

Current Demographic Conditions and Future Scenarios in Mexico's Coastal Zone

Condições Demográficas Atuais e Cenários Futuros das Zonas Costeiras Mexicanas

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ABSTRACT: Knowing the behavior of population dynamics in coastal areas is an essential element for its proper management. Using historical information, in this paper, estimates of the total population in the coastal states of Mexico are made up to the year 2050 with an analysis of the population dynamics in the coastal municipalities for the years 2000, 2005, 2010 and 2015. According to the latest census, Mexican total population reached 102 million people in 2015 with 55,3 million (46 %) living in coastal states. In the 17 coastal states of Mexico, a total of 158 municipalities with direct access to the sea were identified in 2015, in which 18,9 million inhabitants lived. During the period 2010 to 2015 the highest relative population growth rate at state level was observed in Quintana Roo (13.3%). In 2015, the coastal municipality of Tijuana in Baja California State was the most populated in the coastal zone with 1,6 million inhabitants. In 15 years (2000-2015), 4 municipalities have increased their population by 100% or more, prevailing in these localities activities related with international tourism. The coastal population growth rate for the period 2010-2015 showed a deceleration compared to 2005-2010. By the year 2050, a population of 65 million people living in the coastal states of Mexico was estimated. The results presented in this study give elements to the decision makers to strengthen the planning and management processes of the Mexican coastal zone in the medium term.

Keywords: Coastal population; Mexican coastal zone; Coastal population prediction; Population dynamics.

RESUMO: Conhecer o comportamento da dinâmica populacional em áreas costeiras é um elemento essencial para uma gestão adequada. Usando informações históricas neste trabalho, foram feitas estimativas do total da população nos estados costeiros do México até ao ano 2050 usando uma análise da dinâmica populacional nos municípios costeiros para os anos de 2000, 2005, 2010 e 2015. De acordo com o último censo, a população total mexicana atingiu 102 milhões de pessoas em 2015, com 55,3 milhões (46%) vivendo em estados costeiros. Nos 17 estados costeiros do México, foram identificados em 2015, 158 municípios com acesso direto ao mar, nos quais viviam 18,9 milhões de habitantes. Durante o período de 2010 a 2015, a maior taxa de crescimento relativo da população a nível estadual foi observada em Quintana Roo (13,3%). Em 2015, o município costeiro de Tijuana, no estado de Baja California, foi o mais populoso da zona costeira, com 1,6 milhões de habitantes. Em 15 anos (2000-2015), 4 municípios aumentaram sua população em 100% ou mais, predominando nessas localidades atividades relacionadas com o turismo internacional. A taxa de crescimento da população costeira para o período 2010-2015 mostrou uma desaceleração em relação a 2005-2010. No ano 2050, foi estimada uma população de 65 milhões de pessoas vivendo nos estados costeiros do México. Os resultados apresentados neste estudo fornecem elementos para a tomada de decisão para fortalecer os processos de planeamento e gestão da zona costeira mexicana no médio prazo.

Palavras-chave: População costeira; Zona costeira mexicana; Previsão da população nas zonas costeiras; Dinâmicas populacionais.

1. INTRODUCTION

The population dynamics in coastal areas is a topic that should be addressed as a key element in the planning and managing processes of these unique and fragile territorial regions. The spatial distribution of the human settlements, the total population and the population growth rate can influence the development of these areas, by direct modifications in the use of soil, alterations of the landscape and natural vegetation cover, contamination, increase in energy demand, depletion of aquifers and natural resources, impacts on environmental functions and services, loss of biodiversity, increase in the risk and vulnerability to climate change, extreme meteorological events and flood impacts, among other factors. In Mexico's coastal counties (the smallest administrative unit), between 1993 and 2011, 2 million hectares of natural vegetation were lost (POEGT, 2012). This amount represents 6.4% of the original extension and is roughly comparable to the territorial extent of Slovenia in Europe or New Jersey State in USA. In the case of Mexican coastal states, five were categorized in 2015 with an energy deficit (SENER, 2016). In the Northwest region of Mexico (Baja California, Baja California Sur, Sonora and Sinaloa States), 13% of the aquifers are overexploited or salinized (SINA, 2018), most of them located in coastal areas. In the coastal states of Mexico, the number of federal emergency declarations for hydro-meteorological disasters (i.e. droughts, frosts, cold fronts, rains, strong winds, hail, floods and hurricanes) increased from 157 in year 2001 to 1 293 in year 2010 (CNPD, 2018).

Some authors have reported that over 50% of the world population lives within 200 km of the coast (Hinrichsen, 1998), around 1,2 billion at a distance less than 100 km

from the coastline (Small and Nicholls, 2003), and between 625 to 637 million below the altitude of 10 m (Neumann *et al.*, 2015; Merkens *et al.*, 2016). Coastal areas also support a large part of global productive activities such as agriculture, forestry, industry, commerce, tourism, transport, aquaculture, and mining; strategic facilities for defense, navigation, power generation and oil extraction; and are the most visited places for recreational, leisure, and contemplative purposes (Cicin-Sain and Knecht, 1998; Crossland *et al.*, 2005; Kay and Alder, 2005, Azuz *et al.*, 2018a). This additional flow of visitors puts additional pressure on the coastal resources. In 2017 the total number of foreign tourists that visited Mexico was 39,3 million and the hotel occupancy of domestic travelers was 58,9 million. Only 3 of the main beach destinations registered a total of 10,6 million visitors in 2017 - Los Cabos, Baja California Sur, Puerto Vallarta, Jalisco, and Cancún, Quintana Roo (DataTur, 2017).

According with Barragán and de Andrés (2016), in Latin America coastal cities with 100 000 inhabitants or more experienced and impressive growth in 70 years, going from 20 to 180 million people living within 100 km of the coast. In the coastal counties of the United States the population increased from 47 million in 1960 to 87 million in 2008 (Wilson and Fischetti, 2010). In both cases, Latin America and USA, the coastal population growth rate was higher than in inland. In 2008, around 205 million people lived in the coastal regions of the European Union, defined as countries with coastline or with more than half of their population living less than 50 km from the sea (Eurostat, 2011).

According to the latest census, Mexican total population reached 102 million people in 2015 (INEGI, 2018a), with 55,3 million (46 %) of people living in coastal states.

This percentage (46%) has been maintained during the last 4 population census (i.e. 2000, 2005, 2010 and 2015) despite the national population growth. In the 17 coastal states of Mexico, a total of 158 municipalities with direct access to the sea (i.e. coastal counties) were registered in 2015, in which 18,9 million inhabitants lived. The proportion of inhabitants of coastal states living in coastal municipalities has remained approximately at 34% between 2000 and 2015.

Azuz and Rivera (2007) predicted the population growth in Mexico's coastal states for the period 2010 to 2050, obtaining for 2010 a forecast with an error of approximately 2% with respect to the measured value. Azuz and Rivera (2009) analyzed the demographic dynamic at county level for the Mexican coastal zone during the period 2000 to 2005, founding that half of the population living in 156 coastal counties across the nation were located only in 16 municipalities. It was also reported a population reduction in 70 coastal counties, which suggested the existence of nearby poles of population attraction, which fostered the internal flow of people, possibly associated with the availability of jobs related with the development of new tourism centers and the creation of port infrastructures.

At national level, different authors have analyzed the demographic development of the Mexican coastal zone, using different definitions of this territorial region. Cabrera (1993) considering the population located below 500 m of altitude and 100 km to the coastline; Gutiérrez and Gonzalez (1999) looking at coastal settlements with more than 10 000 inhabitants located between seal level and 200 m of altitude; Juárez (2000) using urban locations (more than 15 000 inhabitants) in coastal counties; Padilla-Sotelo (2000) considering municipalities with maritime contact; Gabriel-Morales y Perez-Damian (2006) seeing the counties with direct access to the sea and the inland contiguous counties with maritime influence. At local scale (subnational and county level) several authors explore the relationships between population growth, internal migration, environmental resources, vulnerability, quality of life and socioeconomic development (Castillo *et al.*, 2014; Arizpe-Covarrubias *et al.*, 2015; Solís *et al.*, 2015; González-Baheza and Arizpe, 2018; Torre and Fernández, 2018; Garrocho and Jiménez, 2018).

