Journal of Marine Science and Technology

Volume 24 | Issue 6 Article 8

ASSESSING THE VULNERABILITY OF FISHERY VILLAGES INFLUENCED BY CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITY IN THE COASTAL ZONE OF THE TAMSUI RIVER

Sheng-Yuan Teng
Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C

Ming-An Lee
Department of Environmental Biology and Fisheries Science, National TaiwanOcean University, Keelung, Taiwan, R.O.C.Taiwan Group on Earth Observation, Hsin-Chu, Taiwan, R.O.C, malee@ntou.edu.tw

Jhen Hsu
Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Tzu-Ping Lin
Department of Architecture, National Cheng Kung University, Tainan, Taiwan, R.O.C

Yu-Chen Lin
Department of Tourism and Leisure, National Penghu University of Science and Technology, Penghu,Taiwan, R.O.C

See next page for additional authors

Recommended Citation
Teng, Sheng-Yuan; Lee, Ming-An; Hsu, Jhen; Lin, Tzu-Ping; Lin, Yu-Chen; and Chang, Yi (2016) "ASSESSING THE VULNERABILITY OF FISHERY VILLAGES INFLUENCED BY CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITY IN THE COASTAL ZONE OF THE TAMSUI RIVER," *Journal of Marine Science and Technology*: Vol. 24: Iss. 6, Article 8.
DOI: 10.6119/JMST-016-1205-1
Available at: https://jmstt.ntou.edu.tw/journal/vol24/iss6/8

ASSESSING THE VULNERABILITY OF FISHERY VILLAGES INFLUENCED BY CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITY IN THE COASTAL ZONE OF THE TAMSUI RIVER

Acknowledgements

This study was supported by fishery data from the Tamsui and Chuwei Fishermen's Association. This study was part of the Taiwan integrated research program on Climate Change Adaptation Technology (TaiCCAT), and sponsored by a grant from the Ministry of Science and Technology of Taiwan (MOST 103-2621-M-019-001; 105-2621-M-019-003) and the Fishery Agency of the Council of Agriculture, Executive Yuan, R.O.C. (104AS-17.2.1-FA-F1). The sea level data were provided by the TCCIP (Taiwan Climate Change Projection and Information Platform Project http://tccip.ncdr.nat.gov.tw/NCDR/main/index.aspx)

Authors

Sheng-Yuan Teng, Ming-An Lee, Jhen Hsu, Tzu-Ping Lin, Yu-Chen Lin, and Yi Chang

Journal of Marine Science and Technology, Vol. 24, No. 6, pp. 1115-1126 (2016)
DOI: 10.6119/JMST-016-1205-1

ASSESSING THE VULNERABILITY OF FISHERY VILLAGES INFLUENCED BY CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITY IN THE COASTAL ZONE OF THE TAMSUI RIVER

Sheng-Yuan Teng[1], Ming-An Lee[1, 2], Jhen Hsu[1],
Tzu-Ping Lin[3], Yu-Chen Lin[4], and Yi Chang[5]

Key words: Tamsui River, AHP, vulnerability, climate change.

ABSTRACT

Coastal zones located in populated and rapidly developing areas face high risks of natural and anthropogenic disasters. In this study, a framework was developed to determine the indicators of vulnerability to natural and anthropogenic disasters in Chuwei and Tamsui, two northern Taiwanese fishing villages in the coastal zone of the Tamsui River. The analytical hierarchy process (AHP) was used to determine the vulnerability indices of the locations, with experts evaluating the weights assigned to a range of criteria, namely hydrological data (such as sea surface temperature and sea level), stakeholder perceptions, and fishery data. These two villages have a considerably homogenous exposure (0.202) to hydrological conditions. However, Tamsui had a lower vulnerability value (0.317) than Chuwei (0.348), indicating that Tamsui faced fewer effects from natural and anthropogenic change than did Chuwei. In addition, vulnerability was most heavily influenced by the adaptive capacity of these two villages (Tamsui = 0.276; Chuwei = 0.112). This study suggests that both climate change and human factors (e.g., overfishing and pollution) cause decreases in marine resources, thus affecting the livelihoods of stakeholders.

Paper submitted 02/03/16; revised 03/30/16; accepted 12/05/16. Author for correspondence: Ming-An Lee (e-mail: malee@ntou.edu.tw).

[1] *Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.*
[2] *Taiwan Group on Earth Observation, Hsin-Chu, Taiwan, R.O.C.*
[3] *Department of Architecture, National Cheng Kung University, Tainan, Taiwan, R.O.C.*
[4] *Department of Tourism and Leisure, National Penghu University of Science and Technology, Penghu,Taiwan, R.O.C.*
[5] *Department of Hydraulic and Ocean Engineering and Institute of Ocean Technology and Marine Affairs, National Cheng Kung University, Taiwan, R.O.C.*

I. INTRODUCTION

The world's fisheries provide more than 2.6 billion people with at least 20% of their average annual protein intake (Food and Agriculture Organization (FAO), 2007). However, a pattern of change in the last 10-year average catch potential reflects the troubling global climate change trend, especially in the Pacific Ocean, which has experienced a substantial magnitude of change. Cheung et al. (2010) found that the catch potential of the tropical Pacific in 2055 is projected to decrease by up to 42% compared with 2005. Most marine resources in the world are currently fully exploited, overexploited, or depleted, and the global marine catch rate appears to have reached or exceeded its biological limits (Pauly et al., 2002; FAO, 2008). Furthermore, repercussions from climate change are projected for the tropical and high latitudinal regions in the Pacific. Consequently, it is expected that climate-induced changes will strongly affect global fisheries' production and the food supply for marine life. Therefore, climate change is considered a major threat to marine fisheries (Allison et al., 2009; Cheung et al., 2010; Joseph et al., 2013). Climate-related events, such as the increase of sea surface temperatures (SSTs) (Belkin and Lee, 2014) and sea level (Tseng et al., 2010), can profoundly affect marine ecosystems and the people dependent on them. Thus, for resource managers, stakeholders, and scientists alike, it is crucial to consider how fish-dependent societies will be affected by climate change and how they must adapt to its impact.

Research on vulnerability to disasters, global environmental changes, famine, and poverty has long been conducted in several social science disciplines, such as human geography (Cutter, 1996; Adger, 1999, 2000, 2006). However, few studies have examined vulnerability in the context of marine ecosystems (Adger, 2003; Marshall and Marshall, 2007). Although definitions vary, vulnerability is generally considered the degree to which a system is susceptible to and unable to cope with the adverse effects of a chronic or stochastic disturbance (Cutter, 1996; Adger, 2006). Vulnerability to environmental change

Fig. 1. Map of the study sites in the coastal zone of the Tamsui River Estuary. The village of Tamsui is located in Xinbei City and the village of Chuwei is located in Taoyuan City.

varies across spatial and temporal scales, and among people within a society (Bene, 2009).

In the context of fish-dependent societies, understanding the potential impact of climate change and the capacity to adapt to this change requires an analysis of the conditions (economic, environmental, and social) that contribute to their vulnerability. Several research frameworks have been developed to examine the vulnerability of societies to environmental change (Adger and Vincent, 2005; Bene, 2009), which typically measure three key dimensions: exposure, sensitivity, and adaptive capacity (Adger and Vincent, 2005; Allison et al., 2009; Remelyn, 2015). Exposure is the degree to which a system is affected by climactic events, such as coral bleaching or cyclones, and the characteristics of these events, such as their magnitude, frequency, and duration (Cutter, 1996; Adger, 2006). Sensitivity is the state of susceptibility to harm from perturbations or long-term trends (Adger, 2006), which can be influenced by the extent of dependence on natural resources and the technologies used to harvest them. Finally, adaptive capacity is a latent characteristic reflecting people's ability to anticipate and respond to changes and to minimize, cope with, and recover from the consequences of change (Adger and Vincent, 2005; Gallopin, 2006); it specifically refers to the preconditions that enable adaptation to change (Nelson et al., 2007). Thus, the evaluation of vulnerability is based on multiple criteria. Notably, some scholars have integrated the analytical hierarchy process (AHP) into vulnerability to calculate the weights of such criteria (Zahedi, 1986; Kumar and Vaidya, 2006).

