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ORIGINAL ARTICLE

Regionalized Shared Socioeconomic Pathways: narratives and spatial population projections for the Mediterranean coastal zone

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Abstract Existing narratives and population projections of the global-scale Shared Socioeconomic Pathways (SSPs) do not capture regional differences in socioeconomic development in the Mediterranean region. In this study, we regionalize the global SSPs to account for differences in coastal population development between northern, eastern, and southern countries of the region. First, we develop coastal SSP narratives that include region-specific elements and differentiate between geographical regions. Based on these narratives, we derive coastal population growth rates that vary for each SSP as well as between coastal, inland, rural, and urban areas. We apply these growth assumptions to observed population growth patterns in a spatially explicit manner. The Mediterranean coastal SSPs thereby reflect socioeconomic development patterns across countries as well as coastal versus inland development within countries. Our results show that coastal population in the Mediterranean increases across SSPs 2–5 by 3% to 130% until 2100 except for SSP1, where population declines by almost 20% compared to 2010. We observe considerable differences between geographical regions and countries. In the Mediterranean north, coastal population declines in SSP1, SSP3, and SSP4 and experiences the highest increase of more than 100% in SSP5. In southern and eastern Mediterranean countries, the highest increase in coastal population takes place in SSP3 and amounts to almost 180% by 2100. The regionalized SSP narratives and population projections are intended for assessing future exposure, vulnerability, and impacts of population to coastal hazards and sea-level rise but can also be of use for a wider range of Impact, Adaptation, and Vulnerability (IAV) studies.

Keywords Shared Socioeconomic Pathways (SSPs) · Coastal zone · Narratives · Spatial population projections · Mediterranean · Scenarios

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Introduction

The Shared Socioeconomic Pathways (SSPs) constitute one component of the current climate change scenario framework which has been developed by the climate change research community in recent years (Ebi et al. 2014; O'Neill et al. 2014; Riahi et al. 2017). As climate change impacts are determined by prevailing socioeconomic conditions, the research community called for a new framework which would be more useful for Impact, Adaptation, and Vulnerability (IAV) research to replace the IPCC's Special Report on Emission Scenarios (SRES) (Moss et al. 2010; Hallegatte et al. 2011; Kriegler et al. 2012).

Five basic SSPs have been developed to cover possible challenges for climate change mitigation and adaptation. The SSPs "describe plausible alternative trends in the evolution of society and natural systems over the 21st century at the level of the world and large world regions" (O'Neill et al. 2014, p 389).

Each SSP consists of two dimensions: a qualitative narrative, which explores future socioeconomic developments in form of a storyline (O'Neill et al. 2017), and a quantitative dimension, which quantifies key elements of the narratives in projections for the five SSPs until 2100 (see KC and Lutz (2017) for population projections, Jiang and O'Neill (2017) for urbanization projections, and Crespo Cuaresma (2017), Dellink et al. (2017), and Leimbach et al. (2017) for GDP projections). Combining SSPs with Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011) and Shared Policy Assumptions (SPAs) (Kriegler et al. 2014), which are two further components of the scenario framework, a number of integrated climate scenarios can be developed.

As the basic SSPs have been designed for global-scale assessments, the scenario assumptions reflect developments on regional to local scale to a limited degree (Absar and Preston 2015). If regional or local processes deviate from those assumed at global scales, the use of the basic SSPs in IAV assessments could yield misleading results at regional to local scale. Therefore, decision makers may pursue measures (e.g., adaptation strategies, policies) which do not fit to the characteristics of their area of interest. For this reason, the IAV research community has called for regional and spatially explicit extensions of the basic SSPs depending on the application at hand (van Ruijven et al. 2014; O'Neill et al. 2014; Ebi et al. 2014; Jiang 2014; Hunter and O'Neill 2014; O'Neill et al. 2017). Recent studies have addressed this call with either regional extensions (Absar and Preston 2015; Schweizer and Kurniawan 2016) or spatially explicit extensions (Merkens et al. 2016; Jones and O'Neill 2016) but not both.

We address this gap by (1) extending the basic SSPs to the Mediterranean region, specifically focusing on its coastal zone, and (2) developing gridded population projections. We choose the Mediterranean as it is a socioeconomically diverse region and global scenario assumptions would not necessarily reflect regional differences. Further, the Mediterranean region has experienced rapid socioeconomic growth in recent decades, especially in coastal locations where industry and services (e.g., tourism, ports, fisheries, infrastructure) are concentrated (Benoit and Comeau 2005; EEA 2006, 2014; Piante and Ody 2015). A large share of the Mediterranean population lives in the coastal zone, being exposed to potential hazards such as coastal flooding, salt water intrusion, water scarcity, and land subsidence (Benoit and Comeau 2005; Blue Plan 2008; EEA 2014). In the course of the century, coastal hazards are expected to exacerbate due to climate change (EEA 2014; Wong et al. 2014). Depending on the adaptive capacity and vulnerability of exposed population and assets, impacts will vary regionally (Hallegatte et al. 2013; Wong et al. 2014; Satta et al. 2015). The aim of this study is to develop Mediterranean coastal SSPs which yield plausible results in regional-scale IAV assessments and which can serve as a decision tool for policy makers and stakeholders. We specifically focus on possible futures of population development in coastal areas to span the range of uncertainty in future coastal population change and do not quantify other elements such as GDP, urbanization, or land use.