In Mexico, the General Population Law of 1974 is the legal framework of the population policy and two governmental bodies the National Population Council (CONAPO) and the State's Population Councils (COESPOs) are responsible of the policy implementation and administration of the demography planning at national, state and municipal levels. The main strength

of the population policy is based in the interinstitutional coordination. The National Population Program, as an official governmental program, establishes a population policy linked to public programs and actions that contribute to the socioeconomic development, territorial integration, poverty alleviation, inequity reduction, human welfare investment and the protection of the environment (PNP, 2014). The institutionalization of the population policies promoted the intergovernmental coordination, the capacity to respond to emergent topics and adapt to new challenges, where CONAPO and COESPOs had to settle conflicts between different actors. With this vision, it can be understood that acting on population topics has repercussions within every sphere of the development. At this threshold, the COESPOs are involved into the demographic, social and economic planning, and produced the State Population Programs (Muñoz, 2010; Mojarro *et al.*, 2011).

In this paper we analyze the population dynamics in 158 Mexican coastal counties with direct access to the sea identified in the 2015 population census. As a complement of previous research (Azuz and Rivera, 2007, 2009), it is presented, with five-year intervals, the prediction for the population growth in each Mexican coastal state until 2050.

2. STUDY AREA

Mexico has a territorial extension of 5 million km², from which 1,9 million km² correspond to terrestrial areas and 3,1 million km² to marine zones (see Figure 1). The country poses around 11 122 km of coastline, shared among 17 coastal states and 158 coastal counties (smallest administrative unit) with direct access to the sea. According to Silva *et al.* (2014), sandy beaches comprise 75,7% of the total Mexican coastline. These beaches are worldwide recognized by their beauty and domestic and international visitors enjoy the activities associated with the use of their coastal and marine areas. The east coast (Gulf of México and Caribbean Sea) consists of 6 states: Tamaulipas (TAM), Veracruz (VER), Tabasco (TAB), Campeche (CAM), Yucatán (YUC) and Quintana Roo (QROO), and 3 294 km of coastline, while the west coast (Pacific Ocean and Gulf of Cortés), with 7 828 km of coastline, has 11 states: Baja California (BC), Baja California Sur (BCS), Sonora (SON), Sinaloa (SIN), Nayarit (NAY), Jalisco (JAL), Colima (COL), Michoacán (MICH), Guerrero (GRO), Oaxaca (OAX) and Chiapas (CHIS).

Mexico is considered a mega-diverse country (UNEP/CBD, 2016), part of the group of countries with 70% of global biodiversity. This rich biological diversity is mainly due to its location with coasts in both the

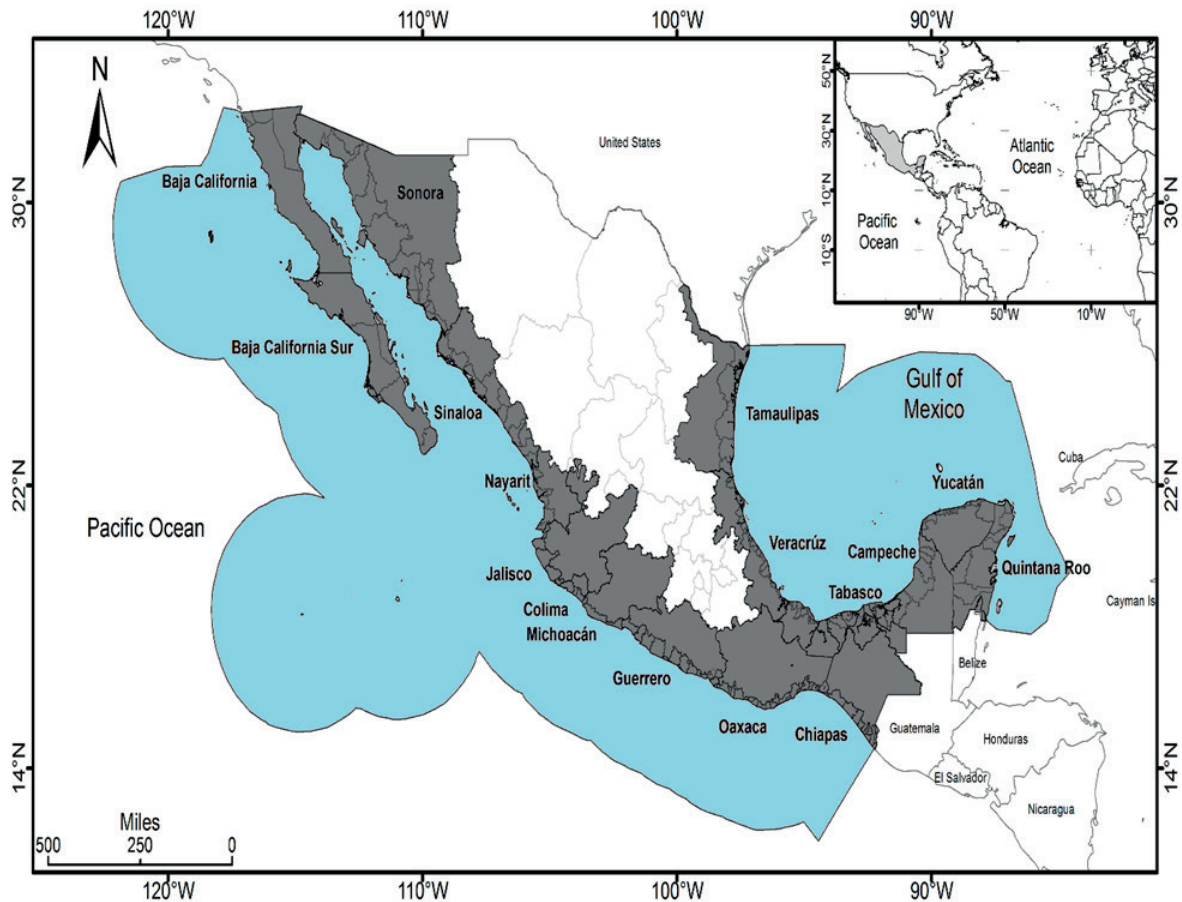


Figure 1. Study area. Mexican coastal states and coastal counties (gray) and Economic Exclusive Zone (light blue).

Figura 1. Área de estudio. Estados e municípios costeiros do México (cinza) e Zona Econômica Exclusiva (azul).

Atlantic and the Pacific Oceans; latitudinal extension (14°-32° North); continental, insular and maritime size; physiographic variety from “sierras” (mountain range) to coastal plains; geomorphology including 2 peninsulas and 2 semi-enclosed seas, the Sea of Cortez and the Gulf of México; and climatology (from humid to desert). The Mexico’s coastal zone includes most of the coastal environments such as: sandy, muddy and rocky coast, wetlands, estuaries, coastal lagoons, tidal inlets, deltas, barrier coasts and several coral reef areas with the second largest in the world (Azuz *et al.*, 2018b).

Three administrative levels operate in the coastal areas of Mexico: the federal (national) level, the state (region or province) level and the municipality (local) level. All these governmental levels have legal, regulatory, management and planning responsibilities over the coastal zone, which often overlap and frequently find problems (e.g. regulatory, economic, technical capacities) to implement long-term projects or actions. The federal inter-ministerial body in charge of the seas and coast in Mexico is the Commission for the Sustainable Development of Seas and Coasts

(Comisión Intersecretarial para el Manejo Sustentable de Mares y Costas – CIMARES), but also the ministry of environment (Secretaría de Medio Ambiente y Recursos Naturales – SEMARNAT), the ministry of agriculture, livestock, rural development and fisheries and food (Secretaría de Agricultura y Desarrollo Rural – SAGARPA), the ministry of development and planning (Secretaría de Desarrollo Agrario, Territorial y Urbano – SEDATU), the tourism ministry (Secretaría de Turismo – SECTUR) and governmental research institutes like the National Institute for Ecology and Climatic Change (Instituto Nacional de Ecología y Cambio Climático – INECC), among many others official bodies that have responsibilities and powers to act in the coastal zone. The official governmental body in charge of the population census is the National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía – INEGI).

