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A four-dimensional population module for the analysis of future adaptive capacity in the Phang Nga province of Thailand

Elke Loichinger, Samir KC and Wolfgang Lutz*

Abstract

In this paper we describe an innovative aspect of the population module in the context of an ongoing comprehensive modelling effort to assess future population-environment interactions through specific case studies. A particular focus of our study is the vulnerability of coastal populations to environmental factors and their future adaptive capacity. Based on the four-dimensional cross-classification of populations by age, sex, level of education, and labour force participation, our approach builds on a recent body of research that has critically assessed the role of demographic differentials as determinants of differential vulnerability and adaptive capacity. We use Phang Nga, a province in the south of Thailand that was severely affected by the tsunami in 2004, to describe current levels of educational attainment and investigate past trends, which in turn serve as input for detailed education projections. These education projections, in combination with projections of economic activity and household survey results about disaster preparedness, feed into further analysis of future adaptive capacity. Given our specifications and assumptions, we find that the educational composition of the province's labour force will shift towards higher levels, and that the population of Phang Nga will be better prepared for future disasters.

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1 Introduction

In this paper we describe one innovative aspect of an ongoing comprehensive modelling effort to assess future population-environment interactions, and in particular the vulnerability of coastal populations to environmental factors and their future adaptive capacity in a number of specific case studies. For our analysis we developed interactive systems models, in which changes in a population module interact with changes in economic and environmental models. This approach follows the research tradition of population-development-environment (PDE) systems studies developed at the International Institute for Applied Systems Analysis (IIASA), such as the studies on Mauritius, Namibia, Botswana, and Mozambique that are summarised in Lutz et al. (2002).

In this paper, we introduce a new PDE analysis for the southern Thai province of Phang Nga (located north of Phuket), which was chosen because it was affected by the 2004 Indian Ocean tsunami, and because it remains highly vulnerable to sea-level rise and storm surge. Applying the new population module, we aim to describe how the future population outlook translates into future adaptive capacity in a disaster-prone area like Phang Nga. The population module has several new features, including a systematic set of four-dimensional (4-D) population scenarios. This set of scenarios assesses population changes in the four-dimensional space, as defined by age, sex, level of education, and labour force participation. By factoring in education and labour force participation, the 4-D model departs from conventional population projections, which makes the development, estimation, and calibration of this population module rather innovative.

This paper also builds on a recent body of research that has critically assessed the role of demographic differentials as determinants of vulnerability and adaptive capacity. These studies have systematically assessed in different specific settings and at the global level the relative importance of age, sex, level of education, and, to a lesser extent, the role of labour force participation. Eleven of these studies were published in a special issue of *Ecology & Society* under the title 'Education and Differential Vulnerability to Natural Disasters' (Butz et al. 2014). A comprehensive summary of these papers can be found in Muttarak and Lutz (2014). A specific focus of these studies was the assessment of the effects of educational attainment relative to the effects of other, more frequently investigated determinants of vulnerability, such as income levels and demographic, geographic, cultural, and institutional factors. These studies found consistently that in all contexts and for both men and women educational attainment was at least as important as—and was in many cases much more important than—income in reducing vulnerability to natural disasters, as measured by responses, impacts, and coping ability. In addition, based on these consistent findings, analyses of times series of mortality from natural disasters between 1970 and 2010 across 156 countries by Lutz et al. (2014) further confirmed that the universal expansion of secondary education can reduce excess deaths from extreme climatic events.

The evidence showing that compared to less educated populations, groups with higher levels of education are less adversely affected by natural disasters, and have better responses and coping abilities when disaster hits, raises the question of the causality of the effects of education in reducing disaster vulnerability. Indeed, causality was established beyond any reasonable doubt in the sense of 'functional causality', as discussed by Lutz and Skirbekk (2014). Following a clearly specified set of criteria, this implies that it is safe to assume that there is a continuation of this strong empirical association for the time horizon of the projections. In short, it appears that high educational attainment has direct and indirect effects that tend to reduce people's vulnerability to natural disasters (Muttarak and Lutz 2014). The direct effects of education include having enhanced cognitive skills for processing risks and risk information, better problem-solving skills, better knowledge acquisition and usage, and increased risk awareness. The indirect effects of education include having a higher income that can be used for disaster preparedness, better access to information related to disasters, and a higher level of social capital.

Given that there is already a large body of literature that shows that education plays an important role in reducing disaster vulnerability, the issue of causality will not be further elaborated in this paper. Instead, we will focus on the definition and the calibration of consistent scenarios for the four-dimensional population module in the specific context of Phang Nga province in Thailand. However, this analysis can also be viewed as a prototype of isomorphic population models of systems studies that can be applied in other settings.

A new feature of this population module is the systematic cross-classification of the population stratified by age, sex, and level of education with labour force participation. Why is this important? When it comes to the association between education and economic activity, many factors contribute to the commonly observed picture that higher levels of educational attainment are associated with higher levels of labour force participation. For example, higher levels of human capital generally entail higher returns (Gunderson and Oreopoulos 2010; Patrinos and Psacharopoulos 2010), which increases the opportunity cost of not being economically active. In addition, having a higher education provides workers with access to jobs that are considered more desirable, because, for example, they offer more attractive working conditions. Moreover, there is often a higher demand for workers with a certain degree of education than there is for workers with no or little education (OECD 2011). For the economy itself, the educational attainment structure of the workforce plays a crucial role for labour productivity and economic output (Lutz et al. 2008). Hence, for any study of the impacts of future changes in the population on the structure of the economy or on economic performance in general, the explicit modelling of changes in economic activity by age, sex, and level of education is an important refinement that makes the output of the population module more relevant to other aspects of socio-economic and environmental changes.

Phang Nga was chosen as the case study for the new 4-D population module because it has become globally known as the Thai province that was hardest hit by

the tsunami on 26 December 2004, in terms of both the number of lives lost and the negative economic impact.[1] In Phang Nga alone, 5880 people died or went missing, and 5597 people were injured. Of the people who died, one-half were identified as foreigners, one-third were identified as Thai, while the nationalities of the remaining victims were unknown. About 80% of the people who were injured or missing were Thai nationals (Jayasuriya and McCawley 2010). Economically, the tourism and the fishery sectors were the most affected. These experiences were among the reasons why we chose Phang Nga as the site of our in-depth PDE study. A considerable amount of data has been collected on the province's residents and on the specific experiences of the tsunami of all residents who lived there for more than 10 years. The availability of these data allows us to focus on the question of the extent to which the residents have learned from their experiences, and have drawn upon these lessons in preparing for the future.