The most rapid warming occurs in marine ecosystems, whose salinity regime is considerably affected by freshwater runoff (Belkin, 2009); thus, most river plumes are warmer than coastal seawater. The Tamsui River has an annual mean runoff of 2500 m^3/h, with the largest basin in northern Taiwan (Fig. 1), and it empties into the Taiwan Strait (TS). Because it carries a large quantity of nutrients (Lee et al., 2014), its estuary with high primary production is an ideal feeding ground for marine life. Therefore, the Tamsui River estuary is regarded as one of the most valuable fishing grounds in northern Taiwan (Gong, 2014).

This study applied AHP to examine the marine resources, biodiversity, and perceptions of relevant stakeholders, evaluate the vulnerability of the Taiwanese coastal fishing villages of Tamsui and Chuwei, obtain the most critical index, and determine the adaptation gap.

II. MATERIALS AND METHODS

1. Vulnerability

A combination of natural and social science approaches were used to develop systematic and flexible methods, as well as investigate population adaptation to climate change, in this study. For the first phase, a quantitative strategy involving a questionnaire was used to discover public perceptions about the risk of disasters at the study sites, and for the second phase a consensus-based consultation was conducted (Alshehri et al., 2015). All dimensions and their corresponding criteria were presented to an expert panel to reach a consensus on the bearing of each dimension and criterion on community resilience to disasters at the study sites. Subsequently, the Delphi analysis result of Chang and Lin (2016) was adopted to merge the aforementioned data into six dimensions and 24 criteria. These dimensions included the marine environment (e.g., SST and sea level); fishery resources (e.g., tropical level, biodiversity); marine industries (e.g., cost and net profit); social and human factors (e.g., tourism, employed populations); fishing operations (e.g., fishing effort, size of fishing vessel); and policy management (e.g., closed fishing season, marine protected area) (Fig. 2).

In the final phase, AHP was used to combine qualitative and quantitative attributes (Wedley, 1990) and calculate the relative weight for each dimension and criterion by incorporating the experts' evaluations. Eleven experts were selected from fishery authorities and professors in related fields, including four professors, two fishermen association leaders, and five government managers. An additional multicriteria evaluation was performed with Expert Choice software based on the expert evaluation of AHP (Saaty, 1980, 1996). Qualitative assessments were further converted into quantitative measures using Saaty's 9-point scale, thus linking the framework together. The parameter weights of vulnerability were assigned according to the responses of the experts. Because the consistency ratio in this study did not exceed 0.1, the matrix was accepted as consistent.

For each site, the criteria data were divided into three categories: (1) exposure (Maina et al., 2008), (2) sensitivity, and (3) adaptive capacity (McClanahan et al., 2008, 2009; Islam et al., 2014). A modified equation (Hajkowicz, 2006) was adopted using a multiplicative approach to reflect the low and high indicator and index values to determine the vulnerability (V) of each site:

$$V = (E \times S \times (1 - AC))^{1/3},$$

where E is the exposure, S is the sensitivity, and AC is the adaptive capacity. The weight of each dimension (WD) was also estimated using the following formula:

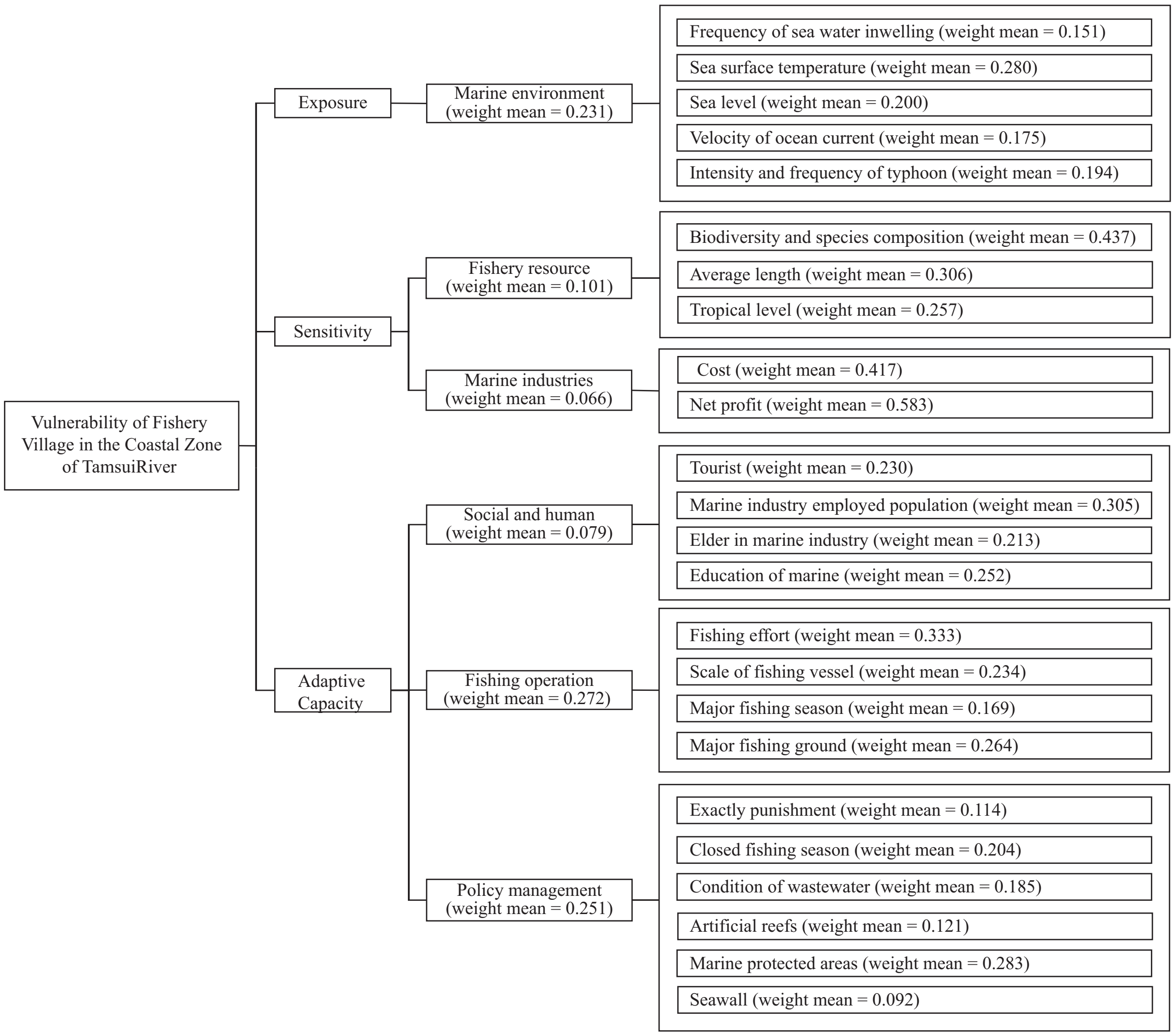

Fig. 2. AHP structure and weights, including three parameters, six dimensions, and 24 criteria to assess vulnerability.

$$WD = \sum_{i=1}^{n} wi * vi \ ,$$

where *wi* is the weight of criteria and *vi* is the value of criteria.