3. METHODOLOGY

In this paper, historic census information about total population at national level and state level was used for

the years: 1930, 1940, 1950, 1960, 1970, 1980, 1990, 1995, 2000, 2005, 2010 and 2015. At county level, the total population was used for the years: 2000, 2005, 2010 and 2015. In all the cases the information comes from official sources of the National Institute of Statistics and Geography (INEGI, 2018a), for decadal information the National Census of Population and Houses provides the data and for the inter-decadal information (1995, 2005 and 2015) the National Counting of Population and Houses.

The historical information was used for predictive purposes. A total population forecast for each coastal state was done for the period 2020 to 2050, in every five years. Following Azuz and Rivera (2007), the population growth forecasts for the coastal states of Mexico were made after the estimation of the parameters of a sigmoidal model (equation 1), which had shown a good predictive performance.

$$P(t) = \frac{A_1 - A_2}{1 + e^{(t-t_0)/dt}} + A_2 \quad (1)$$

In which “P” is the total population at time “t”, “A₁” and “A₂” are the lower and upper asymptotic limits of the function respectively, “t₀” the inflection point of the curve and “dt” is related with their slope. The total population of each coastal state was estimated from 2020 to 2050.

Due to the short period of information available at county level, the analysis of the demographic behavior at this scale (coastal municipalities) was descriptive in nature. Percentile analysis were performed for the total population, absolute population growth and relative population growth rate.

During the study period the number of coastal counties considered changes from 153 in 2000 to 156 in 2005 and later on to 157 in 2010 and 158 in 2015. There are political and administrative reasons for this, e.g. the creation of new coastal counties splitting the territory of one coastal county – which remains as a coastal, or the partition of an originally coastal municipality in two, with one of them ceasing to be coastal. The coastal counties: Juchitan (GRO), Marquelia (GRO), San Rafael (VER), Bacalar (QROO) and Tulum (QROO) belong to the class of new municipalities for which complete census information is not available for the full analyzed period. Also is important to mention that the new municipality of Puerto Morelos (QROO), created in 2016, was not considered in this study.

One hypothesis proposed and analyzed during this

study was the fact that at county level the increase or decrease in population could be associated not only with employment and development opportunities (as a positive element or population attracting factor) but also with the local violence conditions produced by the drug cartels (population expeller). A correlational analysis at county level was performed between the absolute population growth in 2000-2005, 2005-2010 and 2010-2015, and the total number of violent homicides (INEGI, 2018b).

4. RESULTS AND DISCUSSION

4.1 Demography of coastal states

The total population in Mexico reached 102 million people in 2015, with 55,3 million (46 %) living in coastal states (see Figure 2). The east coast, consisting of 6 states and 3 294 km of coastline, registered a total population of 18,4 million people, while the west coast, with 7 828 km of coastline and 11 states, had a population of 36,9 million people. Considering the historic information available, the decadal absolute growth rate shows a constant increase until 1980, moment in which a slowdown in the growth rate is observed. Between 1970 and 1980, 7,6 million (highest decadal value) new settlers established or were born in the coastal states, and for the period 2000 to 2010 the absolute population growth rate was only 7,2 million people. A different absolute growth rate was observed between east and west coasts, while the same decreasing behavior was observed on the west coast, the east coast showed a slight increase during 2000-2010.

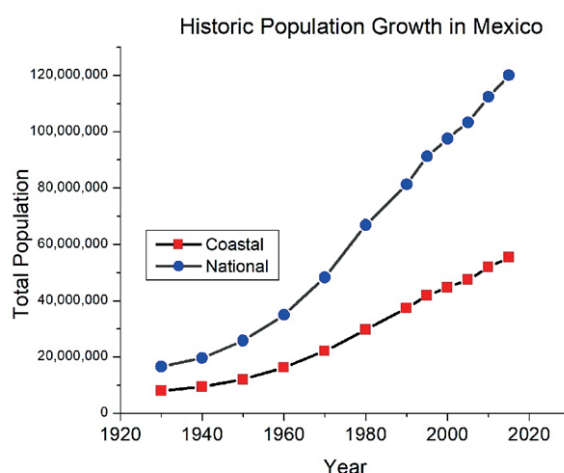


Figure 2. Historic population growth in Mexico. National (circles) and coastal states (squares). Source: data from INEGI, 2018a.

Figura 2. Crescimento histórico da população no México. Nacional (círculos) e estados costeiros (praças). Fonte: dados de INEGI, 2018a.

In 2015 only three coastal states present a total population below 1 million people: Baja California Sur (BCS), Colima (COL) and Campeche (CAM). The state of Veracruz (VER) was the most populated in 2015 with 8,1 million people, followed by Jalisco (JAL), with 7,8 (see Figure 3). For the reference year, the average population density in Mexican coastal states was $58,5 \pm 34,4$ inhabitants/km², going from 126,4 inhabitants/km² in Colima (COL) to 9,6 inhabitants/km² in Baja California Sur (BCS).

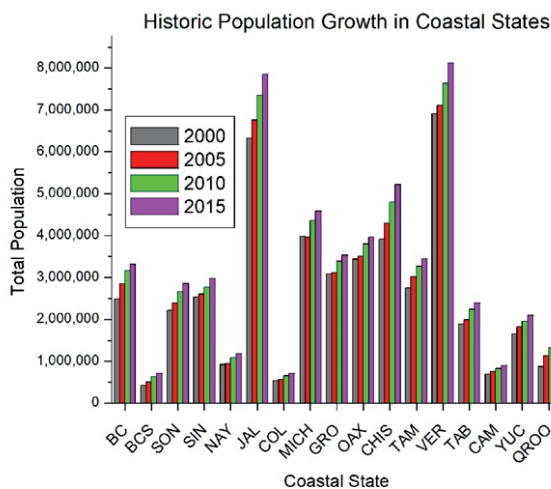


Figure 3. Historic population growth in Mexican coastal states. West coast: Baja California (BC), Baja California Sur (BCS), Sonora (SON), Sinaloa (SIN), Nayarit (NAY), Jalisco (JAL), Colima (COL), Michoacán (MICH), Guerrero (GRO), Oaxaca (OAX) and Chiapas (CHIS). East coast: Tamaulipas (TAM), Veracruz (VER), Tabasco (TAB), Campeche (CAM), Yucatán (YUC) and Quintana Roo (QROO). Source: data from INEGI, 2018a.

Figura 3. Crescimento histórico da população dos estados costeiros do México. Costa oeste: Baja California (BC), Baja California Sur (BCS), Sonora (SON), Sinaloa (SIN), Nayarit (NAY), Jalisco (JAL), Colima (COL), Michoacán (MICH), Guerrero (GRO), Oaxaca (OAX) e Chiapas (CHIS). Costa este: Tamaulipas (TAM), Veracruz (VER), Tabasco (TAB), Campeche (CAM), Yucatán (YUC) e Quintana Roo (QROO). Fonte: dados de INEGI, 2018a.

The west coast population increased with a yearly average rate of 0,45 million, while the east coast did it at a 0,24 million rate. The average relative population growth rate for the Mexican coastal states during the period 2010-2015 was 7,5%, with maximum values in QROO (13,3%) and BCS (11,8%), and minimum percentages in GRO (4,3%) and OAX (4,4%). As previously mentioned, both Quintana Roo and Baja California Sur are states in which tourism is the main driver of economic development and consequently a pole of population attraction. The case of Guerrero and Oaxaca is interesting because the accumulated number of births in each state during the

period 2010-2015 was above the national average, but the migratory balance was negative in each state, -1,7 in GRO and -0,7 in OAX. Also, using the latest information available for birth rates at coastal state (2010), the mean value was $2,37 \pm 0,22$ with maximum values in GRO (2,8) and OAX (2,7), and minimum value in QROO (2,0). A possible explanation for this fact could be the increase in violence associated with drug cartels, which presented an alarming increase mainly in GRO, where the number of homicides increased from 804 to 2 424 between 2000 and 2010 (INEGI, 2018b). Figure 4 shows the historic population growth rate in east and west coast coastal states.