Our focus in this paper is on a discussion of the elements of the innovative population model in its own right. We start by analysing the composition of the population of Phang Nga along four demographic dimensions (4-D): namely, age, sex, highest level of educational attainment, and labour force participation. In the next step, we combine the educational attainment projections with (1) results from a 2013 survey of the province's households on disaster preparedness, and (2) results from a previous global study on the association between education and disaster deaths. This information allows us to make some inferences about how the people of the region are likely to fare if another disaster strikes in the future compared to today, and compared to people in other world regions.

2 Methods and data

2.1 Methods

The education projections are the results of age-, sex-, and education-specific population projections – representing three out of the four core dimensions – using a multi-state cohort-component population projection model. Thus, unlike in traditional cohort-component projections, the input parameters of mortality, fertility, and migration are broken down by educational level, as well as by age and sex. This approach allows us to project the development of educational attainment along cohort lines. The fourth core dimension, labour force participation, enters the model in a subsequent stage, as described below.

In addition to being a popular tourist destination, Phang Nga attracts large numbers of migrant workers, mainly from Myanmar. These migrants are employed primarily in the agricultural sector, but also in the fishery and construction industries, and as domestic workers (Jitthai et al. 2010). Because migrants make up a

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[1]   Phang Nga is the province in which the beach resort of Khao Lak is located.

significant share of the population, in our education projection model we distinguish individuals by country of birth. The cross-classification of educational attainment and country of birth clearly shows that this distinction is beneficial (cf. data section below). However, country of birth is not one of our core dimensions, but is rather an auxiliary dimension based on the specifics of the population structure of Phang Nga.

Our decision to include highest level of educational attainment is based on two considerations. First, on methodological grounds, our aim is to improve the quality of the projection by selecting a dimension that captures differences in fertility, mortality, and migration. We incorporate education differences into all three parameters. Second, on theoretical grounds, we believe the additional dimension is intrinsically interesting, and worthy of further analysis. In our case, we consider educational attainment information to be highly relevant for explaining labour market activity and disaster preparedness.

Details of the method are described in KC et al. (2010). The performed projection steps are:

- Distribution of the baseline population for the year 2010 by age, sex, highest level of educational attainment, and country of birth is estimated.
- Age-, sex-, and education-specific survival rates are applied.
- Transition rates between the educational categories are applied (by age, sex, and country of birth).
- Age- and education-specific fertility rates are applied to the female population aged 15 to 49. Applying a sex ratio of 1.05, total births are divided by males and females, and compose the 0-4-year age group of the subsequent period.
- Net migrants are added or subtracted according to age, sex, educational attainment, and country of birth.

These steps are repeated for each period. The resulting population of each cycle is the new starting population for the next cycle. The projection period starts in 2010 and runs until 2060. The projections intervals are five years.

Next, we generate labour force projections in two stages. First, we calculate labour force participation rates by age, sex, and education for 2010, and design scenarios of future participation up to 2060. Second, we combine these future participation rates with the previously generated education projections in order to calculate the absolute numbers and the educational attainment structure of the future labour force.

The calculation of future vulnerability involves two separate approaches. First, we combine the results from the education-specific population projections with the results of the 2013 survey of Phang Nga households on disaster preparedness to produce an estimate of the vulnerability of the province's population to future disasters. Second, we place Phang Nga in the framework of analysis of Pichler and Striessnig (2013), who focused on the role of formal education, particularly of women, in reducing vulnerability to extreme natural events.

2.2 Data and projection assumptions

The data for the baseline population come from the Thai census 2010, and are broken down by:

- age (five-year age groups),
- sex,
- economic activity (i.e. in the labour force or not in the labour force), and
- five categories of highest completed level of educational attainment (e1: no education/less than primary education; e2: primary education; e3: lower secondary education; e4: upper secondary education; e5: diploma/bachelor's degree and above)

Basic schooling in Thailand lasts for 12 years, and is free. Pupils spend six years in primary education, three years in lower secondary education, and three years in upper secondary education. Only nine years of schooling are compulsory. Upper secondary education is split into a vocational and an academic branch. The academic branch is designed to prepare students for university. But before they can enter university, students need to pass certain entrance exams (Trakulphadetkrai 2011).

The age composition of the population in Phang Nga is very similar to the overall distribution of Thailand: in 2010, 36% of the population were under age 25 and only 8% of the population were aged 65 and older; the respective values for Thailand were 34% and 9%. The current population are profiting from a past reduction in fertility levels, which means that a large share of the population are of working age.

Figure 1 depicts the population structure in Phang Nga in 2010. Even though the age composition of Phang Nga is similar to that of Thailand as a whole, the educational attainment structures of the province and the country differ: compared to the national population, smaller shares of Phang Nga's population have higher secondary or post-secondary education, and larger shares have less than primary education. Of the 20–64 age group, 11% in Phang Nga and 4% in Thailand as a whole have less than primary education, and 26% in Phang Nga and 33% in the country overall have at least higher secondary education.

This picture changes significantly once the data are further disaggregated by country of birth: if we look only at the population born in Thailand while excluding the population born outside of Thailand, the differences in educational attainment between Phang Nga and the whole of Thailand become much smaller. The residents of Phang Nga who were born outside of Thailand had much lower levels of educational attainment than their Thai-born counterparts (Table 1): almost 100% of the adult population of Phang Nga who were born in Thailand had at least completed primary education, compared to one-third of the foreign-born population.

In 2010, the share of the population born outside of Thailand was 12% in Phang Nga and only 3% in Thailand. Within Phang Nga, the age composition of those who were born outside of Thailand was much younger than of those who were born in Thailand (Table 2). This is not surprising, considering that most migrants living in Phang Nga are labour migrants.