We follow a two-step process. First, we develop Mediterranean coastal SSP narratives by combining characteristics of the basic SSPs with coastal elements and region-specific elements that influence socioeconomic development in the coastal zone. We further differentiate between geographical regions based on the current state of socioeconomic development. In a second step, we quantify our narratives to develop gridded population projections for all Mediterranean countries. These projections reflect, in line with the narratives, regional differences across countries as well as differences in coastal versus inland population growth for rural and urban areas in each country. In the next section, the methods employed to develop the narratives and the population projections are explained, followed by a description of the results in the "Results" section. The "Discussion" section discusses the benefits of this work for IAV assessments in the Mediterranean and compares our results to previous work.

Material and methods

Narrative development

We develop Mediterranean coastal SSP narratives using a qualitative approach. The basic SSP narratives by O'Neill et al. (2017) are the starting point of our Mediterranean coastal SSP narratives. To ensure consistency with the basic SSPs and to guarantee comparability between different spatial scales, we choose a top-down nesting approach. In this approach, the basic SSPs serve as boundary conditions for our regionalized narratives but are enhanced with further socioeconomic context on regional and subnational (i.e., coastal) scale (Absar and Preston 2015). We strive to maintain consistency with global developments as local and regional processes are embedded in global-scale processes and do not take place independently from these (van Vuuren et al. 2010; van Ruijven et al. 2014; Kok et al. 2015; Birkmann et al. 2015).

Mediterranean coastal SSP elements

To enhance the basic SSPs with coast-specific context, we employ the global-scale coastal SSP narratives along with the SSP names developed by Merkens et al. (2016). They established coastal SSP elements which promote or restrict human settlement in the coastal zone. These elements are shipping, fisheries, coastal tourism, lifestyle migration, and coastal zone management. To develop assumptions regarding the characteristics of each coastal SSP element, Merkens et al. (2016) interpreted a number of basic SSP elements by O'Neill et al. (2017), such as urbanization, economic growth, inequality, international trade, globalization, consumption and diet, international cooperation, and technology.

We adopt the elements of Merkens et al. (2016) as well as those of O'Neill et al. (2017) and enhance them by Mediterranean-specific elements which constitute additional important driving factors of coastal socioeconomic development. We establish these region-specific elements based on the available literature. In a first step, we use the Web of Science™ database and combine the search terms "Mediterranean," "socioeconomic development," and "coastal" to find peer-reviewed literature for the entire region. As the combination of all three terms results in only 25 publications, we further use a combination of the two terms "Mediterranean" and "socioeconomic development" (120 publications). In a next step, we use terms related to anticipated factors of coastal migration in the region, such as "water use," "tourism," and "fisheries" in combination with "Mediterranean." Additionally, we extend our search to book chapters and reports published by organizations such as Plan Bleu, the European Environment Agency (EEA), and the World Bank. We select the elements water demand (Neverre and Dumas 2015; Koutroulis et al. 2016), land subsidence (Hanson et al. 2011; Hallegatte et al. 2013), second home ownership (WEF 2011), overfishing (EEA 2006; FAO 2014), energy demand (Benoit and Comeau 2005), migration (Kok et al. 2006), and agriculture (Kok et al. 2006; Blue Plan 2008) as these have been studied in detail and are mentioned to be of particular importance for the socioeconomic development of the Mediterranean coastal zone (see supplementary material (SM1) for an overview of all elements included). As our study focuses on the Mediterranean region, we do not consider the coastal areas of the Atlantic Ocean, Black Sea, or Red Sea.