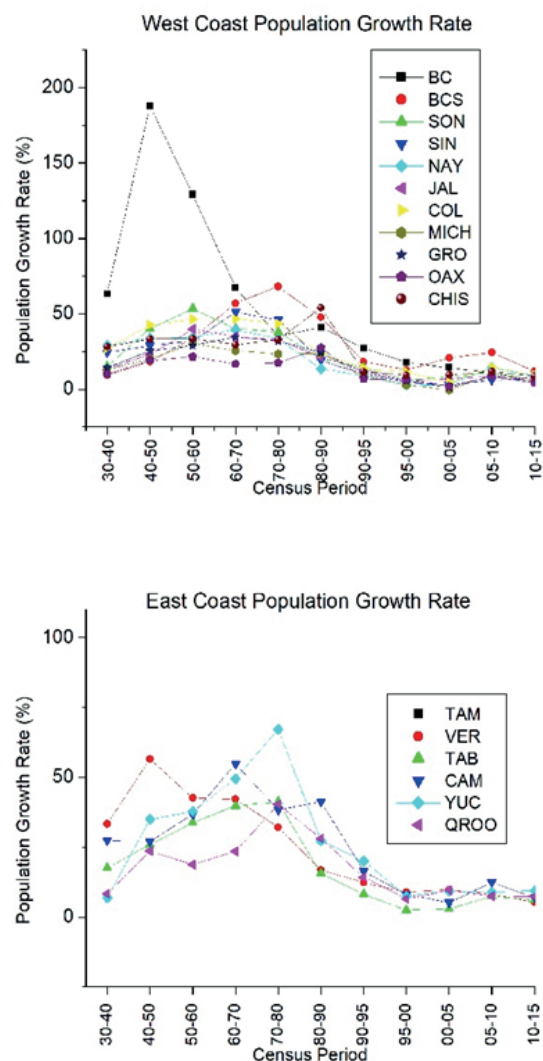


Figure 4. Historic population growth rate in Mexican coastal states. West coast (left) and east coast (right). Source: data from INEGI, 2018a.

Figura 4. Taxa de crescimento histórico da população dos estados costeiros do México. Costa oeste (esquerda) e costa este (direita). Fonte: dados de INEGI, 2018a.

Beside the continuous population growth observed at state level (figure 3), it is interesting to note a generalized (identified in 15 of 17 coastal states) slowdown in the population growth rate between the periods 2005-2010 and 2010-2015. Using the yearly average population growth rate and excluding the two states in which a slight increase was observed (SIN and CAM), in the remaining 15 coastal states the average decrease in the population growth rate was $65\% \pm 14,5\%$.

4.2 Prediction of population growth at coastal states

In order to predict population growth at each coastal state the sigmoidal model gives adequate results (Azuz and Rivera, 2007). It represents the characteristic s-shape curve for population growth, starting with an almost exponential growth following by a reduction in the growth rate and ending with a stabilization period. To validate the models this paper uses commonly used statistical error criteria. The determination coefficient (R^2) for the predictive model and mean absolute percentage error (MAPE) for the hindcast (1930-2015) are shown in Table 1.

According with the model results, at the end of the forecast (year 2050) the most populated coastal states will be Jalisco (JAL) and Veracruz (VER), with 9,3 and 8,3 million people respectively. The state of Veracruz is a long and narrow territory situated in the central part of

the Gulf of Mexico, in which many economic activities are located in the coastal zone, like large port facilities for commercial and fishery uses, coastal power plants (the only nuclear plant in Mexico is located in this state), a well-established agricultural and livestock development, a rich biodiversity, a variety of beach tourism locations in a wide range of costs and several historic places and world heritage sites are located near the coastal zone. The population growth in VER has been and will continue to be clearly associated with its coastal and marine areas. In contrast, JAL is a coastal state with a low level of coastal and marine activities in which the population growth is associated with the state capital which is among the largest cities in Mexico, but with a low relation with its coastal and marine spaces. In the other side of the spectrum, in 2050, only Colima state (COL), the smallest coastal state in Mexico, according to the predictions of the model, it will not reach 1 million inhabitants. The predicted total population in Mexico's coastal states is seen in Table 2.

It is important to mention that the model used has a statistical character that consider only the historic data behavior, contrary to the process-based models (e.g. CONAPO), which incorporate elements such as: birth and death rates, domestic and international migration, gender distribution or structure of ages. Figure 5 shows the observed and predicted total population for two states Quintana Roo (highest R^2 value) and Nayarit (lowest R^2 value).

Table 1. Determination coefficient (R^2) obtained for the population growth predictive model used in each coastal state and the hindcast (1930-2015) mean absolute percentage error (MAPE).

Tabela 1. Coeficiente de determinação (R^2) obtido entre o modelo de crescimento populacional e o erro percentual absoluto (MAPE) do hindcast (1930-2015).

Coastal State Acronym	Determination Coefficient (R^2)	Mean Absolute Percentage Error (MAPE) (%)
BCS	0,9974	6,09
SON	0,9980	4,03
SIN	0,9970	2,45
NAY	0,9912	4,42
JAL	0,9986	2,35
COL	0,9977	3,62
MICH	0,9958	1,65
GRO	0,9984	0,97
OAX	0,9972	1,71
CHIS	0,9976	3,26
TAM	0,9987	3,17
VER	0,9957	2,41
TAB	0,9983	1,91
CAM	0,9976	3,84
YUC	0,9990	1,52
QROO	0,9996	6,28
Average	0,9973	3,53

Table 2. Predicted total population in Mexican coastal states.

Tabela 2. Previsão da população total dos estados costeiros do México.

State	2020	2025	2030	2035	2040	2045	2050
BC	3 665 634	3 902 260	4 105 014	4 275 061	4 415 131	4 528 807	4 619 956
BCS	815 583	915 933	1 012 788	1 103 354	1 185 564	1 258 206	1 320 879
SON	2 984 668	3 130 677	3 260 236	3 373 649	3 471 755	3 555 749	3 627 031
SIN	2 924 835	2 965 205	2 994 379	3 015 303	3 030 230	3 040 838	3 048 355
NAY	1 197 967	1 250 467	1 298 685	1 342 577	1 382 210	1 417 735	1 449 371
JAL	8 098 687	8 396 974	8 648 352	8 857 359	9 029 195	9 169 172	9 282 341
COL	751 275	797 481	839 712	877 727	911 483	941 094	966 795
MICH	4 593 669	4 679 132	4 745 794	4 797 310	4 836 835	4 866 993	4 889 907
GRO	3 576 924	3 644 042	3 694 767	3 732 728	3 760 929	3 781 765	3 797 097
OAX	4 088 464	4 203 826	4 299 370	4 377 497	4 440 719	4 491 450	4 531 882
CHIS	5 498 744	5 773 671	6 001 627	6 186 881	6 334 991	6 451 866	6 543 144
TAM	3 653 080	3 840 128	4 011 829	4 167 724	4 307 864	4 432 717	4 543 065
VER	7 972 547	8 077 646	8 154 917	8 211 324	8 252 288	8 281 925	8 303 307
TAB	2 475 842	2 564 209	2 633 495	2 686 955	2 727 694	2 758 446	2 781 494
CAM	924 698	958 156	984 214	1 004 177	1 019 279	1 030 594	1 039 013
YUC	2 176 997	2 254 976	2 317 063	2 365 651	2 403 166	2 431 828	2 453 553
QROO	1 627 803	1 719 007	1 780 747	1 821 215	1 847 184	1 863 620	1 873 934
TOTAL	57 027 416	59 073 790	60 782 987	62 196 492	63 356 516	64 302 807	65 071 126

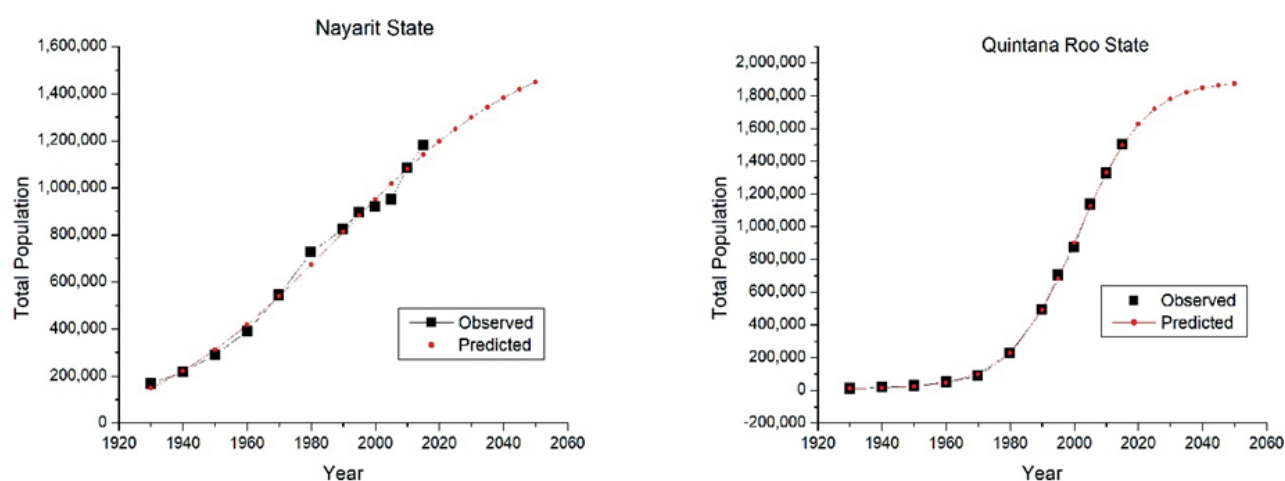


Figure 5. Observed and predicted total population in Nayarit State (left) and Quintana Roo State (right). Source: data from INEGI, (2018a) and model results.