Figure 1:
Population pyramid by age, sex, and highest level of educational attainment, Phang Nga, 2010
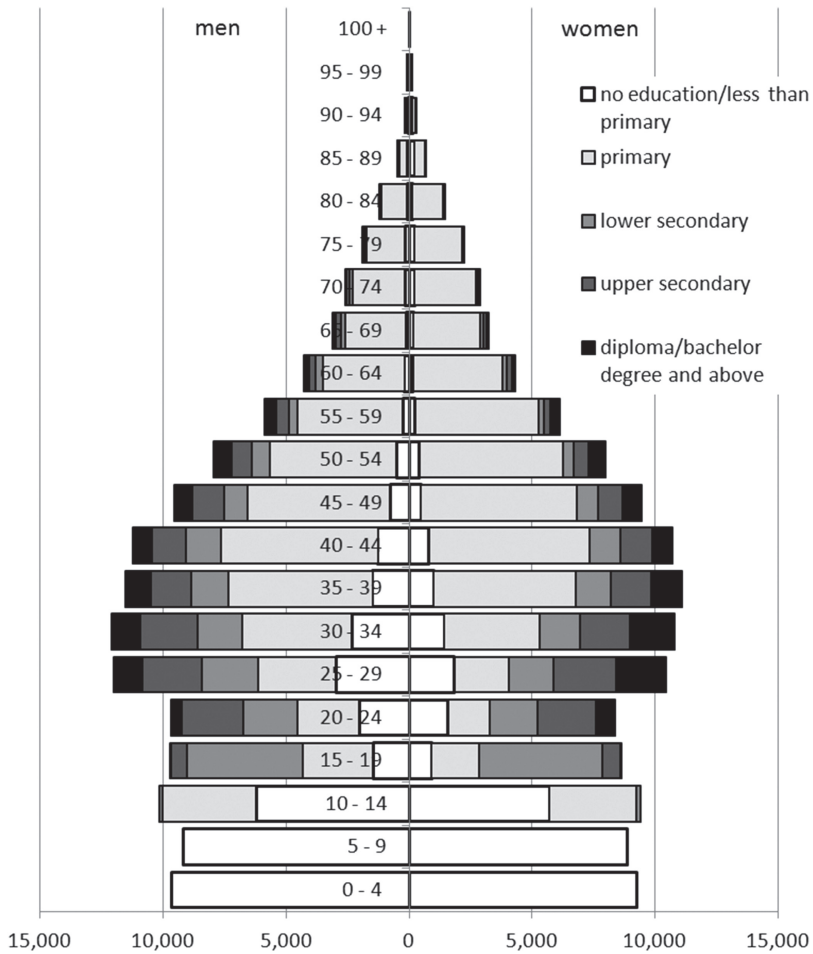
Source: Census 2010, data obtained from the National Statistical Office of Thailand, own calculations.

Given these differences in the age and the education structure by country of birth, as well as the relatively high share of the population born outside of Thailand, we decided to break down the education-specific population projections by country of birth, in addition to age, sex, and education.

Table 1:

Population (ages 20–64) by country of birth and highest level of educational attainment, Phang Nga, 2010

Country of of birth	No education/less than primary	Primary	Lower secondary	Upper secondary	Diploma/bachelor degree and above
Thailand	2%	54%	15%	18%	11%
Outside of Thailand	67%	30%	1%	2%	1%

Source: Census 2010, data obtained from the National Statistical Office of Thailand, own calculations.

Table 2:

Population by country of birth and broad age group, Phang Nga, 2010

Country of birth	Age 0–19	Age 20–64	Age 65+
Thailand	30%	61%	9%
Outside of Thailand	18%	81%	0%

Source: Census 2010, data obtained from the National Statistical Office of Thailand, own calculations.

2.2.1 Educational attainment

In order to design scenarios of future educational attainment, we performed several descriptive analyses to detect past trends in the development of educational attainment. The analysis of educational attainment progression ratios (EAPR) provides insight into past developments in educational attainment, and allows us to make inferences about future developments. EAPRs describe what share of the population in a given age group progress from each level of education to the next higher level: i.e. from no education to primary education, from primary to lower secondary education, from lower to upper secondary education, and from upper secondary education to a diploma/bachelor's degree and above (Lutz et al. 2007). As there are marked differences between the Thai-born and the non-Thai-born population in terms of education structure, the EAPRs were analysed separately for the two groups. The EAPRs for both the male and the female Thai-born population show that there has been a stalemate in the progression from lower secondary to upper secondary education (e3-e4) or from upper secondary to post-secondary education (e4-e5), but that there has been an increase in the shares who progressed from primary to lower secondary education (e2-e3). For men and women born outside of Thailand, the EAPR profiles were rather flat; i.e. no educational progress was detected. As we lack information about how old the migrants were when they entered the country, it is impossible to know whether this result reflects inequalities of opportunity between the migrant and the Thai-born population.

The scenarios of educational attainment that we apply to 15–34-year-olds are as follows:

1. **Constant scenario**. The future educational attainment progression ratios of the Thai-born and the foreign-born population are kept constant at the levels observed in 2010.
2. **Universal lower secondary education by 2030**. This scenario assumes a continuation of the trend towards increasing EAPRs from primary to lower secondary education.
3. **80% have at least upper secondary education by 2030**.[2] This scenario is based on a more rapid increase in education levels than current trends suggest. As in the second scenario, it is assumed that lower secondary education will be universal. But compared to the previous two scenarios, it is anticipated that larger shares of the population will progress from lower to upper secondary education and from upper secondary to post-secondary education.

2.2.2 Fertility

There are no data for the total fertility rate (TFR) for Phang Nga specifically, so we base our main assumption on the overall TFR observed for southern Thailand, and keep this figure constant for all three scenarios of educational attainment. The average TFR for the 2000–2010 period is 1.9, and the education differentials in fertility are obtained from the Multiple Indicator Cluster Survey (MICS) 2005/06. The fertility differentials, defined as the ratio between the education-specific TFR and the total TFR, is 1.2 for women with secondary education or less and 0.65 for women with more than secondary education. The age-specific fertility schedule (ASFR) is taken from the distribution for Thailand in 2010. For sensitivity, we also run projections in which we assume an increase in overall TFR to 2.1 and a decrease to 1.5 by 2020, respectively.