2. Study Sites

Tamsui and Chuwei are the fishery villages nearest to the Tamsui River estuary, with respective populations of 162,221 and 85,565 (Department of Household Registration Affairs, 2015), and they were selected to provide a spectrum of social and environmental conditions (Cinner et al., 2009). Tamsui had approximately 1200 vessels and 2354 fishermen and Chuwei had approximately 430 vessels and 2083 fishermen at the time of the study. Moreover, 72% of the vessels in Tamsui were CT-S type (dynamic or motorized sampan, 12-15 feet long) and 13% were CT-0 type (dynamic or motorized fishing vessels with a gross weight of less than 5 tons and no limit on length). By contrast, CT-R (fishing rafts) and CT-S accounted for nearly 79% of all vessels in Chuwei. Finally, the four major fishing methods in the Tamsui River estuary were pole and line, gill net, long line, and drift-bag net.

3. Hydrological Conditions

Satellite-derived decadal SST data, measured with advanced very high resolution radiometer (AVHRR) sensors from 1985 to 2014 (120°-122°E and 24.52°-26°N), were collected from the National Oceanic and Atmospheric Administration Satellite Active Archive (http://www.class.ngdc.noaa.gov) and the regional AVHRR data library at the National Taiwan Ocean University in Keelung, Taiwan (Lee et al., 2005). The Multichannel Sea Surface Temperature algorithm produced the SST images at a spatial resolution of 1.1 km (McClain et al., 1985).

The daily sea level height data from 1968 to 2013 were provided by the Tamsui Tide Station of the Central Weather Bureau (CWB) (121°25'30"E, 25°10'30"N). These data were subsequently corrected by the Taiwan Climate Change Projection and Information Platform project (http://tccip.ncdr.nat.gov.tw/).

Table 1. Stakeholders' perceptions.

Dimension		Criterion	Tamsui	Chuwei	T-test	Tamsui		T-test	Chuwei		T-test
						Fishermen	Nonfishermen		Fishermen	Nonfishermen	
Hydrological Condition	1-1	Freauency of Extreme Weather	4.02	3.97		4.00	4.18		3.96	4.00	
	1-2	SST Increase	3.11	3.16		2.90	4.06	*	2.70	3.93	*
	1-3	Rising Sea Level	2.89	2.87		2.75	3.82	*	2.67	3.93	*
	1-4	Current Velocity and Direction	4.01	4.08		4.06	3.55		4.39	3.88	
	1-5	Frequency of Seawater Inwelling	2.88	3.55	*	2.90	2.73		3.70	3.73	
	1-6	Impact of Climate Change on Fishery Resource	3.72	3.79		3.59	4.00		3.43	4.07	*
	1-7	Impact of Overfishing on Fishery Resource	3.74	3.79		3.60	4.55	*	3.52	4.20	*
Fishing Operation	2-1	Fishing Ground	3.53	4.03		3.62	3.27		4.43	3.47	*
	2-2	Fishing Depth	3.48	3.71		3.56	3.27		3.87	3.47	
	2-3	Fishing Time	3.37	3.61		3.44	3.00		3.78	3.33	
	2-4	Fishing Type/Method	3.13	3.05		2.91	3.73	*	2.70	3.60	
	2-5	Fishing Risk	3.61	3.68		3.68	3.09		3.91	3.27	*
	2-6	Fishing Vessel Size	3.95	2.89	*	3.99	3.64		3.04	2.67	
	2-7	Difficulty of Sailing	3.58	3.50		3.63	3.18		3.74	3.07	
Enonomic Concern	3-1	Cost	4.35	4.05		4.42	3.82		4.13	3.87	
	3-2	Net Profit	3.97	3.58		4.01	3.64		3.04	2.73	
	3-3	Change in Target Species	2.76	3.45	*	2.75	2.82		2.91	2.87	
	3-4	Catch Length	3.90	3.95		3.93	3.73		3.87	4.07	
	3-5	Catch Influctuation	3.95	3.66		3.91	4.18		3.70	3.60	
	3-6	CPUE Decrease	4.02	4.00		4.05	3.82		4.04	3.93	
Policy Management	4-1	Experience in the Marine Industry	3.97	4.18		3.95	4.09		4.17	4.20	
	4-2	Young Emigration	3.78	4.03		3.74	4.09		4.13	3.87	
	4-3	Hinterland Size	3.51	4.16	*	3.51	3.55		4.22	4.07	
	4-4	Changes to Occupation	3.96	3.08	*	4.00	3.64		3.09	3.07	
	4-5	Transboundary Fishing	3.90	3.11	*	3.91	3.82		2.70	3.27	
	4-6	Closed Fishing Season/Ground	3.87	3.92		3.90	3.64		3.91	3.93	
	4-7	Marine Protected Areas	3.83	3.79		3.84	3.73		3.87	3.93	

Note:
1. "Extreme weather" refers to typhoons and storm surges.
2. "CPUE" means "catch per unit effort."
3. The * symbol indicates a 95% significant difference.

4. Fishery and Biodiversity Data

Annual fishing data, including catch data, economic data, and CT numbers of vessels for the coastal fishery of the two villages during the period from 2005 to 2015, were obtained from the Tamsui and Chuwei Fishermen's Association. Marine biodiversity (H') was defined as the complex of individuals belonging to different species in a biotic community (Odum, 1962). In general, the biodiversity index was generated by using the sample number ratio (Pielou, 1966):

$$H' = -\sum_{1}^{S} \left(Nt/N\right) \ln\left(Nt/N\right),$$

where Nt is the number of the ith species, and S the number of catch species.

The discrepancy of this formula regarding the units of weight and number was corrected by Jerry (1967), and this modified formula was used in the present study:

$$H' = -\sum_{1}^{S} \left(Wt/W\right) \ln\left(Wt/W\right),$$

where Wt is the weight of the ith species.

Species evenness (J') refers to the numerical closeness of the species in an environment. The evenness of a community can be represented by Pielou's evenness index:

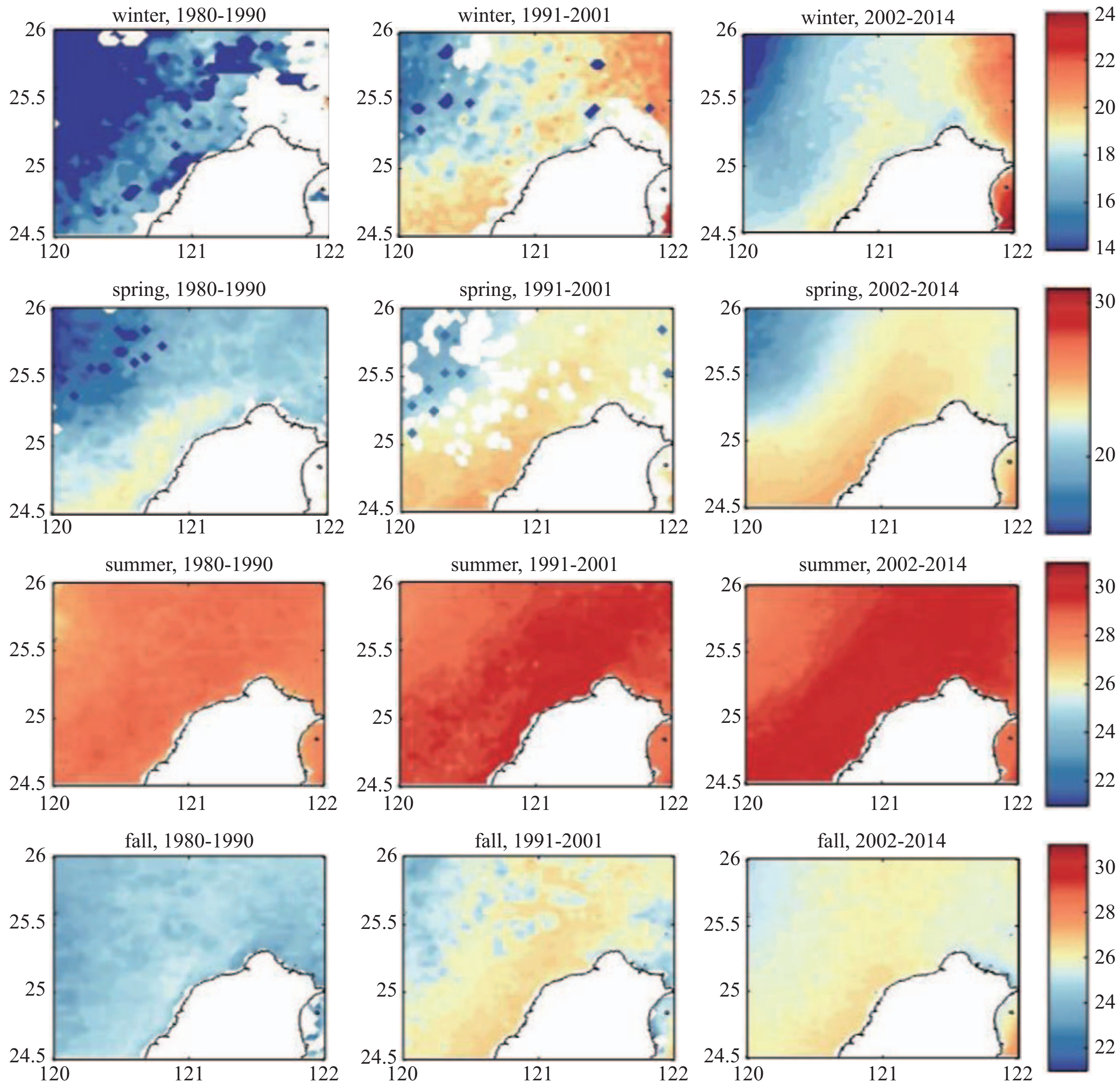

Fig. 3. Decadal variation of seasonal sea surface temperature (°C) from 1985 to 2014.

$$J' = H' / lnS \, .$$

Finally, the Jaccard index (Ja), also known as the Jaccard similarity coefficient, is a statistic used to compare the similarity and diversity of sample sets. It is defined as the size of the intersection divided by the size of the union of the sample sets:

$$Ja = \frac{ab}{(a+b-ab)},$$

where a is the number of catch species in area 1, b is the number of catch species in area 2, and ab is the number of the same catch species between the two areas.

5. Stakeholder Perceptions

The questionnaire for this study was adapted from Ajediran et al. (2013) to determine the perceptions of stakeholders in response to climate-related changes around the Tamsui River. Items were answered on a 5-point Likert scale, reflecting the opinions of each interviewee. The questionnaire contained 27 items (Table 1) that were grouped under the following domains: hydrological conditions (7 items), fishing operations (7 items), economic concerns (6 items), and policy management (7 items). Descriptive mean statistics were used to summarize the data, and relationships among the variables and comparisons between them were evaluated using linear regression analysis and the independent t test, respectively. This study also solicited interviewees' basic information (age, sex, residential area, fishing

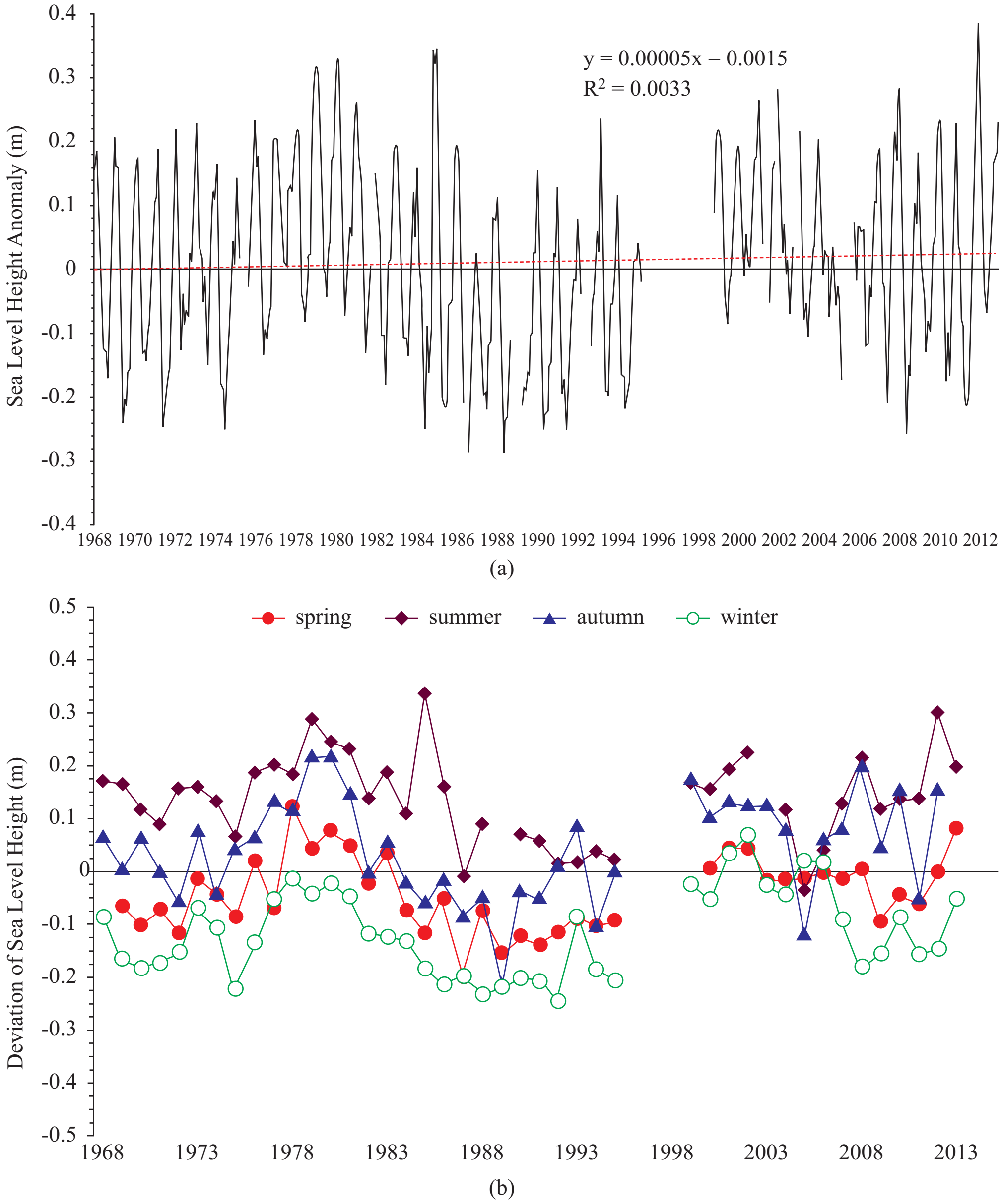

Fig. 4. (a) Sea level height. The black dots are the monthly mean sea level and the red line indicates the trend to rising sea levels from 1968 to 2013. (b) Deviation of sea level height from 1968 to 2013 (Source: CWB).

methods, CT type of vessel, and level of education), and administered the questionnaires face-to-face coupled with semistructured interviews. Before the start of the survey, the purpose of the study was explained to the participants.