Figura 5. População total observada e prevista nos estados de Nayarit (esquerda) e Quintana Roo (direita). Fonte: dados INEGI (2018a) e resultados de modelo.

An advantage of having a medium term (five years) estimate of the total population of each coastal state is that local authorities can use this information for planning purposes. By law, in Mexico the administrative term of local governors is 6 years, in this case they can use these predicted values to establish the requirements of: infrastructure, water availability, public services and employment needs, among other elements, up to the year of 2050.

To end the analysis at state level, a brief note about the similarities founded among population growth rates will be presented. A cluster analysis was performed using the average yearly population growth rate among Mexican coastal states, which shows three well defined groups, one of them formed by BC-TAM and OAX-CHIS, the the group formed by YUC-CAM-BCS-QROO (see figure 6). In the first group, BC and TAM are two coastal states located in the border with USA, one of them in the west coast (BC) and the other in the east (TAM). Both states are strongly influenced by the USA-Mexico border socioeconomic and demographic dynamic. The other two states that joined this group, with a medium level of correlation, were OAX and CHIS. As mentioned before, these states show the lowest population growth rate. In other group, BCS and QROO are the two states

with higher top class tourism facilities and are population attraction poles, the incorporation of CAM and YUC could be associated with the safety conditions observed in both states, which could be an emerging study topic for coastal management in Mexico.

4.3 Demography of coastal counties

Centering the analysis in coastal counties, the results show that the total population living in coastal counties in 2015 was approximately 19 million people, which represents the 34% of the total population in coastal states. In the upper 10% of the most populated coastal counties live more than half of the coastal inhabitants (10,2 million), which represent a pressure focus on well-defined spaces of the coastal zone that need to be properly managed. The coastal counties considered in this study and their total population can be seen in Table S1, in supplementary material section.

Along the Mexican coast, a clear disparity could be observed in terms of coastal settlements: 18 coastal municipalities (11 %) have less than 10 000 inhabitants; 101 (64 %) have more than 10 000, but less than 100 000; in 38 (24 %) there were between 100 000 and less than one million inhabitants, and only one coastal county

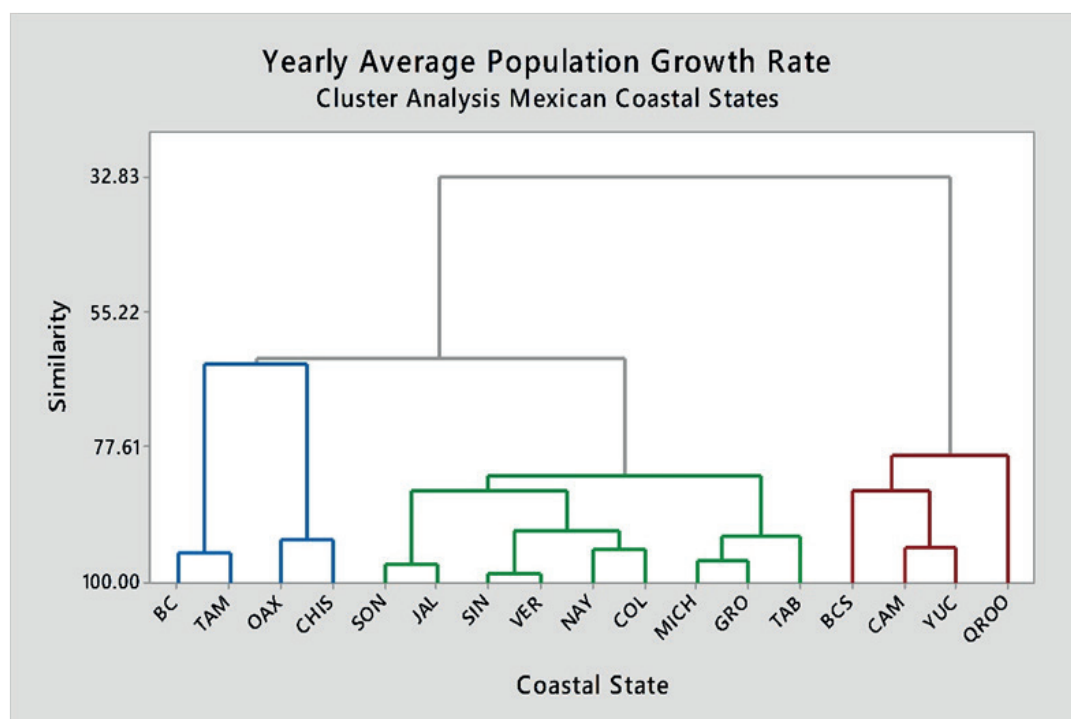


Figure 6. Cluster analysis performed among Mexican coastal states using the yearly average population growth rate for the period 1930-2015, using data from INEGI (2018a).

Figura 6. Análise hierárquica realizada entre estados costeiros usando a taxa de crescimento média anual para o período 1930-2015, com base nos dados de INEGI (2018a).

showed more than one million people. The number of coastal municipalities in each coastal state as well the total coastal population (population living in coastal counties) for the year 2015 can be seen in Table 3. The table also shows an indicator named “coastal density”, defined as the total population living in coastal municipalities divided by the coast length, it need to be used carefully because the population is not distributed uniformly as the indicator assume, on the contrary the population usually is located on a few settlements along the coast. The geographic distribution of the population will be presented and discussed later.

The percentile analysis shows in general that 10% of the most populated coastal counties represent 54% of the coastal states population, while 10% of the municipalities with the lowest population only 0.4%. This relationship was observed during 2000, 2005, 2010 and 2015. On the 16 most populated municipalities in 2000, only 15 remains in 2005, Campeche (CAM) is incorporated by moving Cárdenas (TAB) out of the upper limit. Between 2005 and 2010, all the 16 municipalities considered remain in the upper 10% percentile, merely exchanging positions between them. In 2015, Los Cabos (BCS) is incorporated into the group of the most populated municipalities, displacing Campeche (CAM). The

population growth in Los Cabos is among the highest in Mexico. In 2015, 12 of the 16 most populated coastal counties are located in the west coast: 4 in SIN, 3 in BC, 2 in SON and 1 in BCS, CHIS and GRO (see Table 4). Regarding the less populated municipalities in 2000, 9 were located in YUC, 6 in OAX and 1 in CAM, this proportion was maintained in 2015, with the exception of a new created municipality Juchitán (GRO).

The population growth in Los Cabos (BCS), Mazatlán (SIN), Benito Juárez (QROO) and Acapulco de Juárez (GRO) can be clearly associated with tourism activities and the corresponding infrastructure development. In the case of Tijuana (BC), Mexicali (BC), Hermosillo (SON) and Matamoros (TAM), the observed growth could be the response to their geographic location and administrative level, all the counties are in the border USA-Mexico, a highly dynamic demographic space, and two of them also are state capitals (Mexicali and Hermosillo). Coatzacoalcos (VER) and Cárdenas (TAB) have an important industrial development associated with oil extraction and processing. The other municipalities do not have a predominant activity that can characterize them. Their population growth could be related to commercial, tourist, agricultural, port and/or industrial activities.

Table 3. Number of coastal counties and total population in them (2015) by coastal state, state coastline length (km) and coastal density. (*) In 2016 a new coastal county was created in QROO (Puerto Morelos) this municipality was not considered in this study.