2.2.3 Mortality

Life expectancy in the 2010–15 period is estimated at 72 years for men and at 79.4 years for women. As there are no data at the province level, these estimates are based on data for the southern region of Thailand (NESDB 2013). In terms of the future development of life expectancy, we follow the assumptions made in the same publication, and extend the projection horizon of 2030 by linear interpolation to 2060. This leads to a life expectancy in 2060 of 81.0 for men and of 87.6 for women. Because we lack empirical data for Phang Nga or the southern region, the education differentials in life expectancy are the same as those assumed in KC et al.

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[2] Scenarios 2 and 3 are only applied to the population born in Thailand. It did not seem reasonable to assume that those who came to Phang Nga from abroad, most of whom were unskilled labour migrants, received further education after arriving in Phang Nga. Even though migrant children are entitled to attend school in Thailand, irrespective of their legal migration status, "the majority of migrant children still remain outside the education system" (Jampaklay 2011: 97).

Table 3:
Total migrant stock and composition by country of origin, mid-year, 1990 to 2013

Country	1990	2000	2010	2013
Myanmar	43.4%	58.4%	51.1%	50.8%
Laos	31.2%	23.0%	25.7%	24.9%
Cambodia	14.0%	12.2%	19.0%	20.2%
Others	11.4%	6.4%	4.2%	4.1%
Total	528,693	1,257,821	3,224,131	3,721,735

Source: United Nations, 2013b.

(2010); i.e. compared to their counterparts with secondary education, people with incomplete primary education have an average life expectancy at age 15 that is three years lower, and people with completed primary education have an average life expectancy that is two years lower. Thus, having more than secondary education translates into a two-year increase in life expectancy.

In order to obtain education-specific life table information, it is necessary to combine information about differences in life expectancy by education with life table data. For the population under age 35, the same life table is assumed for each education category; i.e. there are no differences in survival probabilities. For the population over age 35, life tables that include the previously mentioned education-specific differentials in life expectancy are calculated using the Brass-Gompertz relations model. The standard life table is the table for Thailand, as provided by the United Nations (2013a). This procedure is repeated for each projection interval.

2.2.4 Migration

The number of migrants living in Thailand more than sextupled between 1990 and 2013, from a good half million to more than 3.7 million (Table 3), with the bulk of the increase happening after 2000. However, the composition of migrants by country of origin changed little over this period: the majority of migrants still came from Myanmar, followed by Laos and Cambodia. These three countries alone account for over 95% of all migrants living in Thailand. This pattern can be explained by the active recruitment of unskilled workers by the Thai government since 1992, initially only from Myanmar, and later also from Laos and Cambodia (Huguet et al. 2012).

Internal migration   The southern region of Thailand, which is made up of 14 provinces, experienced a net loss of internal migrants between 1965 and 1990. However, the region had more internal in-migrants than out-migrants between 1995 and 2000 (Huguet et al. 2011), and the most recent census figures for 2010 suggest that the numbers of internal in- and out-migrants were roughly equal; i.e. that there was no net gain or loss due to internal migration (NESDB 2013; NSO Thailand,

2014b). The province of Phang Nga had positive internal net migration of 1,570 persons between 2005 and 2010 (NESDB 2013). An analysis of the census data for 1970, 1980, 1990, and 2000 revealed that internal net migration in Phang Nga reached a recent peak in 2000, and declined thereafter (Figure 2). Unfortunately, we have no valid information about the characteristics of internal migrants (i.e. about their composition by age, country of birth, or educational attainment), since the sample sizes in the available census micro-data are too small to allow for any reliable breakdown into sub-populations. Hence, we split the total sample of internal migrants into men and women and apply a standard age-migration profile in which migration peaks during young adult ages.

International migration An examination of the census data since 1970 to determine levels of international migration into Phang Nga indicated that zero immigrants from abroad entered Phang Nga before 1990. As it seems highly unlikely that there were no immigrants entering the province during that time, we assume that the numbers were simply very low, and that the immigrants were not picked up or included in the census. Looking at data from the 2000 census, we found that international in-migration into Phang Nga had been positive between 1995 and 2000, with 4900 persons entering (NSO Thailand 2014c). We have no direct information about either the inflow or the outflow of the number of international migrants for any later point in time. Using an indirect approach in which we compare the population size between 2000 and 2010 and take deaths, births, and internal migration during this period into account, we estimate that international net migration comprised about 4000 persons during this period.

As we mentioned above, in 2010 12% of the population of Phang Nga, or 32,174 persons, were not born in Thailand. Based on the composition of the non-Thai population – who had much lower education levels than the Thai population, and who were concentrated in the 15–49 age group (cf. Table 2) – and on the information about migrants to Thailand overall (cf. Table 3), we assume that the majority of these individuals were labour migrants from Myanmar, Laos, and Cambodia. As irregular migrants were only counted in the latest census taken in 2010, we are unable to make any useful comparisons with previous census years about the composition of the population by country of birth.

Based on the data we have on migration, we designed three migration scenarios regarding migration volume:

1. **Constant migration scenario**. Based on the most recent experiences, internal net migration is set at 1500 persons and international net migration at 2000 person for every five-year period. Thus, in this scenario internal and international migration combined comprise a net gain of 3500 migrants.
2. **Low migration scenario**. In this scenario, both internal and international net migration are gradually reduced to zero by 2020, and are kept constant at that level until 2060. This assumption can still imply a small turnover of migrants. For sensitivity purposes, we also run a scenario in which we only reduce net

Figure 2:
Internal migration: inflow into Phang Nga from the rest of Thailand and outflow from Phang Nga to other Thai provinces, 1970 to 2010. Based on the census question that asked where the respondent lived five years before the census
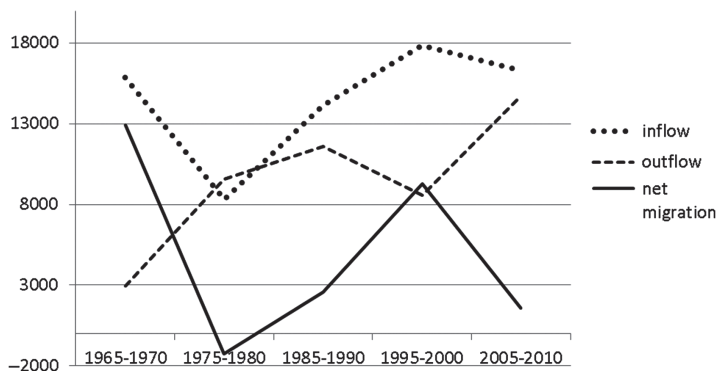

Source: Census micro-data for 1970, 1980, 1990, 2000 from IPUMS (2014), own calculations. Data for 2010 from NESDB (2013).

international migration to zero and keep internal migrations at the current level.
3. **High migration scenario**. Internal net migration is kept constant at 1500/five-year period and international net migration is doubled and set at 4000/five-year period starting in 2010.