III. RESULTS

1. Sea Surface Temperature Variation

Images of the interannual average SST demonstrated that the prevailing northeast winter monsoon caused the China Coastal Current to enter the TS; hence, the SST of the TS remained at 19°C during the winter (Fig. 3). However, the southwest spring and summer monsoon caused the Kuroshio Branch Current (KBC) to enter the TS, resulting in a higher SST of 26°C-28°C. Furthermore, the greater deviation from the interannual average SST during winter and spring indicated that fluctuation in the SST and the trend toward higher temperatures were more significant in those seasons.

2. Sea Level Height Anomaly

The average sea level gradually rose by 0.098 cm per year from 1968 to 2003 (Fig. 4(a)). During that same period, the deviation from the average monthly sea level high in the Tamsui River (121°25'30"E, 25°10'30"N) demonstrated that the sea level increased from July to September (> 0.3 m) but decreased from January to March (≤ 0.3 m). In the winters (January to March),

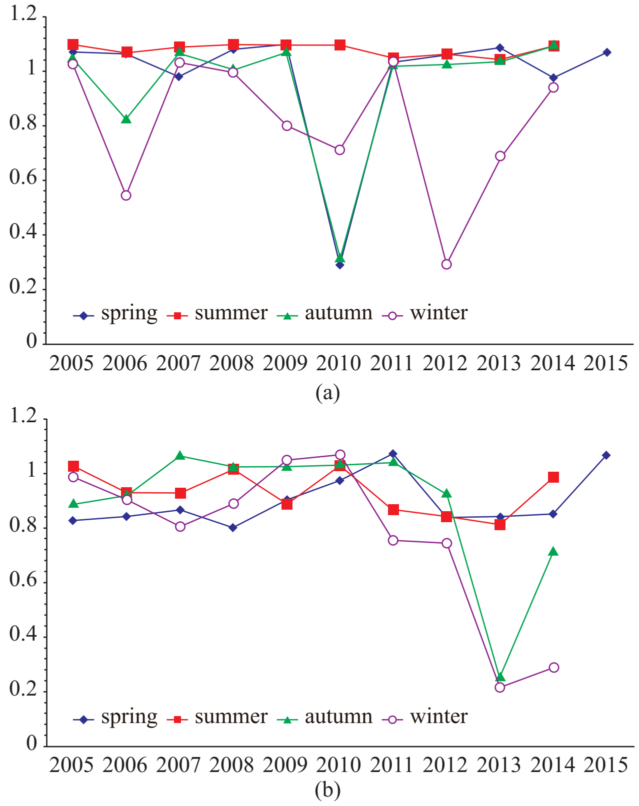

Fig. 5. Seasonal biodiversity of Tamsui village (a) and Chuwei village (b) from 2005 to 2015.

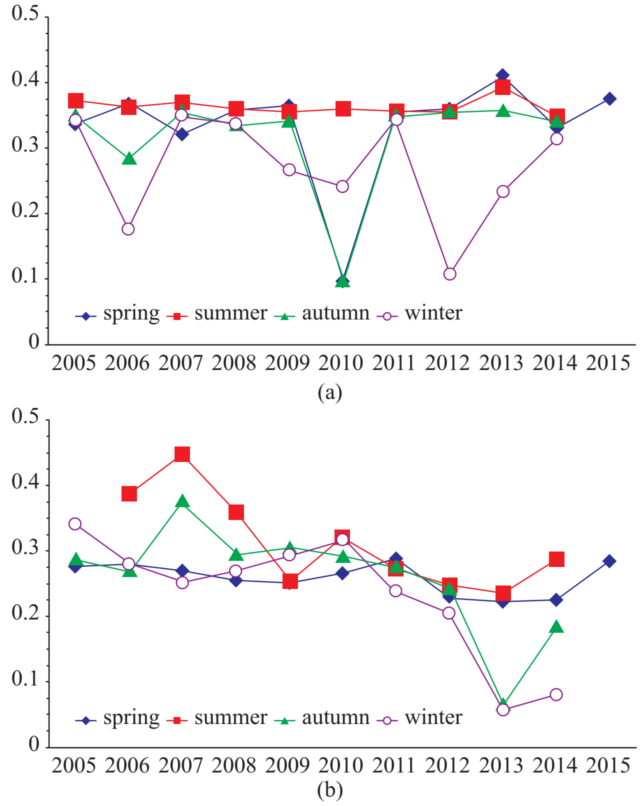

Fig. 6. Seasonal evenness of Tamsui village (a) and Chuwei village (b) from 2005 to 2015.

the sea level was at its lowest and slightly below average (Fig. 4(b)). In short, the results demonstrated apparent seasonal variation in the Tamsui River area sea levels.

3. Annual Catch and Fishery Structure

The value of the biodiversity index of the Tamsui River area was stable during the spring and summer (Fig. 5(a)) at approximately 0.974-1.098; however, catching particular species (i.e., mullet, eels, and larvae) caused this value to dramatically change in autumn and winter. Biodiversity in Chuwei (0.8) was notably lower than that in Tamsui (Fig. 5(b)), particularly in the spring because Chuwei fishermen focus on capturing Spanish mackerel (*Scomberomorus commerson*). Since 2010, the biodiversity value has dramatically decreased in the autumn and winter in both Tamsui and Chuwei because of the increased fishing of mullet.

The evenness index of Tamsui remained constant at 0.35 in the spring and summer (Fig. 6(a)), although it changed in other seasons. In Chuwei, the evenness index was higher than 0.25 before 2010, with the exception of the summer and autumn of 2007 (Fig. 6(b)) when it was substantially higher because the number of species caught during those seasons (8 and 17, respectively) was less than in other seasons. After 2010, the variation in evenness dramatically changed. A comparison of the number of species caught by the two villages (Fig. 7) revealed that the Jaccard index value in winter (> 0.3) was higher than that in other seasons, which indicates that the caught species

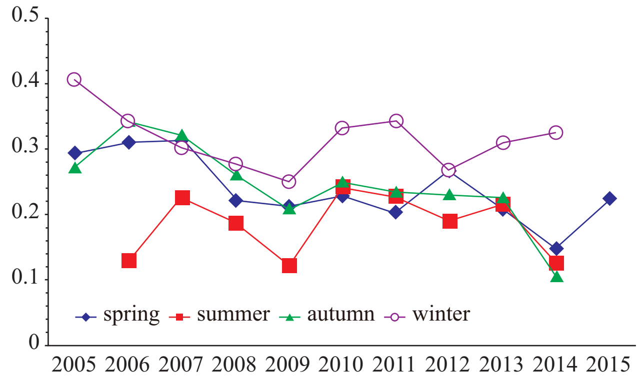

Fig. 7. Seasonal Jaccard coefficient for catch species of both communities from 2005 to 2015.

were mostly similar. By contrast, the Jaccard index value was the lowest in summer (< 0.15).

4. Stakeholder Perceptions

A total of 130 stakeholders were given the questionnaires and interviewed (Table 2). The results indicated that 84% (102) were fishermen, and the remaining 16% (28) were fishery agents, local residents, and others involved in the fishing industry. In Tamsui, most of the fishermen were 50-59 years old, with

Table 2. Questionnaire results.

Village	Sample size	Inward transitionsreported	Occupation	Number that transitioned (inward)	%	No response
Tamsui	100	92	Fisher	71	77	8
			Researcher/Administrator	15	16	
			Labourer	6	7	
Chuwei	50	38	Fisher	23	61	12
			Researcher/Administrator	11	29	
			Labourer	4	10	

70% of the interviewees having been fishermen for more than 30 years; additionally, the predominant education statuses were completion of junior high (31%) and elementary school (35%). In Chuwei, 86% of the participants were more than 50 years old, and 48% of them were more than 60 years old; additionally, the predominant education statuses were completion of junior high school (33%) and senior high school (28%). The fishing methods in Tamsui were primainly gill net (33%), pole and line (28%), larval fishing (14%), and longline (13%), with the CT breakdown of vessel types being CT-S (51%), CT-3 (17%), and CT-2 (13%). In Chuwei, the main fishing methods were gill net (57%) and pole and line (25%), with CT-R and CT-S accounting for nearly 75% of the CTvessels. Overall, the vessels of the participants in Chuwei were generally smaller than those of the participants in Tamsui.

