate by Xiamen government. In the early 1990s, salt pans and coastal wetlands were transformed into aquaculture ponds. As an urban fringe with a high population, its leading industries are manufactory and aquaculture. In 2003, fishing and aquaculture in the Bay were confined by policy in order to keep water clean. Many fishermen lost their jobs and income.

3.2. Data processing

The basic data of land use change was two remote sensing images respectively acquired in 1987 and 2009. All of the data was applied to construct land use/cover database by visual interpretation, with a total area of 68.5 km^2. Several types of coastal wetlands were found around Maluan Bay through field investigation. According to the physiographic factor and socio-economic characteristics, types of land use were divided into three major categories: water bodies, vegetations and built-up lands. Water bodies were classified as aquaculture pond, mudflat, and bay, and vegetations were classified as forest and farm, while built-up lands as village, industrial estate, road, and construction site. So there were 9 types of land use in total (Fig. 3).

In the early 1990s, the area was divided into three parts in planning scheme based on location along the boundary of villages: the western, the northern (part A) and the southern (part B) area. According to the plan, three parts developed in different modes over past 2 decades. When a new plan was implemented in 2005, the western area was divided into two parts (part C and part D). Thus four parts of Maluan Bay, community A, B, C, and D, represent four different development modes (in Table 2).

Note: R1, R2, R3 or R4 means the type of land use is ranked of 1, 2, 3 or 4 as illustrated in Table 1. Signs of ABCD point out the location of four communities in the map, which were in different development modes as illustrated in Table 2.

According to Eq. (2) and Table 1, *EI* was calculated and shown in Table 3. The range of *EI* is from 100 to 400 because there are 4 ranks of land use. *EI* above 300 means natural ecosystems are severely damaged.

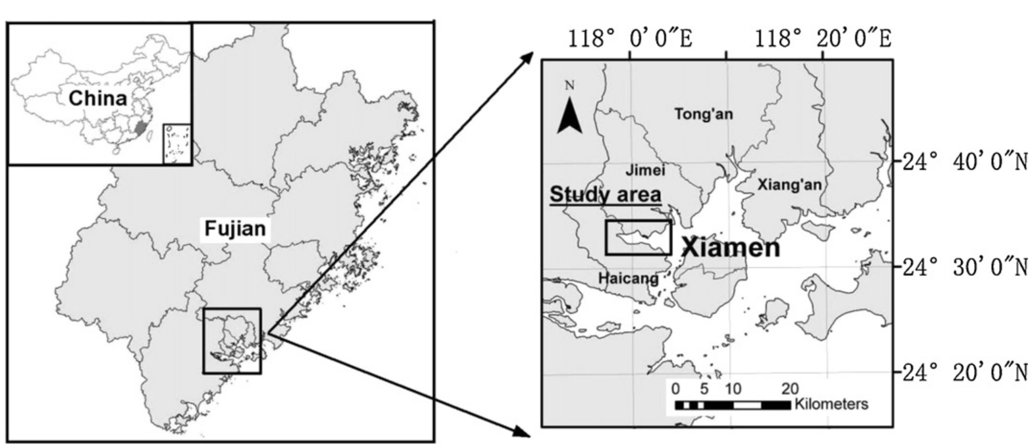

Fig. 2 – Location of the study area.

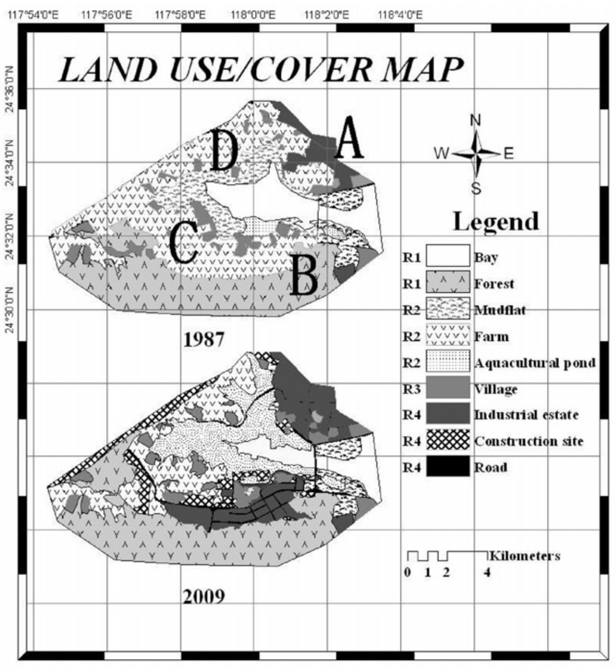

Fig. 3 – Land use/cover map of Maluan Bay in 1987 and 2009. It can be seen industrial estate was located in part A, while other parts were rural spaces in 1987. Land use pattern changed significantly around the bay during 1987–2009. (i) A large number of farmlands were transformed into industrial lands in part A and B; (ii) most of the mudflats were reclaimed to aquacultural ponds around the bay; (iii) there were some construction sites in part C in 2009.