We assume that internal migration involves only individuals born in Thailand, and that international migration involves only individuals born outside of Thailand. If the data situation had permitted, we would have avoided working with net migrants, and would have instead modelled separately the inflows and the outflows of both internal and international migrants (Rees et al. 2011; Rees et al. 2012). Internal net migrants are assigned the educational attainment distribution of the population in the respective age and sex group already residing in Phang Nga. In terms of the education structure, net international migrants in each five-year period are assigned the average of the projected education structure of the populations in Myanmar, Laos, and Cambodia, as assumed under the Global Education (GET) scenario (Lutz et al. 2014). This education scenario assigns country-specific future educational attainment based on global education trends during the last 40 years, and is considered to be the most likely education scenario. This leads to a dynamic increase in the educational attainment level of international migrants between now and 2060.

Figure 3:

Labour force participation rates by age, sex, and highest level of educational attainment, Phang Nga, 2010
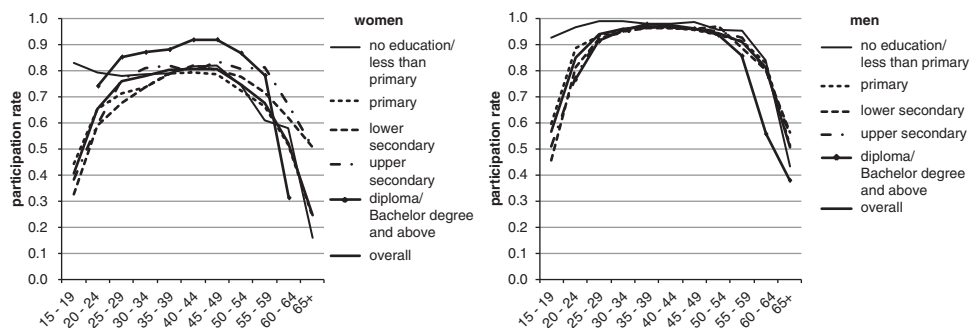
2.2.5 Labour force participation

The age-, sex-, and education-specific profiles of labour force participation, defined according to the ILO definitions of economic activity, show several of the characteristics typical of developing countries. Participation levels are high for both men and women (Figure 3). The differences in participation levels by education are larger for women than for men, and the differences observed for women are smaller than the differences commonly observed in developed countries. The pronounced positive correlation between educational level and participation rate among women holds for all age groups; the stark decline for the highest education group after age 60 is based on very few observations.

The two scenarios of labour force participation are:

1. **Constant scenario**. Future labour force participation rates are kept constant at the levels observed in 2010.
2. **Female participation levels reach male levels in 2060**. Currently, female participation is lower than male participation. This scenario assumes that participation rates are equal in 2060. This implies no change in participation for males.

We use the profiles for men and women and do not differentiate by country of birth, since (1) we only have data for one point in time, (2) the great majority of the population are Thai, and (3) we did not want to introduce more uncertainty about future developments.

3 Results

To quantify the effects of changing levels of fertility and migration, we start by presenting a range of possible future trajectories of total population size in which we modify levels of fertility and the volume of migration. For this analysis, we employ the educational attainment assumptions of the universal lower secondary scenario. While it is impossible to assign a probability of occurrence to any of the three education scenarios, the universal lower secondary education scenario is the most likely outcome of our three scenarios, as it is based on a continuation of past attainment trends.

Next, we fix our assumptions for fertility and migration at the current level; i.e. age- and education-specific fertility rates and internal and international net migration volumes are kept constant. Applying the three educational attainment scenarios means that any change in the population size and age structure are driven by changes in the education composition of the population: for example, more women with post-secondary education will mean fewer births due to the observed education differentials in fertility (cf. section 2.2.2), which lowers the average TFR.

Finally, for the estimation of future labour force developments and vulnerability to natural disasters, we use the results from the three education scenarios and combine them with the respective prevalences for economic activity and disaster preparedness.

3.1 Population projections

The population in Phang Nga increased from 209,400 in 1990, to 234,200 in 2000, and to 258,500 in 2010; thus, the population increased by around 10% during each 10-year period (NSO Thailand 2014a). This implies that the Indian Ocean tsunami in 2004 did not significantly affect the total population size in the province, especially because foreign tourists accounted for almost half the death toll. To define a possible outcome range for the future population size, we calculated various combinations of assumptions about future fertility and migration, with the TFR set at 1.5, 1.9, and 2.1. The volume of internal net migration is set at zero and 1500; and the volume for international net migrations at zero, 2000, and 4000, as specified by the three migration scenarios. The underlying education scenario is the universal secondary education scenario. For the eight combination scenarios presented, the projected total population in 2060 lies between just over 250,000 and just below 400,000 (Figure 4). Only the combination of zero internal and international net migration and TFR = 1.5 leads to a smaller population size in 2060 than in 2010. All of the other scenarios lead to a projected increase. A TFR of 1.5 in combination with constant net migration numbers, as well as a TFR of 1.9 in combination with zero net migration, lead to a population peak before the end of the projection period.