Tabela 3. Número de municípios costeiros e sua população em cada estado costeiro (2015), comprimento da costa (km) e densidade populacional da costa. () Em 2016, um novo município costeiro foi criado no estado de QROO (Puerto Morelos), este município litorâneo não foi considerado neste estudo.*

Coastal State	Number of Coastal Counties	Population Living in Coastal Counties	Coastline Length (km)	Coastal Density (inhabitants / coastline km)
BC	4	3 213 360	1493	2 152
BCS	5	712 029	2131	334
SON	13	2 084 906	1209	1 724
SIN	10	2 542 446	622	4 088
NAY	5	407 287	296	1 376
JAL	5	387 630	351	1 104
COL	3	337 331	142	2 376
MICH	3	222 441	228	976
GRO	13	1 295 569	522	2 482
OAX	20	628 865	568	1 107
CHIS	10	758 614	266	2 852
TAM	6	1 075 191	433	2 483
VER	29	2 214 886	720	3 076
TAB	4	664 713	200	3 324
CAM	6	720 004	425	1 694
YUC	13	208 249	340	612
QROO*	9	1 464 060	1176	1 245
Total	158	18 937 581	11,122	

Table 4. Total population in the most populated coastal municipalities (upper 10% percentile).

Tabela 4. População total nos municípios costeiros mais populosos (percentil superior 10%).

Coastal State	Coastal Municipality	Total Population (people)			
		2000	2005	2010	2015
BC	Tijuana	1 210 820	1 410 700	1 559 683	1 641 570
BC	Mexicali	764 602	855 962	936 826	988 417
SIN	Culiacán	745 537	793 730	858 638	905 265
GRO	Acapulco de Juárez	722 499	717 766	789 971	810 669
SON	Hermosillo	609 829	701 838	784 342	884 273
VER	Veracruz	457 377	512 310	552 156	609 964
QROO	Benito Juárez	419 815	572 973	661 176	743 626
TAM	Matamoros	418 141	462 157	489 193	520 367
SIN	Mazatlán	380 509	403 888	438 434	502 547
BC	Ensenada	370 730	413 481	466 814	486 639
SIN	Ahome	359 146	388 344	416 299	449 215
SON	Cajeme	356 290	375 800	409 310	433 050
SIN	Guasave	277 402	270 260	285 912	295 353
CHIS	Tapachula	271 674	282 420	320 451	348 156
VER	Coatzacoalcos	267 212	280 363	305 260	319 187
TAB	Cárdenas	217 261	219 563	248 481	258 554
BCS	Los Cabos	105 469	164 162	238 487	287 671

Considering all the coastal municipalities during the analysis period (2000-2015), and using an empirical classification, 22 to 25 percent have large population (>100 000 inhabitants), 11 to 13 % are low populated (<10 000 inhabitants) and 62 to 64% have a medium population size (see Table S2 in supplementary material). Figure 7 shows the spatial distribution in 2015 of the total population in the Mexican coastal zone (coastal municipalities) using the intervals described previously.

During the period 2000-2005 the absolute population growth rate shows an increase in 55 percent of the coastal counties and a population decrease in 44 % of the municipalities. The new coastal settlers were 1 382 065 people and the number that left the coastal zone was 144 092 people. Between 2005 and 2010 the numbers were completely different, 94% of the coastal counties experienced population increase, 1.7 million inhabitants arrived or born in coastal municipalities, and only 10 counties reported a population decrease. In the last period (2010-2015) a similar pattern was observed, 142 coastal counties experienced a population increase (1 325 559 inhabitants) and only 10 a decrease (26 571 inhabitants). The marked decrease in population in Othón P. Blanco (QROO) municipality can be explained by the creation of a new county (Bacalar), which was created from the partition of the first (see Figure 8).

The performed Kolmogorov-Smirnov test shows significant differences ($p < 0.05$) between the distribution

of the absolute population growth rate of 2000-2005 with the other two periods 2005-2010 and 2010-2015, and no difference between the last two periods. Figure 8 shows the absolute population growth for the period 2010-2015 in the coastal counties with more and less (even negative) population growth (upper and lower 10% of the total of coastal counties).

The relative population growth rate at county level presented an interesting behavior during the study period (2000 to 2015). Considering the differences among population growth rates during the periods 2000-2005 and 2005-2010, 76% coastal municipalities experienced an increase and 24% decrease. Unexpectedly, the results for the periods 2005-2010 and 2010-2015 showed a reversed pattern, only 25% of the coastal counties exhibited an increase and 75% revealed a decrease in the population growth rate. The population explosion experienced in the Mexican coast during the period 2005-2010 was followed by a significant slowdown in the population growth rate during 2010-2015.

For example, the population growth rate in Solidaridad (QROO), the municipality where Cancún is located in the Caribbean Sea, registered the highest population growth rate of all the coastal counties during the period 2000-2005 (113%), then drop to 17,5% between 2005-2010 (13th place) and increases only 32% for the period 2010-2015 (again 1st place). Another example from the west coast is Bahía Banderas (NAY), in the state of Nayarit,

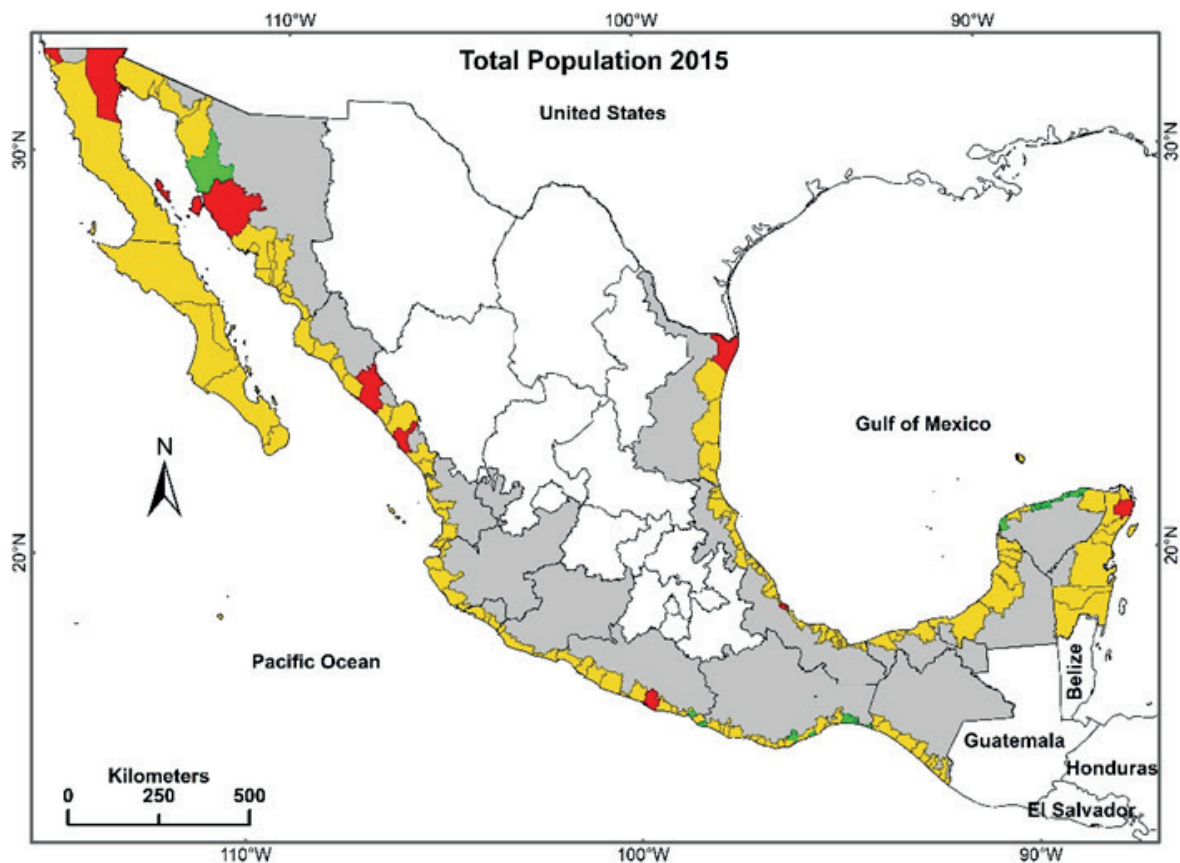


Figure 7. Spatial distribution of the total population (2015) at county level in Mexican coastal zone. Red color: municipalities with more than 100 000 inhabitants; yellow color: counties with population between 10 000 and 100 000 inhabitants; and green color: municipalities with less than 10 000 inhabitants. Source: data from INEGI, 2018a.