The participants from the two villages had similar perceptions (Table 1). Specifically, economic and policy management concerns were rated higher than 3.75 (out of 5) in both of the villages. However, considerable differences were observed in the responses regarding the frequency of seawater inwelling, the participants' vessel sizes, and target species. The most noticeable differences were observed in the responses to hinterland size, changes to occupation, and transboundary fishing. Both fishermen and nonfishermen from each village were compared to prevent occupation from influencing the results.

All of the participants from Tamsui had similar perceptions about economic concerns. They universally identified economic changes as a result of climate change, except for target species (which scored < 2.8), and fishermen and nonfishermen both had strong perceptions about policy management (these scored approximately 4). However, they had different perceptions of the environment, and a 1-point difference was observed in the Tamsui participants' perceptions about SST increases and rising sea levels. The participants from Chuwei differed in their perceptions of environmental concerns even more than those from Tamsui did, and both the fishermen and nonfishermen exhibited few differences about fishing. However, for economic and policy management concerns, the Chuwei participants provided responses similar to those provided by the Tamsui participants.

5. Vulnerability

Of the six AHP dimensions, fishing operations (0.272), policy management (0.251), and the marine environment (0.231), exhibited the most weight (Fig. 2). The experts and scholars generally considered these parameters to be more crucial than the other parameters, of which only fishery resources (0.101) received a weight higher than 0.1; the weights of marine industries and social and human factors were 0.066 and 0.079, respectively (Fig. 2).

Regarding hydrogeological parameters, the SST (0.28) received the highest weight, with the sea level, velocity of ocean currents, and intensity and frequency of typhoons receiving similar weight values. Only the frequency of seawater inwelling (0.151) received a lower weight value than the other parameters. These consistently high weights reveal that as the effects of climate change gradually become more serious, research interest in the effects of climate change have increased.

The dimensions of fishery resources and marine industries were also assessed to determine sensitivity. The weight of fishery resources was a composite of the weights of biodiversity and species composition, the average length of catch, and the tropical level. Of these parameters, species composition (0.437) received the highest weight, followed by the average length (0.306) and tropical level (0.257). The marine industries dimension was composed of cost (0.417) and net profit (0.583), and received the lowest weight value (0.066) of the six dimensions. Moreover, fishing position, time, and depth increased operation costs, while vessel modification affected fishing costs. According to the questionnaire results, the fishermen placed significantly high priority ($P < 0.05$) on fishing position, time, and depth. In addition, the fishermen from Tamsui purchased larger vessels than those from Chuwei, in the hope that they could adapt to environmental changes, regardless of whether the changes were natural or anthropogenic. Therefore, vessel modification differed significantly ($P < 0.05$). Of the sensitivity variables, vessel modification had the lowest weight; therefore, it was the least important.

Finally, the adaptive capacity of the villages (divided into social and human factors, fishing operation, and policy management) was also assessed. Of these parameters, fishing operation (0.272) and policy management (0.251) received the highest weight values, which demonstrated that adaptive capacity is the most crucial parameter, and social and human factors received a weight of 0.079. The limited resources and small hinterland size in the

Table 3. Initial vulnerability of Tamsui and Chuwei.

Village	Exposure	Sensitivity	Adaptive Capacity	Vulnerability
Tamsui	0.202	0.219	0.276	0.317
Chuwei	0.202	0.234	0.112	0.348

two villages probably prevented this parameter from substantially affecting the participants.

Within the fishing operation parameter, fishing effort received the highest weight value (0.333), indicating that the experts and scholars considered effort to be a crucial factor affecting the local fishing resources. However, the fishermen also adapted to changes in fishing resources by adjusting their fishing grounds, fishing season, and scale of fishing vessels, as reflected in the sensitivity variables. Within the policy management parameter, marine protected areas (MPAs) received the highest weight value (0.283), because most fishermen were willing to adhere to relevant rules. According to the AHP analysis (Table 3), the vulnerability parameters received lower priority in Tamsui (0.317) than in Chuwei (0.348), suggesting that there was less impact from climate change occurring in Tamsui than in Chuwei. In the future, more integral data concerning vulnerability should be collected to help fishing authorities understand the current conditions in the two villages.

IV. DISCUSSION

1. Exposure

The considerable number of canyons in the TS produce complex current and hydrogeological changes (Jan, 2002). Taiwan is located in the west of the north Pacific, near the western current cycle and in the path of the KBC that is an extension of the North Equatorial Current. The KBC flows across the northeast of Luzon Island and then continues along eastern Taiwan into northern Taiwan and the East Sea (Nitani, 1972).

The SST of the East China Sea rose by 2.2°C between 1982 and 1998 (Belkin, 2009). This extremely rapid rate is consistent with the rapid winter warming noted in the western East China Sea (> 0.8°C/decade) (Ho et al., 2004; Wang, 2006). It is also the most rapidly warming of all large marine ecosystems (LMEs), whose salinity regimes are significantly affected by freshwater runoff (e.g., the North Sea, Baltic Sea, Black Sea, and East China Sea) (Belkin, 2009). The SST of these LMEs is strongly affected by river runoff because it enhances vertical stratification, thereby contributing to the extremely rapid warming observed in the western East China Sea (Ho et al., 2004). Most river plumes are warmer than coastal seawater. Extreme events are likely to have the highest impact, but they are not reflected by mean temperature changes (Cinner et al., 2011). The time series and seasonal results from the Tamsui Tide Station revealed that the sea level rise was not significant. However, Tseng et al. (2010) reported that the East Asia tide-gauge stations around Taiwan showed an average trend of +2.4 mm/year from 1961 to 2003, which is higher than the reported global rate of +1.8 mm/year for the same period. These stations also demonstrated significantly higher sea level rise rates (+5.7 mm/year) compared with global values (+3.1 mm/year) from 1993 to 2003.

As the climate warms, more water is transported from the ocean to the land because warmer air contains more water vapor. This phenomenon also increases the potential for heavy rainfall, because warming-related changes in large-scale circulation influence the strength and extent of overall monsoon circulation (IPCC, 2007). The results of hydrogeological changes are similar to the changes in SST, sea level, ocean current velocity, and typhoon intensity and frequency, as demonstrated in this study; only seawater inwelling showed no apparent change. The questionnaire results reveal that the observed effects of ocean current velocity and typhoon intensity vary depending on the background of the interviewee. Specifically, fishermen with high levels of education and more marine knowledge were aware of the changes in the sea level and SST; however, most of them remained oblivious because the change is gradual. The results also suggest that climate change and human factors (e.g., overfishing and pollution) simultaneously cause decreases in fishery resources, and that nonfishermen believe that human factors have a stronger effect than climate change.

2. Sensitivity

Because fishing methods are adjusted to suit seasonal changes in the Tamsui River from March/April to September, the major methods are long line and drift-bag net. However, following the warming summer temperatures, fishermen occasionally use gill nets in mid-August (typically, gill nets are the major fishing method used from September to January). Furthermore, almost all of the fishermen conduct maintenance in February, resulting in fewer fishing days in that month; they noted that sometimes no fishing is recorded in February.