For all of the following results only one scenario for fertility and migration is used: the present values for age- and education-specific fertility rates are kept

Figure 4:
Total population of Phang Nga, based on eight combinations of fertility (TFR),
internal and international net migration
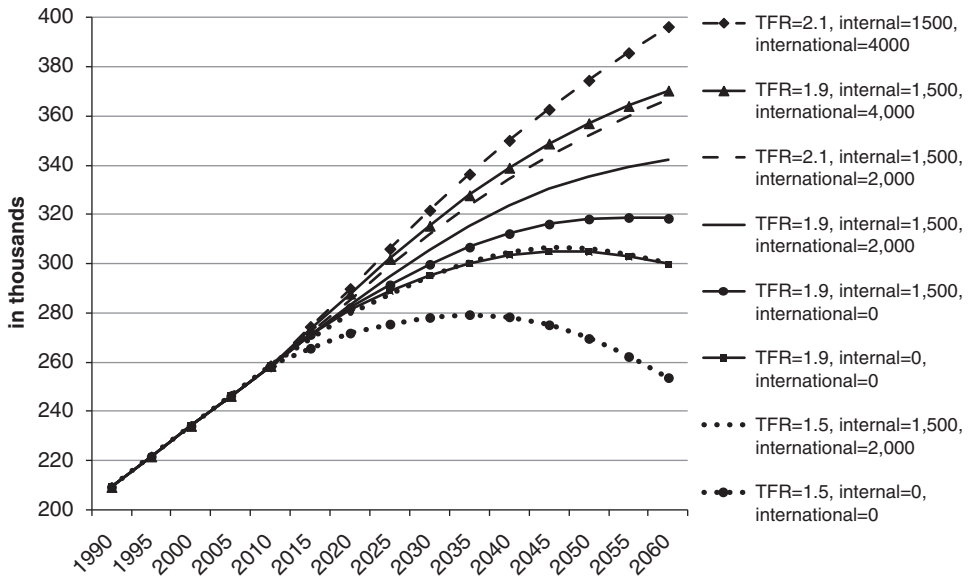
constant, and internal and international net migration are set at a level of 1500 and 2000, respectively, for the whole projection period. In terms of the projected total population, the three education scenarios do not differ much: they vary between 335.7 and 340.6 thousand persons in 2060. This means that the differences between the education groups in terms of fertility and mortality patterns do not have the potential to significantly influence the development of Phang Nga's population in terms of its size. The development of the overall TFR and the volume of migration have much larger effects on future population size. However, as we can see in Figure 5, the educational composition of Phang Nga's future population varies significantly depending on the education scenario: the constant scenario still leads to an increase in the share of the population with at least lower secondary education as younger, better educated cohorts replace older cohorts. The increase in the share of adults with at least lower secondary education is much smaller though—from 37% in 2010 to 58% by 2060—than it is in the two cases in which universal lower secondary education is achieved (81%).

Figure 5:
Educational composition of the population ages 15+, Phang Nga, by education scenario, 2010 to 2060
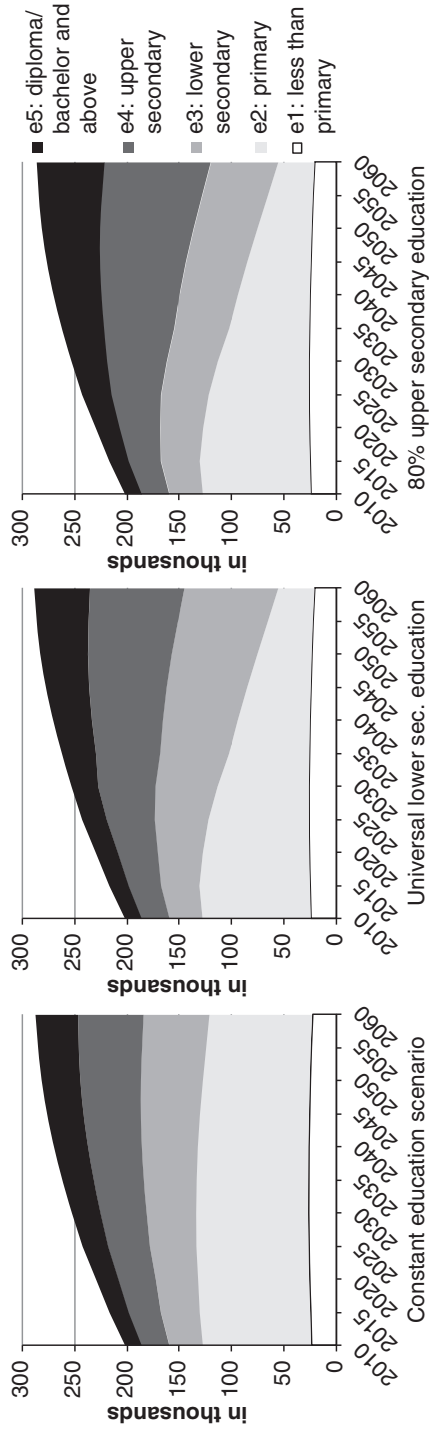
Source: Own calculations.

Table 4:

Composition of the labour force ages 15+, by three education scenarios, 2030 and 2060, in combination with the constant labour force participation scenario

|	Education scenario	At most primary education	Secondary education	Post-secondary education
2010	–	63%	28%	9%
2030	Constant education scenario	51%	38%	11%
	Universal lower sec. education	41%	48%	11%
	80% upper secondary education	41%	44%	15%
2060	Constant education scenario	40%	47%	13%
	Universal lower sec. education	13%	68%	19%
	80% upper secondary education	13%	64%	23%

Source: Own calculations.

3.2 Labour force projections

In order to see the effect of the three different education scenarios on the composition of the labour force in Phang Nga, labour force participation is initially kept constant at the age-, sex-, and education-specific rates observed in 2010 (cf. Figure 3). For each education scenario, the labour force is likely to be composed of workers with higher levels of educational attainment than is currently the case, in which 63% of workers have primary education or less, 28% have lower or upper secondary education, and only 9% have a post-secondary degree (Table 4). Presumably, these changes in the education structure of the labour force will lead to increases in productivity. Even though we do not attempt to quantify these increases in the population module, the large projected decrease in the share of the labour force with primary education or less will very likely be beneficial for economic output.

In order to see the effect of changing labour force participation rates, the second education scenario (universal lower education) is combined with the two scenarios of labour force participation. Since the differentials in education-specific participation rates do not vary much between men and women (cf. Figure 3), we see no significant difference in the educational composition of the labour force when we compare the two participation scenarios. However, as expected, the absolute size of the labour force changes in the different scenarios (Figure 6). If participation rates stayed at current levels, the labour force would be significantly smaller in the years to come than if female participation levels reached male levels by 2060. The aggregate labour force participation rates on the right illustrates this even better, as they also include information on the development of the total population over age 15. In the constant case, overall participation would decline from 0.77 to 0.68 in the coming decades; whereas in the case of an equalisation of participation rates, overall participation would almost return to current levels after an initial decline.