Geographical regions

We differentiate between geographical groups based on the current state of socioeconomic development. Therefore, we analyze freely available data of indicators which represent our SSP elements (Garschagen and Romero-Lankao 2015, SM2). As a further determining factor, we use the countries' membership in international organizations since all member countries are bound to policies imposed by these organizations (Benoit and Comeau 2005). Due to a lack of region-wide data coverage, it is not possible to determine the current state of socioeconomic development for every country in a consistent manner. Therefore and due to the fact that long-term scenarios are connected to high uncertainties, we decide to distinguish between two geographical regions with large differences in socioeconomic development in our narratives: the northern Mediterranean, including all countries which are members of the European Union (Spain, France, Italy, Slovenia, Croatia, Greece, Cyprus, Malta), and the southern and eastern Mediterranean, including the Maghreb countries (Libya, Tunisia, Algeria, Morocco), the countries of the Middle East (Syria, Lebanon, Israel, Palestine, Egypt), and the (potential) candidate countries of the EU (Bosnia and Herzegovina, Montenegro, Albania, Turkey). This approach has been used in previous work (Benoit and Comeau 2005; Blue Plan 2008; WEF 2011) and is in line with the generic nature of SSP narratives, which provide broad descriptions of future developments (O'Neill et al. 2017).

Scenario assumptions

In a next step, we develop general assumptions for our Mediterranean coastal SSP elements, which provide the basis for the narratives. Therefore, we adopt the assumptions of Merkens et al. (2016) and extend them by the region-specific literature used for establishing the Mediterranean elements, as well as scenario literature of other regionalized scenarios (Kok et al. 2006; WEF 2011; Kok et al. 2015) and coastal scenarios (Nicholls et al. 2008; Foresight 2011). In case the available literature does not provide enough support for the assumptions, we additionally make use of expert judgment. An overview of the scenario assumptions along with the literature used can be found in SM3.

We use the current state of socioeconomic development (see above, SM2) as a starting point for each of the five SSP narratives, since future socioeconomic development is determined by historical development (Absar and Preston 2015; Merkens et al. 2016). Based on this current state, we adjust the general assumptions (SM3) to each of the five SSPs, differentiating between the two geographical regions. In our narratives, we refrain from using a specific coastal zone definition as it depends on the aim of the projection and, therefore, should be specified in the quantification of the narratives.

Gridded population projections

For the gridded population projections, we quantify the developed narratives following the methodology employed in Merkens et al. (2016). Based on the assumption that future population patterns in coastal areas are determined by historical growth patterns, we employ the observed growth difference to account for different growth rates both within and across countries (see SM4 for projection equations).

To do so, we first divide each country into four zones: coastal urban (CU), coastal rural (CR), inland urban (IU), and inland rural (IR). The country boundaries are defined by the Global Administrative Areas (GADM) dataset version 2.8 (GADM 2015). To distinguish between urban and rural areas, we use the Global Rural-Urban Mapping Project's (GRUMP) urban extents grid (CIESIN et al. 2011), which has been used in a number of previous studies (McGranahan et al. 2007; Balk et al. 2009; Jones and O'Neill 2016). We differentiate between coastal and inland locations based on a hybrid coastal zone definition, which combines an elevation-based approach using the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) version 4.1 with a spatial resolution of 3 arcsec (approximately 90 m at the equator) (Jarvis et al. 2008; Farr et al. 2007) with a coastline buffer. Commonly used approaches based exclusively on an elevation threshold, such as the Low Elevation Coastal Zone (LECZ) that includes all land up to 10 m in elevation with hydrological connection to the sea, would not sufficiently reflect the Mediterranean coastal zone from a socioeconomic perspective as factors of coastal migration (e.g., shipping, second home ownership) expand beyond the LECZ in this region. Therefore, we extend the definition by employing a coastline buffer that we apply to the global, self-consistent, hierarchical, high-resolution geography database (GSHHG) coastline version 2.3.6 (Wessel and Smith 1996). Buffers of different extents have been used before to define coastal areas (Small and Nicholls 2003; Nicholls et al. 2008); a buffer of 20 km has proved most suitable for our analysis as it covers the extent of large coastal cities (Kummu et al. 2016). Using this hybrid definition, we distribute coastal population in a wider coastal zone, thus avoiding possible overestimation of the population exposed to coastal hazards.

Second, we determine growth rates for each zone and country based on past population development, employing the UN-adjusted population count grids of the Gridded Population of the World (GPWv4) dataset from 2000, 2005, and 2010. GPWv4 is currently the latest gridded population dataset that covers the whole Mediterranean. Its spatial resolution is 30 arcsec (CIESIN 2016). Based on the established growth rates, we calculate the observed urban and rural growth differences of each country. The growth difference does not reflect whether the total population grows or declines; a positive/negative growth difference indicates higher/lower population growth in coastal areas compared to inland areas whereas a growth difference of 0 shows no difference in population growth between coastal and inland locations. To differentiate between geographical regions and SSPs, we modify the observed growth differences by using modification factors that we select from the range of the observed growth differences. For this purpose, we interpret the narratives (1) to determine whether the modification factor of each SSP and geographical region is positive or negative and (2) to establish distinct modification factors per zone (urban/rural), geographical region, and SSP (see also "Mediterranean coastal SSP narratives" section). This approach is in accordance with previous scenario literature (Nicholls 2004; Nicholls et al. 2008; Neumann et al. 2015; KC and Lutz 2017; Jiang and O'Neill 2017) and leads to the adjusted urban and rural growth differences for each geographical region and SSP shown in Table 1.