The results of the present study indicated that Tamsui had few fish species but high total catch counts; by contrast, Chuwei had lower total catch counts but more fish species. This finding may be related to the large fishing vessels used by the Tamsui fishermen. Moreover, fishing techniques and the differentiation of species have recently become advanced and detailed. Although climate change affects species and marine resources, the participants did not have strong perceptions of these effects. However, they did have strong perceptions about the seasonal changes regarding fishing positions and target species. Fishermen notice seasonal dynamics and consider them to be the causes of increased species diversity over time. Previous studies have suggested that marine species are affected by multiscale climatic forces (Tzeng et al., 2012; Lan et al., 2014). For example, the Japanese eel and gray mullet are two of the most valuable commercial fish species in Taiwanese coastal fisheries, but fluctuations in annual eel recruitment may be driven by nonlinear interactions with various climatic factors (Hsieh et al., 2005). The abundance and migration behavior of gray mullet in the TS are also affected by climate variations, particularly the annual Pacific Decadal Oscillation, which exhibits the strongest significant correlation with gray mullet CPUE (Lan et al., 2014).

In the future, differentiating between pelagic and dermal species would facilitate accurate determination of catch similarity in the two villages. Overfishing leads to increased sensitivity of fish populations to climatic fluctuations, rendering it difficult to distinguish the effects of overfishing from those of the climate change; however, overfishing might also change the distribution of the population by removing parts of fish populations in certain areas (Worm and Myers, 2004). Additional studies of population dynamics should be conducted to solve this problem, and they should consider potential feedback from changes in the pelagic ecosystem. Moreover, comprehensive investigations of the influence of climate variability should include the aspects of fishing behavior and logbook data from Tamsui and Chuwei.

In 1998, the New Taipei City Government restructured Tamsui Fisherman's Wharf, a modern fishing port, to combine recreational and traditional fisheries. However, to improve the environment, the local fish market was removed, resulting in local fishermen having difficulty selling products, and indirectly increasing prices ($P < 0.05$). To increase net profits following the cost increase and total fishing catch decrease, the government offered a fuel subsidy and raised the unit price of fish. Notably, the fishermen did not notice a difference in net profit, although the experts and scholars did.

3. Adaptive Capacity

At locations where fishery management is effective, marine reserves are unlikely to produce a net spillover benefit for the total fishery. However, marine reserves may be beneficial where the fishery has been mismanaged and stocks are severely depleted (Buxton et al., 2014). In this study, although seawalls received the lowest weight, the fishermen in both villages stressed their importance. Because the Port of Taipei caused less of an effect than the sea current velocity, the overall effect did not appear. It is hoped more flat data from the CWB can be analyzed to realize the impact of current and tide. The government enforces several management policies regarding, for instance, artificial fish reefs, MPAs, the management of wastewater, and closed fishing seasons and areas. Most fishermen are willing to comply with such policies, but also want the government to increase the efficiency of policy management and standardize the penalties. These policies should also be discussed further with authorized agents and stakeholders.

Related studies (McClanahan et al., 2008, 2009) have suggested that people with low adaptive capacity may be unwilling or unable to adapt to policy actions that have high adjustment costs, such as policies regarding protected areas. Instead, areas where people have a low adaptive capacity may be suited to management actions that require little adaptation, such as changes in allowable gear use or fishery closures that allow for periodic harvests (Cinner et al., 2009). These actions can be viewed as starting points for management policies that stabilize or improve resource conditions and fishermen's incomes (McClanahan et al., 2008; Worm et al., 2009) while long-term strategies for developing adaptive capacity are enacted.

Experts consider the recovery of adaptive capacity and the composition of livelihoods in fishing villages the main considerations when facing climate change. However, fishery authorities consider essential management measures to be the crucial factors for reducing the vulnerability of ecosystems and fishery-based livelihoods. The current survey of fishermen revealed that they have noticed the effect of climate change on the marine environment around the Tamsui River, although they mostly agreed that overfishing was the key factor resulting in decreased marine resources, in addition to pollution and the Port of Taipei seawall. Implementing measures that reduce the vulnerability of fishermen's livelihoods are the most crucial task in addressing the uncertainty of natural climate variability.

V. CONCLUSION

Despite the daunting challenges resulting from the increased crowding and warming of the planet, there are encouraging signs that human intervention can be effective and beneficial at improving the capacity of marine ecosystems to adapt to climate change. Information on the sources of both biophysical and social vulnerabilities of communities to climate change (Boruff et al., 2005; Allison et al., 2009; Cooley et al., 2012) can encourage solutions targeting particular adaptation strategies (e.g., increasing the adaptive capacity of a community or restoring degraded coastal habitats) that make a positive difference. The sensitivity of populations to climate change is then integrated with their exposure to derive measures that mitigate the potential impact of climate change on the three ecosystem components (Remelyn, 2015). To obtain the vulnerability measure for each component, cross-tabulation is used to combine the potential impact of each component with the corresponding adaptive capacity of the fishery ecosystems. In this study, the vulnerability of Chuwei and Tamsui was most heavily influenced by their adaptive capacity, because it ranged widely between the samples. By evaluating the vulnerability of these coastal fishing villages, it can be concluded that climate change and anthropogenic pressure both reduce marine resources, thus affecting the livelihoods of stakeholders. Moreover, the results of this study can inform management institutions during policy development. Addressing the uncertainty associated with natural climate variability is crucial for reducing the vulnerability of fishermen's livelihoods.

ACKNOWLEDGEMENTS

This study was supported by fishery data from the Tamsui and Chuwei Fishermen's Association. This study was part of the Taiwan integrated research program on Climate Change Adaptation Technology (TaiCCAT), and sponsored by a grant from the Ministry of Science and Technology of Taiwan (MOST 103-2621-M-019-001; 105-2621-M-019-003) and the Fishery Agency of the Council of Agriculture, Executive Yuan, R.O.C. (104AS-17.2.1-FA-F1). The sea level data were provided by the TCCIP (Taiwan Climate Change Projection and Information Platform Project http://tccip.ncdr.nat.gov.tw/NCDR/main/index.aspx).

REFERENCE

Adger, W. N. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. World Development 27, 249-269.

Adger, W. N. (2000). Social and ecological resilience: are they related? Progress in Human Geography 24, 347-364.

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. Economic Geography 79, 387-404.

Adger, W. N. and K. Vincent (2005). Uncertainty in adaptive capacity. Comptes Rendus Geoscience 337, 399-410.

Adger, W. N. (2006). Vulnerability. Global Environmental Change-Human and Policy Dimensions 16, 268-281.

Ajediran I. B., A. D. Sylvester and T. I. Fidelis (2013). Health related quality of life amongst people affected by leprosy in South Ghana: A needs assessment. Leprosy Review 84, 76-84.

Allison, E. H., A. L. Perry, M. C. Badjeck, W. N. Adger, K. Brown, D. Conway, A. S. Halls, G. M. Pilling, J. D. Reynolds, N. L. Andrew and N. K. Dulvy (2009). Vulnerability of national economies to the impacts of climate change on fisheries. Fish and Fisheries 10, 173-196.

Alshehri S. A., Y. Rezgui and K. Li (2015). Delphi-based consensus study into a framework of community resilience to disaster. Natural Hazards 75(3), 2221-2245.

Belkin, I. M. (2009). Rapid warming of Large Marine Ecosystems. Oceanography 81, 207-213.

Belkin, I. M. and M. A. Lee (2014). Long-term variability of sea surface temperature in Taiwan Strait. Climatic change 124, 821-834.

Bene, C. (2009). Are fishers poor or vulnerable? Assessing economic vulnerability in small-scale fishing communities. Journal of Development Studies 45, 911-933.

Boruff, B. J., C. Emrich and S. L. Cutter (2005). Erosion hazard vulnerability of US coastal counties. Journal of Coastal Research 21(5), 932-942.

Buxton, C. D., K. Hartmann, R. Kearney and C. Gardner (2014). When is spillover from marine reserves likely to benefit fisheries? PLoS One 9(9), e107032.