Figura 7. Distribuição espacial da população total no nível municipal na zona costeira mexicana (2015). Cor vermelha: municípios com mais de 100 000 habitantes; cor amarela: municípios com população entre 10 000 e 100 000 habitantes e cor verde: municípios com população abaixo de 10 000 habitantes. Fonte: dados de INEGI, 2018a.

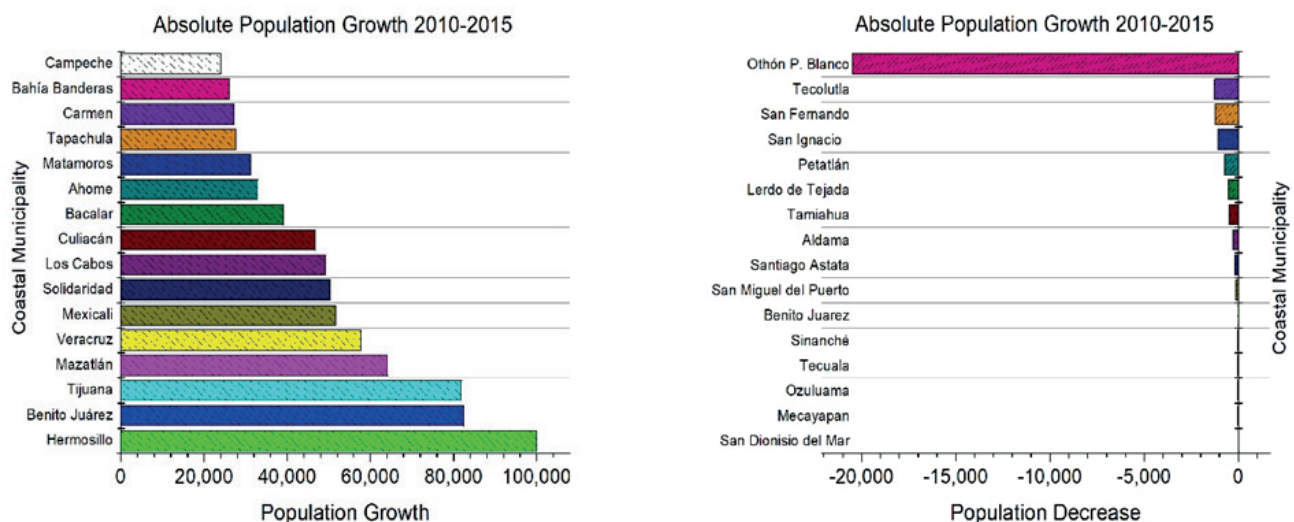


Figure 8. Absolute population growth in Mexican coastal counties during the period 2010-2015. Left: upper 10% with higher increase. Right: lower 10% of counties with lowest changes or population decrease. Source: data from INEGI, 2018a.

Figura 8. Crescimento populacional absoluto nos municípios costeiros mexicanos durante o período 2010-2015. Esquerda: 10% com maior aumento. Direita: 10% dos municípios com menores mudanças ou decréscimo populacional. Fonte: dados do INEGI, 2018a.

where a large tourism project was developed and deployed "Riviera Nayarita". This project was a population attractor for most of the coastal counties located in this state. In this specific municipality (Bahía Banderas), the population growth rate was 40% (2000-2005), locating the municipality in the 5th place at national level. Then, during 2005-2010, this county took the first place with a value of 48% and, in the last measured period (2010-2015), it was located in the third place with a population growth rate of 21%.

Unfortunately, this economic and social development related to touristic activities and tourism expansion, have adverse environmental effects like pollution; changes in land use; loss of biodiversity, natural vegetation and ecosystem services; aquifer depletion; coastal erosion problems, and the increased vulnerability of coastal communities to the impacts of climate change and extreme weather events, to mention a few problems.

For the west coast, only 15 of 91 coastal municipalities

registered increases in the population growth rate between 2005-2010 and 2010-2015, while for the east coast the number was 24 of 64. For the west coast, the states in which the largest number of coastal counties experienced an increase in the population growth rate were SIN and OAX, with 6 each one; and for the east coast, VER and YUC, with 8 each. The highest population growth rate change was observed in Elota (SIN), a medium size agricultural coastal county without port or touristic activities; and the highest decrease in population growth rate was reported in Aquila (MICH), a medium size municipality in which the violence associated with the drug cartels became important locally. Figure 9 shows the spatial distribution of the population growth rate between 2010 and 2015 in the Mexican coastal zone, applying the following criteria in the coastal counties growth rate: a) negative or zero, b) up to 10%, c) up to 20% and d) more than 20%.

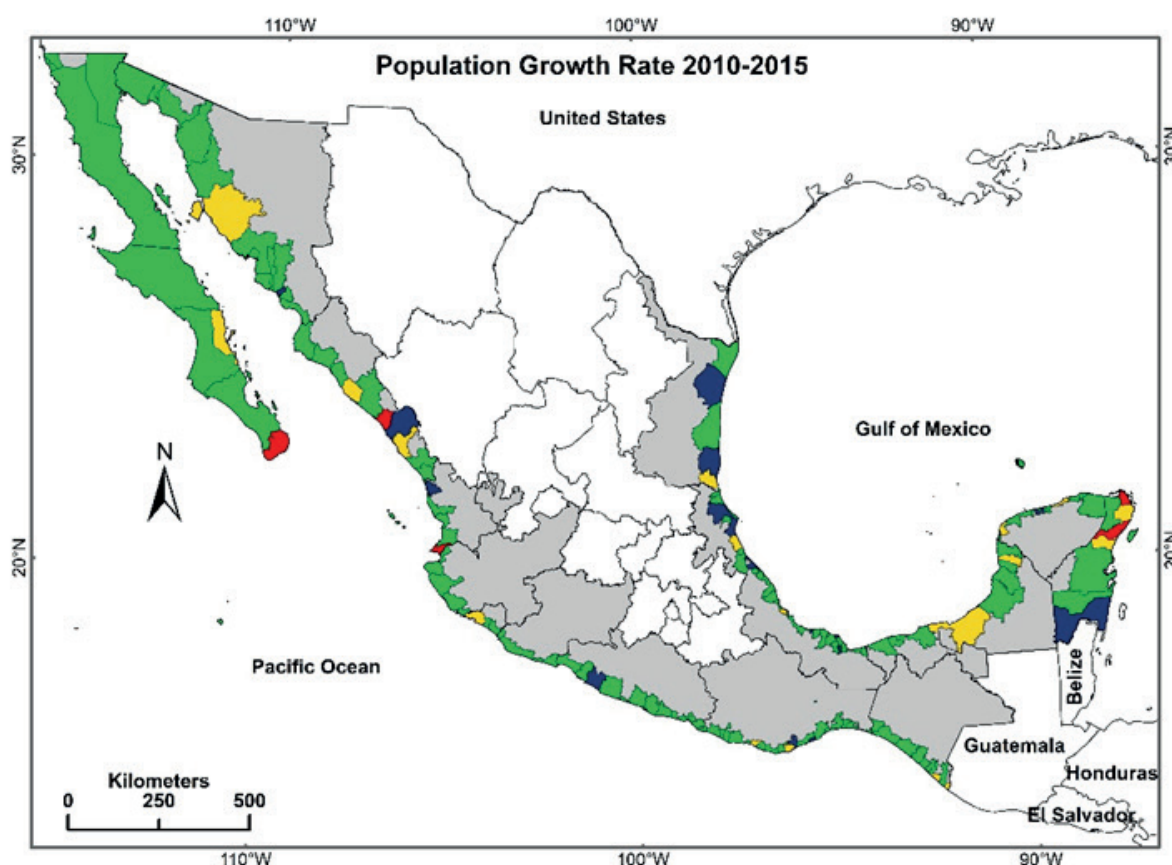


Figure 9. Spatial characterization of the population growth rate (2010-2015) in Mexican municipalities. Blue color: negative growth (reduction in population); green color: positive growth rate until 10%; yellow color: growth rates between 10 and 20% and; red color: population growth rates greater than 20%. Source: data from INEGI, 2018a.