Next, we employ the national-level urbanization (Jiang and O'Neill 2017) and population projections (KC and Lutz 2017) of the basic SSPs available in the SSP database (IIASA 2016). Based on these projections, we split the total national population into urban and rural population for each SSP and projection year. To differentiate between coastal and inland population, we apply the adjusted growth differences to the urban and rural population totals. Based on the total population in each zone (CU, CR, UI, IR), we calculate the growth rate of each zone and apply it to the GPWv4 dataset in 5-year steps from 2010 to 2100 (see SM4 for equations). This way, we ensure both consistency with the global projections and spatial explicitness.

Results

Mediterranean coastal SSP narratives

Each narrative presents a storyline of socioeconomic development in the Mediterranean region as well as its coastal zone for each SSP and differentiates between the two geographical regions, namely the northern Mediterranean and the southern and eastern Mediterranean. It further describes the implications of these developments for population growth in the coastal zone, in rural and urban locations. The characteristics of each coastal SSP element as described in the narratives are shown in Table 1 along with the modification factors used for the urban (GD^U) and rural (GD^R) growth differences. The following section provides excerpts of the narratives, reflecting the reasoning for future coastal population growth in each SSP. The full narrative can be found in SM5.

SSP1—Green Coast

As this pathway focuses on sustainable development, coastal population growth decreases compared to inland locations in the whole Mediterranean. Coastal ecosystem protection and decreasing importance of fisheries lead to declining population growth in coastal rural areas. Restrictive policies inhibit migration to coastal urban areas. Nevertheless, due to the importance of shipping and inertia of urban infrastructure, coastal urban population growth is marginally lower than in inland locations. These growth trends in rural and urban areas are more pronounced in the northern Mediterranean as compared to the southern and eastern parts of the region as socioeconomic development of the countries converges gradually in the course of the century. Therefore, we reduce the observed rural growth difference by 3% in the north and by 1% in the south and east and the urban growth difference by 2 and 1%, respectively.

Table 1 Characteristics of each Mediterranean coastal SSP element in each SSP and geographical region, with the modification factors of rural (GD^R) and urban (GD^U) growth differences

Mediterranean coastal SSP element	SSP1 Green Coast		SSP2 No Wind of Change		SSP3 Troubled Waters		SSP4 Fragmented Coast		SSP5 Coast Rush	
Geographical region	North	South and east	North	South and east	North	South and east	North	South and east	North	South and east
Shipping	→	↗	↑	↓	↘	↓	↑	→	↑	↗
Fisheries	↓	↘	↑	↑	↗	↑	↑	↑	→	→
			Large-scale	Small-scale	Small-scale, subsistence		Mostly large-scale	Mostly small-scale	Large-scale	
Overfishing	↘	↘	↑	↗	↑	↑	↑	↑	↑	↑
Coastal tourism	→	↗	↑	→	↘	↓	↑	↗	↑	↗
	Sustainable, low-impact, no mass tourism				No international tourism		High for elites, low for remaining population		Mass tourism	
Lifestyle/ Second home ownership	↓	↓	↑	→	↘	↓	↑	↗	↑	↗
							High for elites, low for remaining population			
Coastal zone management	↑	↗	→	↓	↘	↓	↑	↓	↑	↗
	Efficient, towards sustainability		Moderate efficiency	weak	weak		Towards elite's benefit; little interest in sustainability		Efficient, towards economic growth	
Water demand	↘	↘	→	↑	↑	↑	↑	↑	↑	↑
Subsidence	↘	↘	↑	↑	↑	↑	↘	↑	→	→
							Highly managed for elite		Highly engineered solutions	
Modification GD^R	- 3%	- 1%	± 0%	± 0%	+ 0.5%	+ 1%	+ 1%	+ 2%	+ 2%	+ 3%
Modification GD^U	- 2%	- 1%	± 0%	± 0%	- 1%	- 0.5%	+ 1%	+ 2%	+ 3%	+ 4%

↑ high, ↓ low, → moderate, ↗ increase, ↘ decrease

SSP2—No Wind of Change

This pathway is characterized by continuing historical patterns. Therefore, population growth patterns in the coastal zone continue like before as well. In coastal rural areas of the Mediterranean north, population growth is mainly driven by tourism and second home ownership. In the south and east, population growth in coastal rural locations is higher due to the continuing importance of small-scale fisheries. Regarding coastal urban areas of the north, population growth is primarily determined by the importance of shipping and tourism. Compared to this, coastal urban areas of southern and eastern countries experience lower population growth, as their participation in international trade and tourism activities is limited. Consequently, we use the observed urban and rural growth differences without modifying them.