As illustrated in Table 3, the values of *EI* in four communities were similar in 1987, because they were at the same level in economic development at that time. Most of natives lived on agriculture and fishing, with low but stable income. So we believed that four communities evolved from the same starting point. From 1987 to 2009, *EI* of four communities increased differently because urban areas sprawled from one community to another. Xiamen city was in the island to the east of this area. The east part, community A and B, was influenced by urban expansion of Xiamen city firstly. Government and enterprises found the location advantages in community A and B in the 1990s, so the government established a new town in community A for commerce and habitat, and an industrial estate in community B for industry development. Government also purchased lands from villages and provide to enterprises at a low price at the early 1990s. Besides, preferential taxes policies were provided for industry investment, in order to help community A and B to attract industrial investments. Community C and D were ignored because they are far away from the downtown of Xiamen city. Ten years later, commercial and residential areas occupied a high proportion in community A; manufactory became the leading industry in community B. At the same time, farming and aquaculture were the leading industry and widely promoted in community C and D. After rapid development in more than 15 years, land became shortage in existing industrial estate. In 2007, community C was designated as a new industrial estate by government because of its good location, transportation and terrain for industry. And the infrastructures need much improved. That is why there are so many construction sites there in 2009. As shown in Table 3, the sequence of *EI* in four communities in 2009 is A > B > C > D.

Table 3 – Value of *Exposure Index* in four communities.

	A	B	C	D
EI_{1987}	220	198	191	199
EI_{2009}	348	302	275	270

In order to know how the natives are affected, we attempted to gather some information through investigation. Semi-guided interviews and social surveys were conducted in this area in December 2009. Before the investigation, investigators were specifically trained on communication skills to ensure reliability of the results. Profiles of four communities are illustrated in Table 4. Fifty or sixty native people were investigated in each community. The sampling rate was between 0.6% and 1%. The answers only depended on their view on reality.

3.3. *Analysis of sensitivity and adaptive capacity*

Social survey gathered information about natives' socio-economic attributes. The social attributes are, among others, resident's age, education, household size, location of residence. Meanwhile, resident's economic attributes are income level, jobs, farm size, and type of land ownership. Their personal views on the change of living condition and environment management of government were also gathered. This information was used to build indicator system to analyze sensitivity and adaptive capacity to land use change. The survey break from limitations of using statistical data, and

Table 2 – Essential information of four communities.

Community	Name of villages in the community	Leading industry	Main income of natives	Population	
				Native	Immigration
A	Maluan, Xibin	Manufactory and commerce	House rent and commerce	6600	30,000
B	Xinan, Xiayang, Xianglu	Manufactory and aquaculture	House rent and aquaculture	10,000	60,000
C	Yunwei, Dingmei, Houke	Agriculture	Land compensation	5000	10,000
D	Chenjin, Zhendai, Dongyao, Pulin	Agriculture	Farming	11,000	Very few

Note: The population of each community was estimated from the data of 2003.

Table 4 – The profiles of the investigated residents.

Profiles	Frequency (%)
Gender	Male: 133 (59.11%); female: 92 (40.89%)
Age	≤24: 14 (6.28%); 25–30: 46 (20.63%); 31–40: 64 (28.7%); 41–50: 46 (20.63%); 51–59: 28 (12.56%); ≥60: 25 (11.21%)
Education level	Primary school: 84 (37.5%); junior school: 78 (34.82%); senior school: 52 (23.21%); college and above degree: 10 (4.46%)
Family size	1: 9 (4%); 2–3: 74 (32.89%); 4–6: 110 (48.89%); more than 7: 22 (9.78%)

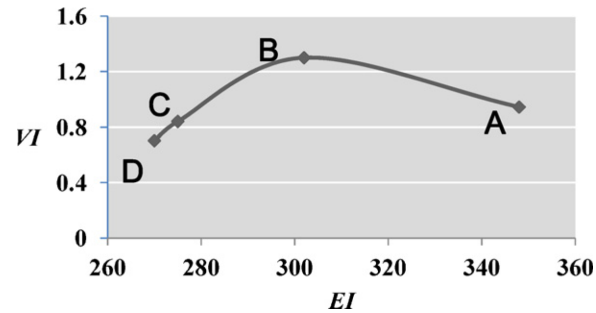

Fig. 4 – Correlation of *Vulnerability Index (VI)* and *Exposure Index (EI)*. Community B is more vulnerable than A, C and D.

the data truly reflected perceptions and responses of natives to land use change. Some results are shown in Table 5.