Figura 9. Caracterização espacial da taxa de crescimento populacional (2010-2015) em municípios mexicanos. Cor azul: crescimento negativo (redução da população); cor verde: taxa de crescimento positiva até 10%; cor amarela: taxas de crescimento entre 10 e 20% e; cor vermelha: taxas de crescimento populacional superiores a 20%. Fonte: dados do INEGI, 2018a.

4.4 Demographic changes and violence in Mexico's coastal zone

It is clear from the previous analysis that during the last 15 years, one of the most important element controlling the population growth in Mexican coastal zone is the creation of touristic facilities, but the slow down in growth rates or even the decrease in population is a more complex problem. The domestic and international migration could explain partially this phenomena, but a new and complex element to measure and deal with it come into scene in coastal management in Mexico. During the last years in the Mexican coastal zone, the generalized violence level associated with the drugs traffic and drugs cartels activities has created conditions of insecurity that together with the existing impunity cause the population to decide to move to other safer places. Durin (2012), with information of 2010, show a map of displacements due to criminal and communal violence in which 4 of the 5 states with higher rates of displacement are coastal states (TAM, GRO, OAX and CHIS). In the coastal municipalities with important tourist activity, tourism increases the demand for drugs, which increases violence due to the control of the market between rival gangs. Other coastal municipalities may be in areas of production or transportation of the drug, which also increases the level of insecurity of the population. Taking into account how complicated it is to obtain information on the subject, it was considered as an indicator of the level of violence in each coastal municipality, the number of violent homicides recorded by the government. A correlational analysis was performed between the

absolute population growth rate at county level and the change in violent homicides number. For the period 2000-2005 no significant correlation was found at 0,05 significance level; for the period 2005-2010 a significant positive correlation was obtained ($r=0,65$) and for the period 2010-2015 a negative significant correlation appear ($r=-0,32$). Figure 10 shows the results obtained.

During the period 2005-2010, the six more violent counties were Tijuana (BC), Culiacán, Mazatlán, Ahome and Navolato in SIN and Acapulco (GRO). In the next analysis period (2010-2015), only Acapulco remain with positive values in the homicides growth rate, but the population growth rate decrease markedly in the three more violent counties: Tijuana, Culiacán and Acapulco, only Navolato experienced a marked increase in the population growth rate, possibly due to the internal migration among violent counties in the same state. During this time (2010-2015), Comalcalco (TAB) and La Paz (BCS) they ranked in the highest positions of the homicide rate, La Paz is an interesting object of study because traditionally has been considered a quiet and safety place. The next population census (2020) could give us more elements to validate the hypothesis that local safety/violent conditions conditioning the population growth at county level in several coastal states in Mexican coastal zone.

5. CONCLUSIONS

The total population in Mexican coastal states reached 55.3 million inhabitants in 2015, this amount represents 46% of the national population. The people living in

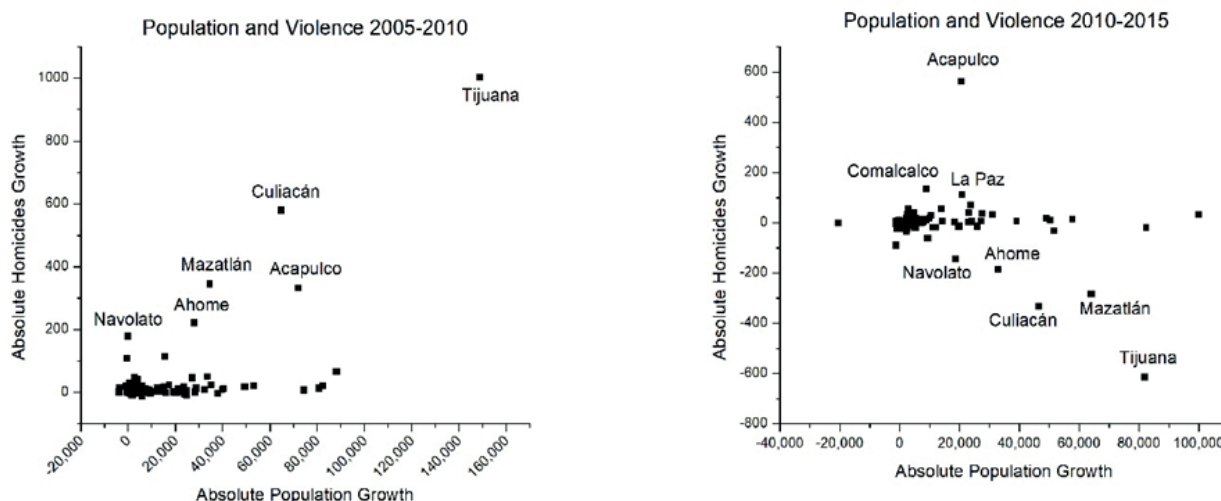


Figure 10. Relationship between absolute population growth rate and absolute homicides growth in Mexican coastal counties during the periods 2005-2010 (left) and 2010-2015 (right). Source: data from INEGI, 2018a,b.

Figura 10. Relação entre a taxa de crescimento populacional absoluta e o crescimento absoluto de homicídios nos municípios costeiros mexicanos durante os períodos 2005-2010 (esquerda) e 2010-2015 (direita). Fonte: dados do INEGI, 2018a, b.

the 158 coastal municipalities was 18,9 million, which represents the 34% of the population existing in coastal states. The most populated coastal states were Veracruz in the east coast, with 8.1 million, and Jalisco in the west coast, with 7,8 million. Veracruz is a coastal state which bases its development on activities related to the sea and the coast, while Jalisco is a more inland oriented state. The mean population growth rate in coastal states for the period 2010-2015 was $7,5\% \pm 2,5\%$, with maximum and minimum values in Quintana Roo (13,3%) and Guerrero (4,3%), respectively. The mean population growth rate registered in 2010-2015 was the lowest value since the beginning of the census information (1930).

The estimated population in coastal states for the year 2050 was predicted in 65 million inhabitants. According with the forecast, the most populated coastal state will be Jalisco with (9,3 million), followed by Veracruz (8,3 million). In the reference year, only Colima state remains below the 1 million limit. For the prediction values, the mean absolute percentage error was estimated in 3,5%. The forecast performed from 2020 to 2050, every 5 years, will allow the decision makers to have elements to carry out a correct coastal management, in terms of needs, resources distribution and space uses.

The available information allowed an analysis of population growth at municipal level considering the years 2000, 2005, 2010 and 2015. Although the number of municipalities with sea front considered presented differences between these years, due to administrative and/or political issues, the amount of new or missing counties was small, from 153 in 2000 to 158 in 2015. The 18,9 million people living in coastal counties are located in a small number of municipalities producing a population pressure on coastal resources, the 16 most populated coastal municipalities concentrate 10,2 million inhabitants, 12 of them in the west coast, with 8 million people.

The absolute and relative population growth rate at county level show very interesting results. For the period 2005-2010, 146 municipalities showed population growth, while in 10 the population decreased (the population that stopped living in coastal municipalities was 9 447 inhabitants). For the next census period 2010-2015, the number of counties with positive absolute growth rate was 142 and 15 show population decrease, in this case the number of people that left the coastal municipalities was 26 571, creating a slowdown in the growth of the Mexican coastal zone population.

The population growth at county level in Mexican coastal zone may be due to domestic migration, which can be associated with better living conditions and job

opportunities, most of the times linked with the tourist development of the coastal areas.

In the case of population decrease in coastal counties, one possible explanation, hypothesized in this paper, is the increase in violence generated by the drugs trafficking cartels. At the local level, the fear generated by these gangs may be sufficient reason to change residence to another municipality or, in some cases, to another state. If this were the case, this terrible emerging issue in the management of Mexican coasts should be considered as a central element in government policies and social responses to give viability to a peaceful and safety coastal region, where sustainable development is sought.

ACKNOWLEDGEMENTS

The authors acknowledge the Center of Excellence in Design and Innovation in Engineering (Centro de Innovación y Diseño - CIED) of CETYS University (Centro de Enseñanza Técnica Y Superior) for their support. Also to the International Scientific Network for Coasts and Seas (RICOMAR-CONACYT).

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