SSP3—Troubled Waters

This pathway is characterized by regional rivalry, which decreases coastal attractiveness for human settlement. As living standards decrease, this pathway is characterized by little mobility of the population and thus little coastal migration. In coastal rural locations, population grows due to increasing importance of fisheries despite the fact that coastal waters are overfished to large extents. Coastal urban areas lose their attractiveness compared to inland cities due to declining shipping and tourism. Therefore, population growth in coastal urban locations is almost exclusively driven by natural growth and does not differ from inland areas. These population growth patterns are less pronounced in the south and east than in northern countries. In the south and east, coastal rural locations experience higher growth and coastal cities do not lose their advantage over inland cities as severely. The reason for this is the presently higher importance of fisheries and lower importance of shipping and tourism in southern and eastern countries. Especially in the south and east, the population is forced to move closer to the coast as desertification advances. To account for these growth patterns, we modify the rural growth difference by +0.5% in northern countries and +1% in southern and eastern countries and the urban growth difference by −1 and −0.5%, respectively.

SSP4—Fragmented Coast

This pathway is characterized by high inequalities across and within countries, with a wealthy elite which comprises a small

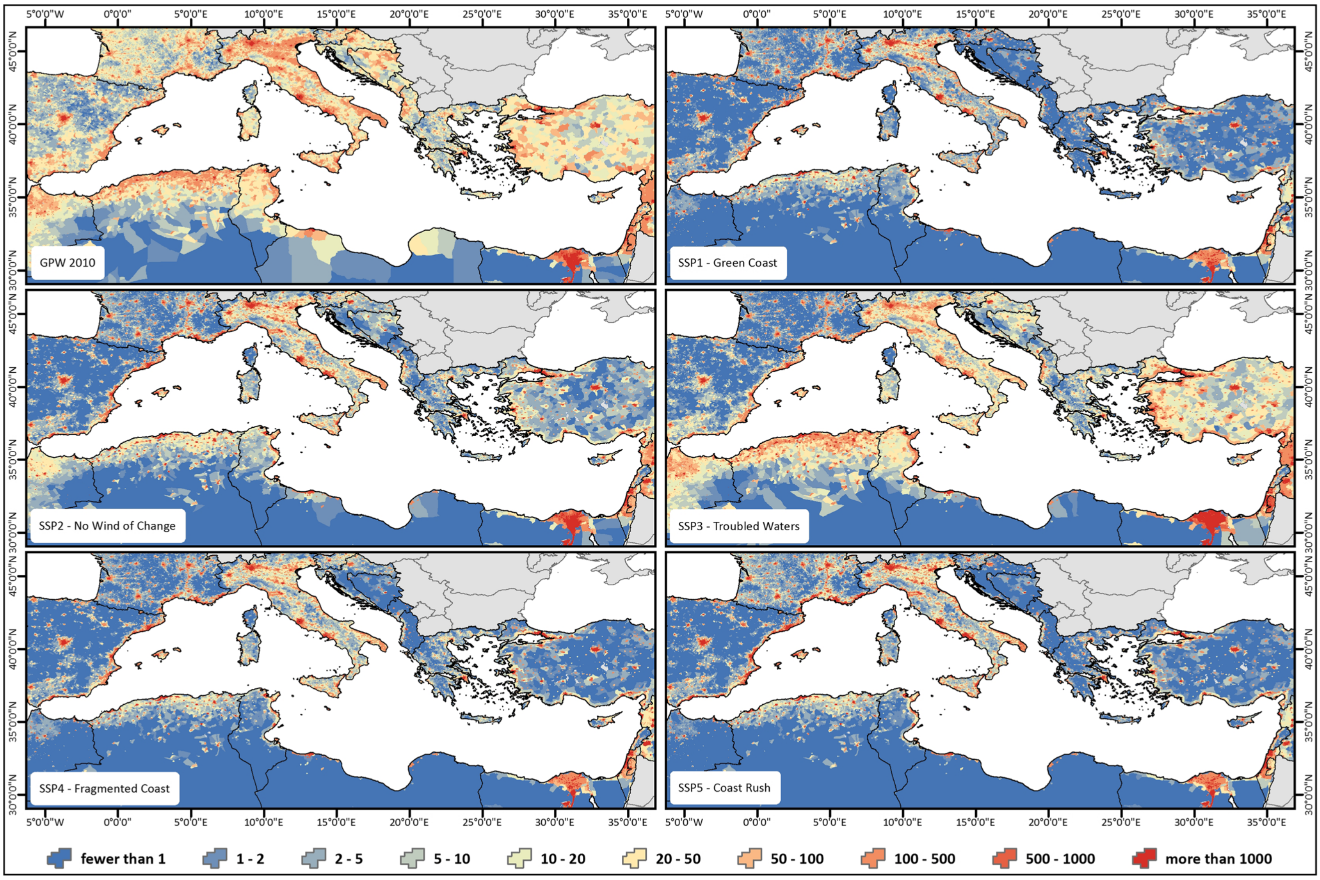

Fig. 1 Selected population grids. Population per grid cell for the base year 2010 and each SSP in 2100. Pixel size = 30 arcsec