According to Eq. (3), indicators in Table 5 were standardized to get rid of dimension. Then the *SI* and *AI* of all communities were calculated respectively. *SI* and *AI* were respectively equal to the geometric mean of their indicators based on Eq. (4). Community B got the highest value of *SI* while A got the highest value of *AI*. The sequence of sensitivity was B > A > C > D, and the sequence of adaptive capacity was A > B > C > D.

3.4. *Comparing of Vulnerability Index in four communities*

VI was calculated based on the results of *SI* and *AI* (Eq. (1)). The values of *VI* and *EI* in four communities are presented in Fig. 4.

The result demonstrates that vulnerability of communities tends to increase with the increase of *Exposure Index*, although this correlation does not follow a linear trend. The curve of *VI*–*EI* is an inverted-U shape. Community B is the most vulnerable one in four communities. Explanations for the curve are: (1) community D follows relatively slow process of socio-economic change, and traditional villages still maintain stability. (2) Land use is changed rapidly in community B and C, leading to rapid socio-economic transformation. The traditional agricultural system is collapsing, but emerging system on industry and commerce is not established completely. The natives lose their lands and jobs, lack of skills to find jobs in factories, which makes them more vulnerable. In other words, the natives in these communities lost too much and gain too little from development. (3) In community A, urban residential and commercial lands are well established and dominant in this area. Economic development and land use type are both relatively stable. Natives have much time to adjust to the new environment and many chances to find jobs in service sector than in other areas, which then translated into a stronger adaptive capacity.

Obviously four communities presented change of gradient from rural space to urban space. From a temporal perspective, all communities around Maluan Bay will transform into urban spaces in different time frame because of the urban expansion. As shown in Fig. 5, all of the communities were rural areas in the 1950s. Community A, B, and C underwent the transformation process respectively in the 1980s, 1990s, and 2000s. Different communities share the same process, which included three stages: land acquisition for construction, industrial estate development, and improvement of urban communities. The process started in community A in the 1980s, and later in other communities. Spatial gradient of vulnerability in four communities in the 2000s can be considered as representing temporal gradient of one community in four stages. Therefore, the results of vulnerability analysis over space helped us to know how vulnerability of a community changed in the land use change process. Rural community will be vulnerability within the land use change process. However, with resilience in difficult

Table 5 – Indices quantification of sensitivity and adaptive capacity.

Indicator	A	B	C	D
People considering environmental degradation (%)	20	41	26	32
People without stable jobs (%)	36	45	47	57
Households losing their agricultural lands (%)	98	88	52	11
Households lack of secure water (%)	46	85	58	27
Households losing traditional houses (%)	90	55	22	17
SI	0.266	0.322	0.206	0.133
People with high school education or above (%)	25	45	33	11
People with living space more than 20 m^2 (%)	72	62	86	97
People with higher income (>125 $ per month)(%)	74	47	29	34
People satisfied with environment management (%)	44	35	35	27
People optimistic about the future (%)	58	39	58	48
AI	0.282	0.248	0.245	0.190