Figure 6:
Size of the labour force and aggregate labour force participation rate of the population ages 15+, by two labour force participation scenarios, 2010 to 2060, in combination with the universal lower secondary education scenario
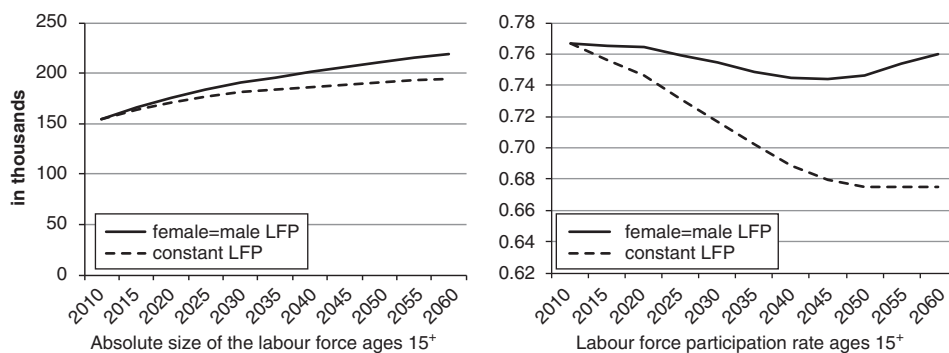
Source: Own calculations.

There is of course uncertainty about how labour force participation will evolve, particularly since our study area is rather small and only comprises about 260,000 persons. Still, irrespective of how future participation rates develop, the educational attainment structure of the population will very likely shift towards higher levels. Thus, we can assume that in the future the labour force will be composed of workers with higher human capital than today's workers have. The assumption that men and women will participate equally represents an extreme scenario; since this scenario has not materialised in even the most egalitarian societies, it is highly unlikely that it will apply to Phang Nga. In addition, the participation rates of the population ages 65+ are currently higher than they are in more advanced economies, and might decline in the future. An indication of this trend is the decline in the share of the population working in the agricultural sector. The share of the employed population who work in this sector in Phang Nga decreased between 1990 and 2000, from 65.3% (1990) to 55.4% (2000) (NSO Thailand 2014a). Changes in the sectoral composition of the elderly labour force (i.e. away from agriculture, in which informal employment is particularly common in Thailand (ILO 2013)) and in retirement provision (i.e. away from the traditional system based primarily on family support and towards a system of pension benefits) would very likely lead to lower participation levels among older people than we currently observe. Given these considerations about the economic activity trends among women and older workers, the equalisation scenario is clearly a maximum scenario. Even the constant scenario in which participation levels remain the same may not accurately reflect future developments. Still, since any assumptions about a decline in participation levels would be pure speculation, we abstain from showing any labour force scenario with reduced participation.

Table 5:
Disaster preparedness by sex and highest level of education attainment, survey population ages 25–54

	% No	% Yes	N
Male			
Lower secondary education or less	91.8	**8.2**	61
Upper secondary education and above	64.0	**36.0**	25
Female			
Lower secondary education or less	82.6	**17.4**	46
Upper secondary education and above	67.6	**32.4**	37

Note: The question in the survey was: 'Does your household have any preparation in case a disaster strikes?' The answers are only those of respondents without previous disaster experience (*n* = 169).

Source: Provincial survey 2013, please see text for details, own calculations.

3.3 Examples for an application to project disaster vulnerability

In our first attempt to quantify the province's future vulnerability to disaster, we combine the results from the education-specific population projections with findings from the 2013 survey of a provincial representative sample of 467 households in Phang Nga on disaster preparedness (for details about the survey, see Basten et al. 2014). Of the many factors that contribute to Phang Nga's vulnerability to natural disasters, education turned out to play a prominent role: Muttarak and Pothisiri (2013) investigated how well the coastal population was prepared for earthquakes and tsunamis, and found that the disaster preparedness of individuals increased with the level of formal educational attainment. Making use of the figures in the table below, which are based on data from the 2013 survey of households in Phang Nga on disaster preparedness, we calculated the share of the 25–54-year-old population in Phang Nga who said they had prepared for disasters, based on the sub-sample of those who did not experience the 2004 tsunami (Table 5). There is a clear education gradient: 36% of the males and 32.4% of the females with at least upper secondary education said their household had undertaken some kind of disaster preparation, whereas the respective numbers for those who had at most lower secondary education were 8.2% and 17.4%.

The distribution is based only on the sub-sample without disaster experience. If we had included the whole sample, the fact that the share of the population in the sample who had already experienced the tsunami in 2004 would have changed over time could have biased our outcome: their share would not have been constant, and their numbers would have diminished as younger cohorts replaced older cohorts. Assuming there is no natural disaster between now and 2040, no one in the specified age group will have previously experienced a disaster if there is a disaster at any point after 2040.

Table 6:
**Disaster preparedness, population ages 25–54, by education scenario and sex, 2010 and 2040 to 2060**

Scenario 1: constant enrolment rates			
Year	**% total**	**% male**	**% female**
2010	18.1%	14.9%	21.5%
2040	20.7%	18.1%	23.5%
2050	21.2%	18.7%	23.8%
2060	21.4%	18.9%	23.9%
Scenario 2: universal lower secondary education			
Year	**% total**	**% male**	**% female**
2010	18.1%	14.9%	21.5%
2040	23.8%	22.0%	25.6%
2050	25.5%	24.3%	26.8%
2060	26.2%	25.2%	27.2%
Scenario 3: 80% have at least upper secondary education			
Year	**% total**	**% male**	**% female**
2010	18.1%	14.9%	21.5%
2040	26.0%	25.3%	26.8%
2050	28.2%	28.2%	28.2%
2060	28.7%	28.9%	28.5%

Source: Own calculations.

Due to the projected changes in the education level of the population, combining the survey results with the education projections leads to an increase over time in the share of 25–54-year-olds who are disaster-prepared, as shown in Table 6 (column 2). Not surprisingly, the increases are particularly pronounced for the two scenarios with significant increases in completed lower secondary education. Columns 3 and 4 give the results additionally by sex, pointing out the gender differences in disaster preparedness and educational attainment.