Chang, Y. and B. H. Lin (2016). Improving marine spatial planning by using an incremental amendment strategy: the case of Anping, Taiwan. Marine Policy 68, 30-38.

Cheung, W. W. L., V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. E. G. Watson, D. Zeller and D. Pauly (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology 16, 24-35.

Cinner, J. E., T. R. McClanahan, T. M. Daw, N. A. J. Graham, J. Maina, S. K. Wilson and T. P. Hughes (2009). Linking social and ecological systems to sustain coral reef fisheries. Current Biology 19, 206-212.

Cinner, J. E., C. Folke, T. Daw and C. C. Hicks (2011). Responding to change: using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers. Global Environmental Change 21, 7-12.

Cooley, S. R., N. Lucey, H. L. Kite-Powell and S. C. Doney (2012). Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow. Fish and Fisheries 13(2), 182-215.

Cutter, S. L. (1996). Vulnerability to environmental hazards. Human Geography 20, 529-539.

Food and Agriculture Organization (FAO) (2007). The State of World Fisheries and Aquaculture 2006. Food and Agriculture Organization of the United Nations, Rome.

Food and Agriculture Organization (FAO) (2008). The State of World Fisheries and Aquaculture (SOFIA). Food and Agriculture Organization of the United Nations, Rome.

Gallopin, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change 16, 293-303.

Gong, G. C. (2014). The project of monitoring sewage systems of Tamsui River: Marine Environment. (in Chinese)

Hajkowicz, S. (2006). Multi-attributed environmental index construction. Ecological Economics 57, 122-139.

Ho, C. R., C. Y. Lin, S. J. Huang, N. J. Kuo and Q. Zheng (2004). Sea surface temperature variations in the China seas. In: Proceedings of the 13th Workshop of OMISAR (WOM-13) on Validation and Application of Satellite Data for Marine Resources Conservation, October 5–9, 2004, Bali, Indonesia, paper 02-05.

Hsieh, C. H., C. Reiss, W. Watson, M. J. Allen, J. R. Hunter, R. N. Lea, R. H. Rosenblatt, P. E. Smith and G. Sugihara (2005). A comparison of long-term trends and variability in populations of larvae of exploited and unexploited fishes in the Southern California region: A community approach. Oceanography 67, 160-185.

Intergovernmental Panel on Climate Change (IPCC) (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Islam, M. M., S. Sallu, K. Hubacek and J. Paavola (2014). Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. Regional Environmental Change 14, 281-294.

Jan, S., J. Wang, C. S. Chern and S. Y. Chao (2002). Seasonal variation of the circulation in the Taiwan Strait. Journal of Marine Systems 35, 249-268.

Jerry, L. W. (1967). Use of biomass units in Shannon's formula. Ecological Society of America 49(1), 153-156.

Joseph, V., A. Thornton, S. Pearson and D. Paull (2013). Occupational transitions in three coastal villages in Central Java, Indonesia, in the context of sea level rise: a case study. Natural Hazards 69(1), 675-694.

Kumar S. and O. Vaidya (2006). Analytic hierarchy process: An overview of applications. European Journal of Operational Research 169(1), 1-29.

Lan, K. W., M. A. Lee, C. I. Zhang, P. Y. Wang, L. J. Wu and K. T. Lee (2014). Effects of climate variability and climate change on the fishing conditions for grey mullet (*Mugil cephalus* L.) in the Taiwan Strait. Climatic Change 126(1), 189-202.

Lee, M. A., Y. Chang, F. Sakaida, H. Kawamura, C. H. Cheng, J. W. Chan and I. Huang (2005). Validation of satellite derived sea surface temperatures for waters around Taiwan. Terrestrial, Atmospheric and Oceanic Sciences 16, 1189-1204.

Lee, T. Y., Y. T. Shih, J. C. Huang, S. J. Kao, F. K. Shiah and K. K. Liu (2014). Speciation and dynamic of dissolved inorganic nitrogen export in the Danshui River, Taiwan. Biogeosciences 11, 5307-5321.

Maina, J., V. Venus, T. R. McClanahan and M. Ateweberhan (2008). Modelling susceptibility of coral reefs to environmental stress using remote sensing data and GIS models. Ecological Modelling 212, 180-199.

Marshall, N. A. and P. A. Marshall (2007). Conceptualizing and operationalizing social resilience within commercial fisheries in northern Australia. Ecology and Society 12, 1.

McClain, E. P., W. G. Pichel and C. C. Walton (1985). Comparative performance of AVHRR-based multichannel sea surface temperatures. Journal of Geophysical Research 90, 587-601.

McClanahan, T. R., J. E. Cinner, N. A. Graham, T. M. Daw, J. Maina, S. M. Stead, A. Wamukota, K. Brown, V. Venus and N. V. C. Polunin (2009). Identifying reefs of hope and hopeful actions: contextualizing environmental, ecological, and social parameters to respond effectively to climate change. Conservation Biology 23, 662-671.

McClanahan, T. R., J. E. Cinner, J. Maina, N. A. J. Graham, T. M. Daw, S. M. Stead, A. Wamukota, K. Brown, M. Ateweberhan, V. Venus and N. V. C. Polunin (2008). Conservation action in a changing climate. Conservation Letters 1, 53-59.

Nelson, D. R., W. N. Adger and K. Brown (2007). Adaptation to environmental change: contributions of a resilience framework. Annual Review of Environment and Resources 32, 395-419.

Nitani, H. (1972). The beginning of the Kuroshio. In "Kuroshio" (Stommel, H. and K. Yoshida, Eds.), University of Tokyo, Tokyo, 129-163.

Odum, E. P. (1962). Relationships between structure and function in the ecosystem. Japanese Journal of Ecology 12(3), 108-118.

Pauly, D., V. Christensen and S. Guenette (2002). Towards sustainability in world fisheries. Nature 4418, 689-695.

Pielou, E. C. (1966). Shannon's formula as a measure of species diversity: its use and misuse. The American Naturalist 100, 463-465.

Remelyn I. de Ramos. (2015). Assessing vulnerability of fisheries in the Philippines to Climate Change Impacts. SEARCA (The Southeast Asian Regional Center for Graduate Study and Research in Agriculture) Agriculture and Development Seminar Series 2015, Philippines.

Saaty, T. L. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.

Saaty, T. L. (1996). Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications, Pittsburgh.

Tseng, Y. H., L. C. Breaker and E. T. Y. Chang (2010). Sea Level Variations in the Regional Seas around Taiwan. Journal of Oceanography 66, 27-39.

Tzeng, W. N., Y. H. Tseng, Y. S. Han, C. C. Hsu, C. W. Chang, E. Di Lorenzo and C. H. Hsieh (2012). Evaluation of Multi-Scale Climate Effects on Annual Recruitment Levels of the Japanese Eel, *Anguilla japonica*, to Taiwan. PLoS ONE 7(2), e30805.

Wang, F. (2006). Long-term variability of temperature in the Yellow Sea and the East China Sea in the past 40 years. Presented at the PICES 15th Annual Meeting, Yokohama, Japan, 175.

Wedley, W. C. (1990). Combining qualitative and quantitative factors—an analytic hierarchy approach. Socio-Economic Planning Sciences 24, 57-64.

Worm, B. and R. A. Myers (2004). Managing fisheries in a changing climate. Nature 429, 15.

Worm, B., R. Hilborn, J. K. Baum, T. A. Branch J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. K. Lotze, P. M. Mace, T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson and D. Zeller (2009). Rebuilding global fisheries. Science 325, 578-585.

Zahedi, F. (1986). The analytic hierarchy process: a survey of the method and its applications. Interfaces 16(4), 96-108.