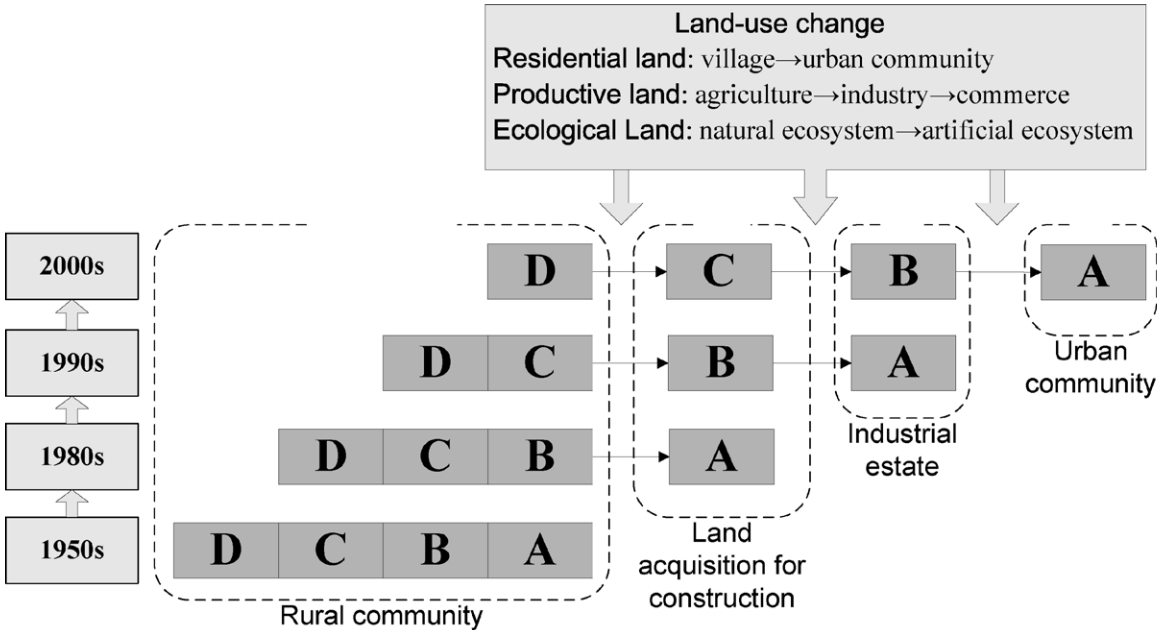

Fig. 5 – Transformation of four communities over past 6 decades.

situations, it will be adaptive and less vulnerable after its turning into urban community.

4. Discussion and conclusions

China is witnessing the largest rapid urbanization in human history with about 12 million farmers move to cities each year (Normile, 2008). However, urbanization has negative impacts, particularly as a cause of environmental pollution derived by intensive energy consumption and material flows, and leading to dramatic changes in land use, loss of biodiversity, habitat fragmentation and a decline in ecosystem services (Zhao et al., 2008). This case study articulated the effects of land use change on coastal communities during rapid urbanization, and offered a vulnerability analysis framework for sustainability. As Hinkel (2011) pointed out, the one-size-fits-all vulnerability label is not sufficient, but the measurement of vulnerability can be appropriate and useful to identify vulnerable people, region or sectors at local scales under strict conditions. Most existing studies on vulnerability assessment either compare time series change within the same region or community (Liu et al., 2008; Nicholls, 2004; Schröter et al., 2004), or across different region or community in one time section (Romon, 2009; Vanessa et al., 2010). It is often difficult to have access to accurate data on socio-economic attributes in the past. Our comparison of vulnerability in different communities that are undergoing similar transformation process but with a clear time lag may shed some lights to temporal trend of vulnerability within a single community that follows similar transformation trajectory. Further studies in different places are required before any general conclusions can be made.

Generally, the curve of *VI–EI* is an inverted-U shape, which means *VI* will raise at first and drop later with the growth of *EI*. It is uncertain if there are other stages in coastal communities' development. Besides, we cannot conclude every community would develop through the path from rural stage to urban stage. In this case, the land use intensity of community D did not change significantly during 1987–2009, the *EI* and *VI* of this community was the least. If the land use will not evolve from agriculture to industrial and finally to urbanization in this community, the *VI* might decrease, considering the *AI* will improve with the development of Xiamen City while the *SI* will remain stable. Furthermore the four stages are definitely typical ones for coastal communities in China, because they represent four types of driving forces for land use change, which are agricultural, governmental, industrial, and commercial forces. Agricultural force is the weakest one with the limit of productivity. Governmental and industrial forces always get entangled and are the most powerful forces to change the land use intensity. It is a weak pressure on land use intensity that land use type changes from industrial use to commercial use or residential use. These findings suggest that the more powerful driving force, the more pressure on land use intensity and the more the impact on native residents. However, if the community owns a strong adaptive capacity, their vulnerability can be trailed off.

Our results have important policy implications, both for China and other developing countries that are undergoing rapid urbanization. Under the rapid urbanization process, peri-urban local communities lost their land and often livelihood, which makes them particularly vulnerable group. Less educated and job-trained, they are often left behind in the new cash economy. However, hidden behind the prosperity of cities, vulnerability of these communities does not receive enough policy attention they deserve. Our result suggests that policy intervention at earlier stage of landuse change is essential, in particular in terms of assisting simultaneous development of service economy, more public investment into the training and education of local community, and attention to retain the social fabric of local community as a whole might reduce vulnerability of these communities, help them to benefit from the development and aid their smooth integration into the city.

Most existing studies on vulnerability assessment either compare time series change within the same region or community (Liu et al., 2008; Nicholls, 2004; Schröter et al., 2004), or across different region or community in one time section (Romon, 2009; Vanessa et al., 2010). It is often difficult to have access to accurate data on socio-economic attributes in the past. Our comparison of vulnerability in different communities that are undergoing similar transformation process but with a clear time lag may shed some lights to the longitudinal trend of vulnerability within a single community that follows similar transformation trajectory.

It is unclear to what extent the relationship between *Vulnerability Index* and *Exposure Index* obtained here is generalizable. Further studies in different places are required before any general conclusions can be made. Nevertheless, the results have strong policy implications, which suggest the need for tailor-made policy responses to enhance adaptive capacity of local communities that are exposed to rapid land-use change, and ensure the development associated with the landuse change can benefit the local community as well.

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