In another attempt to quantify the expected positive effect of higher educational attainment levels on the region's vulnerability to natural disasters, we positioned Phang Nga in a global overview that shows the relationship between the proportion of women aged 20–39 with at least secondary education and the log number of deaths from climatic natural disasters (Figure 7). This graph is part of the analysis by Pichler and Striessnig (2013), which confirmed previous findings about the correlation between women's educational attainment and the number of deaths due to natural disasters (Striessnig et al. 2013). Locating Phang Nga according to its share of women aged 20–39 with at least lower secondary education in 2010, and

Figure 7:
Relationship between disaster deaths and female education

Countries with more than 30 disasters
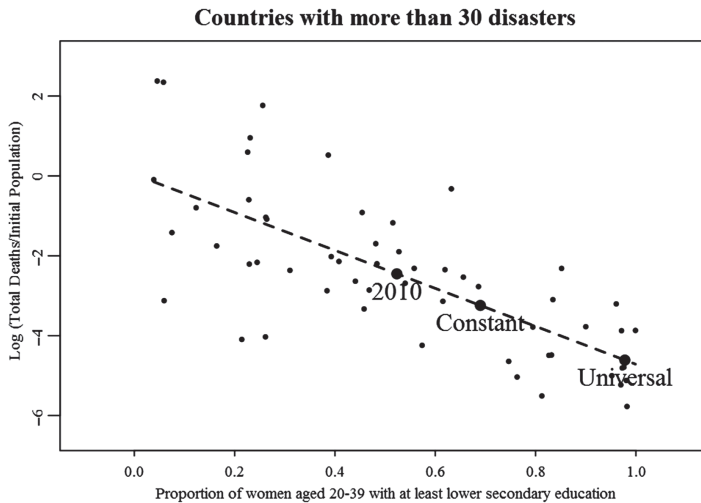
Source: Reproduction of Figure 2 in Pichler and Striessnig (2013), p. 86: relationship between the log of deaths from climatic natural disasters including floods, droughts, and storms per 1000 of the 1980 population (CRED 2004) and female education, proportional to secondary and higher education among women aged 20–39 (Lutz et al. 2007), for 56 countries with one or more disasters on average per year. Modification: addition of the position of Phang Nga (1) 2010 (2) under the constant education scenario in 2060 (3) under the universal lower secondary education scenario in 2060.

under the constant and the universal lower secondary education scenario in 2060 on the regression line in Figure 7, we would expect that if Phang Nga were to be hit by another natural disaster, the number of deaths would be lower in the future than it would be today.

4 Conclusion

In this paper we introduced the innovative four-dimensional structure, and presented the first results of the population module designed for an inter-disciplinary systems model of population-environment interactions and the assessment of likely future vulnerabilities to natural disasters in the specific case of the Phang Nga province in Thailand. Combining alternative scenarios of future education distributions and labour force participation by age and sex, we illustrated the scenario space in the population module that should be considered in the fuller model of population-development-environment interactions, which is still under development. This is to our knowledge the first such comprehensive four-dimensional population projection

cross-classifying education and labour force participation by age and sex, apart from an earlier application developed for Austria (Loichinger and Lutz 2014).

In terms of demographic outcomes, we showed how the future development of the absolute size of the population of Phang Nga depends on internal and international migration and the levels of fertility, although the likely range of future fertility is rather narrow because the current levels are already low. Changes in the volume of migration have the potential to significantly influence overall population development. This is an area in which the population module will be significantly influenced by the economic development module, which is not yet operational, but will be added in future research. Based on expected changes in the educational composition of future cohorts, increases in the educational level of Phang Nga's population are very likely. But here again, there may be feed-backs from other parts of the model to these education trends. Future research linking the four-dimensional population module with economic and development modules will provide better insight into Phang Nga's future adaptive capacities.

This exploratory work on scenarios for the population module of a broader model for the province of Phang Nga showed that, if past trends continue, Phang Nga will most likely have a population and a labour force with higher levels of human capital than in the past. The functional causality between the level of education and the reduction in disaster vulnerability has been established elsewhere, and was discussed in the introduction. This link between the disaster preparedness levels of individuals and their levels of education will likely mean that the future population of Phang Nga will be less vulnerable than the current population to natural disasters or extreme events such as tropical storms resulting from climate change. These results are, however, tentative, and the whole systems model will undergo extensive sensitivity analyses and testing that will include likely feed-backs from other modules of the model, as well as further assessments of the validity of the assumption of functional causality.

Internal as well as international migration has the potential to quickly change the population size and the age, sex, and education composition of a small area like Phang Nga. Unfortunately, of all the data used for this article, the data for migration have the most limitations. Irregular migrants from outside of Thailand may not be adequately represented in the census data, even though the latest census in 2010 was supposed to cover them. Similarly, we have no information about the education levels of internal or international migrants. However, as most of the international migrants in the province are labour migrants from Myanmar, Cambodia, and Laos (United Nations 2013b), assigning them the education profile of the populations in these respective countries seems justifiable. At the same time, we are aware that migrant selectivity could affect the accuracy of our projections: for example, if the labour migrants who come to Phang Nga continue to be mainly unskilled, our assumption about the education profiles of international migrants will be biased towards higher levels of education than will actually be observed.

In general, the size and the composition of the future in- and outflow of internal migrants will depend in part on the development of labour demand and supply in

both Phang Nga and the rest of Thailand. Aspects of this issue will be covered in the upcoming economic development module. International in- and out-migration may also be influenced by changes in migration regulations and policies.

Another limitation of our study is that we had to use data for the southern region when specific provincial information for Phang Nga was not available; e.g. for the overall TFP level and education differentials in fertility. We also made the simplifying assumption in the absence of any further information that all of the internal migrants were born in Thailand, and that all of the international migrants were born outside of Thailand. This assumption is clearly not accurate, but should not introduce a large bias, not least because the net migration numbers that went into the projections are quite low.

The novel 4-D population module presented in this paper allows us to project future populations by age, sex, level of education, and labour force participation. The application of this approach to the population of Phang Nga showed that in the coming five decades the province can expect to have a population and a labour force who are better educated than they are today. This trend may be expected to translate into a greater adaptive capacity for future environmental challenges, as it has been previously shown that better educated societies and communities are less negatively affected by natural disasters, and are better able to cope with their consequences.

Acknowledgments

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