share of the population and a poorer population group which makes up the rest of the population. Coastal population growth increases compared to inland population growth in the whole region. Among the elite, coastal population growth in rural areas is mostly driven by tourism and ownership of second homes and by small-scale subsistence fisheries among other population groups. Urban areas experience high population growth since they are regarded as economic engines. Coastal growth is higher in the south and east compared to the north because coastal population growth is mainly driven by poorer population groups. Further, in countries affected by advancing desertification, people are forced to move closer to the coast. Due to these developments, we increase the rural and urban growth differences by 1% in the north and by 2% in the south and east.

SSP5—Coast Rush

In this highly globalized world, the coastal zone is extremely attractive, leading to higher population growth in the coastal zone compared to inland locations in all Mediterranean countries. In coastal rural areas, tourism and second homes are the main drivers of population growth. Population in coastal urban areas increases since economic activity is concentrated in these locations. Due to high urbanization rates and urban sprawl, many rural areas are urbanized. These growth trends are more pronounced in the Mediterranean south and east than in the north because of catch-up effects. Therefore, we increase the observed rural growth difference by 2% in northern countries and by 3% in the south and east and the urban growth difference by 3 and 4%.

Mediterranean population projections

The population grids produced (Fig. 1) have a spatial resolution of 30 arcsec (~1 km at the equator) and are available in 5-year increments from 2015 to 2100 for each SSP. The data are publicly available at https://doi.org/10.6084/m9.figshare.4187295.v1. In the following section, we present the results of the coastal population patterns under each SSP. To allow for comparison with previous studies, we have calculated these numbers for the Mediterranean LECZ.

The absolute LECZ population in the whole Mediterranean ranges from 34.1 (SSP1) to 96.2 million (SSP3) in 2100, which corresponds to a decline of approximately 18% in SSP1 and a growth of over 130% in SSP3 compared to 2010 (see SM6). The share of the coastal population increases in four SSPs from 8.9% in 2010 to up to 13.3% (SSP3) in

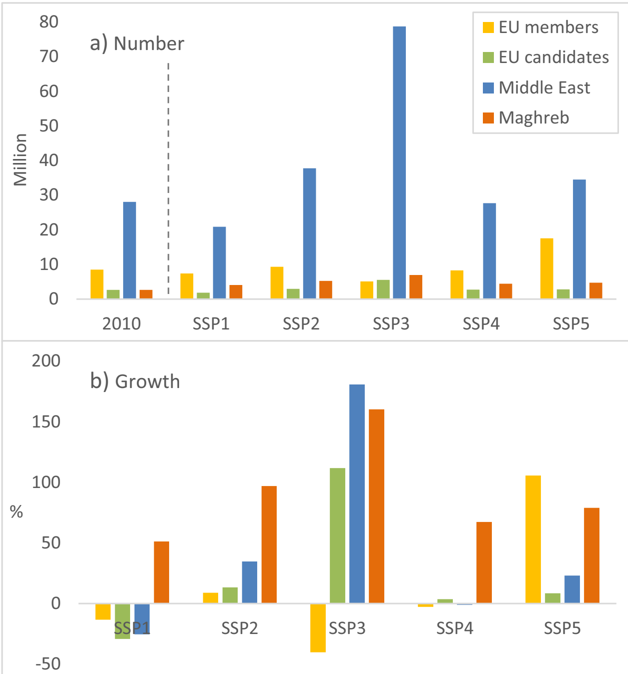

Fig. 2 LECZ population for each country group and each SSP in 2100 in comparison to the base year 2010. **a** Number gives the total population count. **b** Growth represents the growth of the LECZ population relative to the base year 2010

2100 but declines in SSP1 to 7.0%. In total, coastal population growth in the Mediterranean is higher than inland population growth in all SSPs apart from SSP1.

To illustrate regional differences, Fig. 2 presents the LECZ population for four country groups: EU member states, EU candidate countries, the Middle East, and the Maghreb (see "Geographical regions" section).[1] The highest population number in the Mediterranean LECZ is found in the Middle East across all SSPs (Fig. 2a). This is due to the densely populated Nile Delta and amounts to a maximum of 78.7 million in SSP3; the lowest LECZ population lives in EU candidate countries. Compared to the base year 2010, EU member states experience an increase in LECZ population across SSP2 and SSP5 only and the coastal population ranges from 5.1 million (SSP3) to 17.5 million (SSP5). In EU candidate countries, coastal population increases in all SSPs, aside from SSP1. In 2100, the LECZ population ranges from 1.8 million in SSP1 to 5.5 million in SSP3. Countries of the Middle East experience coastal population growth in SSP2, SSP3, and SSP5. The LECZ population ranges from 20.9 million (SSP1) to 78.7 million (SSP3). Different to the other groups, coastal population increases across all SSPs in the Maghreb region and ranges from 4 million (SSP1) to 6.9 million (SSP3).

LECZ population growth relative to the base year 2010 in each country group is mostly positive but decreases in SSP1 in all countries aside from the Maghreb region (Fig. 2b). Until 2100, EU member states experience the highest increase of 106% in SSP5 and the highest decrease of over 40% in SSP3. EU candidate countries undergo the highest increase in SSP3 (112%) and the LECZ population declines by about 29% in SSP1. Similarly, in the Middle East, the highest growth occurs in SSP3, in which the LECZ population increases by over 180%, and the population decreases by approximately 25% in SSP1. In Maghreb countries, coastal population growth amounts to a minimum of 51% in SSP1 to a maximum of 160% in SSP3.

[1] See SM7 for the LECZ population per country.

Discussion

Our regionalized coastal SSPs can be used for IAV assessments in the Mediterranean, as they reflect regional differences in socioeconomic development in a plausible manner. Areas with high exposure to coastal hazards can be identified under different SSPs to inform adaptation planning and to raise awareness among decision makers, stakeholders, and the public regarding these locations. Individual SSPs can be compared with each other to determine the most desirable pathway and to introduce policies accordingly as to pursue this pathway (Özkaynak and Rodríguez-Labajos 2010; Birkmann et al. 2015). When doing so, challenges for mitigation and adaptation within the global SSP framework need to be incorporated.

Our narratives describe plausible pathways of socioeconomic development in the Mediterranean region and its coastal zone. Based on the developments described in each SSP narrative, SSP1 (Green Coast) could be seen as the most desirable pathway as it strives for sustainability and directs migration away from the coast. However, the projected population potentially exposed to coastal hazards can differ considerably across countries and SSPs (Fig. 2a). In EU countries, exposure is highest in SSP5, lowest in SSP3, and only second lowest in SSP1. This is different in the other three country groups, where exposure is highest in SSP3 and lowest in SSP1. One reason for this lies in the fact that our results reflect the underlying demographic assumptions of the input data (KC and Lutz 2017; Jiang and O'Neill 2017). Therefore, exposure is highest in SSP3 in most countries, even though the coast is more attractive in SSP4 and SSP5. This is not the case in EU member states where demographic change leads to declining population in SSP3 and high international migration into the EU results in high population growth in SSP5.

Impacts of coastal hazards do not only depend on exposure but also on the adaptive capacity of the population. In the Mediterranean south and east, exposure is highest under SSP3, which is characterized by high adaptation challenges due to low living standards, weak policies and institutions, and highly dispersed settlements. Low adaptive capacity

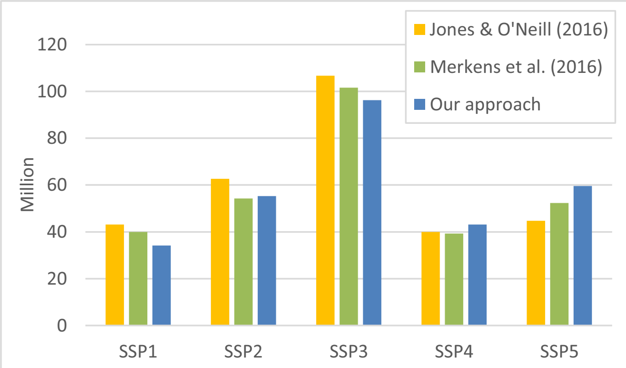

Fig. 3 Mediterranean LECZ population in 2100 in Jones and O'Neill (2016) and Merkens et al. (2016) compared to our regionalized SSPs

combined with high coastal population may result in high impacts in case of a coastal hazard. In the Mediterranean north, exposure is highest under SSP5, but due to high urbanization, high living standards, and effective policies and institutions, the adaptive capacity is also high. For example, technical solutions and efficient policies and institutions are expected to reduce the number of people flooded by extreme flood events. On the other hand, residual risk is high and in case adaptation measures fail during a flood event, damages in the Mediterranean north will be extremely high in SSP5 due to the concentration of population and assets in the coastal zone.

We compare our population projections with the spatial SSPs of Jones and O'Neill (2016) and the coastal SSPs of Merkens et al. (2016). All three population projections compare well in the Mediterranean but also show marked differences (Fig. 3). In the global-scale approaches of Jones and O'Neill (2016) and Merkens et al. (2016), the Mediterranean LECZ population ranges from around 40 million in SSP4 to over 100 million in SSP3, whereas in our approach, it ranges from 34 million in SSP1 to 96 million in SSP3. The range of LECZ population is almost identical in all three approaches, but the pathway with the lowest coastal population differs (SSP4 versus SSP1). This discrepancy reflects our coastal assumptions which expect coastal population growth to be restricted in SSP1 and favored in SSP4.

The Mediterranean LECZ population of our regionalized SSPs is lower in SSP1 and SSP3 and higher in SSP4 and SSP5 compared to both global-scale approaches. This corresponds to a relative difference ranging from −21% (SSP1) to +33% (SSP5) in comparison to Jones and O'Neill (2016). These large differences reflect that Jones and O'Neill (2016) do not specifically account for coastal development in their projections. Compared to the projections of Merkens et al. (2016), the LECZ population of our approach is between 15% lower (SSP1) and 14% higher (SSP5). This is due to the fact that although Merkens et al. (2016) implement coastal assumptions, we use higher modification factors of the observed growth differences to account for the characteristics of the region (see Table 1). In this way, we aim to account for a larger range of plausible coastal population development.

Our study exhibits the following limitations. In the process of developing regionalized narratives, it proved difficult to find appropriate coastal migration factors, particularly regarding rural migration. In order to develop more robust migration factors, a questionnaire survey or a participatory approach (i.e., involving stakeholders) may be useful, which would lead to higher SSP acceptance among stakeholders (Kok et al. 2006; Nicholls et al. 2008; Absar and Preston 2015; Kok et al. 2015). Further, we only differentiate between two geographical regions. We use stylized assumptions, which may not apply to all countries of the geographical region and, therefore, should be revised for smaller-scale studies. Further, due to a lack of gridded population data with high temporal coverage, our projections rely on a short observation period of 10 years that does not necessarily reflect long-term population development in the coastal zone. Additionally, we do not model the effects of urban sprawl on population distribution, which could lead to underestimation of urban areas in scenarios with considerable urban sprawl such as SSP5 (O'Neill et al. 2017). When using our population projections for other applications, their coastal focus should be kept in mind. We have modeled the coastal population living along the Mediterranean Sea only, excluding the coastal areas of the Atlantic Ocean, Black Sea, and Red Sea.

It is important to note that the developed SSPs do not predict what will happen by 2100 but provide plausible pathways for society to develop in course of the century. Future developments may deviate from the ones described in our SSPs and other extensions of the basic SSPs might come to different results. Despite the fact that our SSPs have specifically been developed for coastal IAV applications in a climate change context, they can also serve as boundary conditions for other utilizations due to their generic nature. The SSP framework generally assumes socioeconomic development to take place independently from climate change. This assumption is debatable (Absar and Preston 2015; Jones and O'Neill 2016) as coastal migration patterns in the Mediterranean will change once climate change impacts like sea-level rise and more frequent flooding become increasingly noticeable (EEA 2014).

Conclusion

This study advances previous research and meets the research community's call for extensions of the basic SSPs in two ways, (1) by regionalizing them to the Mediterranean coastal zone and (2) by producing gridded population projections for the region. Our SSP narratives are consistent with the global-scale SSPs and reflect distinct socioeconomic developments in northern, southern, and eastern Mediterranean countries as well as in coastal versus inland locations, based on additional region-specific elements. We interpret these narratives to develop a set of gridded population projections for the five SSPs. Our Mediterranean coastal SSPs span the range of population growth (SSPs 2–5) and decline (SSP1) in the Mediterranean region and its coastal zone. They compare well to the global coastal SSPs of Merkens et al. (2016) but also show regional differences, therefore qualifying for regional IAV assessments. The developed SSPs are particularly suitable for analysis of population exposure to sea-level rise and other coastal hazards. Thereby, locations with high exposure can be identified in order to draw the attention of decision makers towards these areas. Accordingly, adaptation strategies can be developed to reduce exposure.

Future work can adopt and further extend the Mediterranean coastal SSPs for national to local assessments. This would allow for using more location-specific variables and participatory approaches such as stakeholder workshops in order to reflect local developments. Absar and Preston (2015) suggest analyzing a number of case studies for this exercise. To be able to not only assess exposure but also vulnerability and risk, future work could additionally enhance the developed population projections by implementing socioeconomic variables like GDP and age. In addition, it might be of interest to develop spatial population projections that account for possible rates of future sea-level rise and the influence on coastal population patterns. We encourage other researchers and decision makers to utilize the developed narratives and population projections for other applications related to IAV research.

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