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The role of scientific expertise in local adaptation to projected sea level rise

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ABSTRACT

Adaptation to sea level rise (SLR) is primarily taking place at the local level, with varied governments grappling with the diverse ways that SLR will affect cities. Interpreting SLR in the context of local planning requires integrating knowledge across many disciplines, and expert knowledge can help planners understand the potential ramifications of decisions. Little research has focused on the role that experts play in local adaptation planning. Understanding how and when local governments undertake adaptation planning, and how scientists and scientific information can be effectively incorporated into the planning process, is vital to guide scientists who wish to engage in the planning process. This study aimed to establish how experts are currently involved in SLR planning, identify any gaps between planners' needs and expert involvement, and determine the characteristics of experts that are perceived as highly valuable to the planning process. We surveyed individuals involved with planning in a broad range of US coastal communities about SLR planning and the role that experts have played in the process. We found that SLR planning is widespread in cities across geographic regions, population sizes, and population characteristics and has increased rapidly since 2012. Contrary to our expectation, whether a SLR plan existed for each city was not related to the percentage of the population living on vulnerable lands or the property value of those lands. Almost all cities that have engaged in SLR planning involved experts in that process. Planners identify atmospheric scientists, oceanographers, economists and political scientists, and geologists as currently underutilized according to planners' needs. Members of these expert disciplines, when involved in planning, were also unlikely to be affiliated with the local planning government, but rather came from other governmental and academic institutions. Highly effective experts were identified as making scientific research more accessible and bringing relevant research to the attention of planners. Results from our dataset suggest that planners perceive local SLR planning could benefit from increased involvement of experts, particularly atmospheric scientists, oceanographers, economists and political scientists, and geologists. Since experts in these disciplines were often not affiliated with local governments, increasing the exchange of information between local governments and academic and other (non-local) government organizations could help draw valued experts into the planning process.

1. Introduction

A great deal of scientific scrutiny has been devoted in recent years to measuring the current effects and modeling the anticipated effects of anthropogenic climate change-induced sea level rise (SLR), which threatens coastal communities worldwide (IPCC, 2013; Nicholls and Cazenave, 2010; Strauss et al., 2015). Population projections coupled with SLR vulnerability estimates predict that 4.2 to 13.1 million people are at risk of coastal inundation from SLR by 2100 in the United States alone (Hauer et al., 2016), with associated mass population movements that would disrupt social systems far removed from the coast (Hauer, 2017). Adaptation planning by communities that can expect to be (or are already) affected by SLR may help to mitigate the socio-economic and ecological impacts of SLR and reduce the vulnerability of the

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public. Effective adaptation planning requires access to relevant scientific information to understand the problem (Adger et al., 2005). However, local governments have not responded rapidly to this potential threat: there were relatively few adaptation plans even in developed countries prior to 2009 (Berrang-Ford et al., 2011; Ford et al., 2011). When planning is undertaken, the interests of the policy and scientific communities often fail to align (Sarewitz and Pielke, 2007), or the available scientific information does not match what is needed by policy-makers (Pielke, 1995). Understanding how many local governments are undertaking adaptation planning, how planning proceeds, and how scientists and scientific information can be effectively incorporated into the planning process is vital to facilitate effective planning and guide scientists who wish to engage in the planning process.

Although effective adaptation planning can and should take place across multiple spatial scales with roles for different levels of government (Adger et al., 2005), thus far, much of the climate adaptation taking place in developed countries has occurred through the efforts of local or regional governments (Wheeler, 2008; Ford et al., 2011; Bierbaum et al., 2013). This local focus is partially a practical necessity: while sea levels are rising globally, both exposure and vulnerability to SLR will be hyperlocal due to geographical differences in physical risk factors and their interactions with local population factors (Hauer et al., 2016). Unlike climate mitigation, which has the greatest effect at the largest possible governance scale, most of the costs and benefits of local adaptation measures will be borne at the local level without necessarily causing spillover effects, either positive or negative, to other jurisdictions (Tol, 2005). In this way, local adaptation aligns more closely with the incentives of the public and local policymakers.

Even at the local scale, significant barriers to action may exist. Planners may perceive that climate change consequences are remote (Rasmussen et al., 2017), the public may not perceive sea level adaptation as necessary (Neumann et al., 2000), and although SLR is among the most recognizable consequences of climate change for local planners (Baker et al., 2012), the myriad potential ramifications of SLR for a given locality are not always apparent. SLR planning is a multi-faceted problem that encompasses many different disciplines including the natural sciences, social sciences, law, and governance. A local planner may be aware of the issue but have difficulty analyzing or accessing scientific information to understand the depth and scope of the problem and develop appropriate plans to meet these challenges (Moser and Luers, 2008; Fu et al., 2017). Experts from different disciplines collect scientific information in different ways (Mastrandrea et al., 2010), and transdisciplinary teams have been found to consistently present complementary information that is helpful in the policy process (Mastrandrea et al., 2010; Marshall et al., 2017).

Involving experts is one way that local planners can overcome the complexity of SLR planning and increase their awareness of potential impacts (Moser and Luers, 2008). A case study of coastal managers in California shows they are limited by the time and resources available for their staff to gather and assess relevant information and that they are interested in more interactive forms of learning such as opportunities to meet with scientists (Tribbia and Moser, 2008). However, they are currently more likely to get information from newspapers than scientific journals or local experts (Tribbia and Moser, 2008). It is increasingly recognized that the traditional ways of presenting scientific information are not adequate for the decision-making process but that information is also necessary for the planning process. Investigating the role experts play in SLR planning can expose the ways that scientific knowledge can be better incorporated into local coastal planning.

In this study, we use the term 'scientific information' to refer to any body of knowledge produced through research-based methods of inquiry and generated according to the methods that are broadly considered appropriate by practitioners in that field (Van Kerkhoff and Lebel, 2006). This definition of scientific information encompasses peer-reviewed journal articles produced in the natural sciences and spans literature from the social sciences, policy analyses, and other outputs that have not necessarily undergone a formal peer review. The terms 'scientists' and 'experts' are used herein interchangeably to refer to a wide range of individuals, including natural and social scientists, policy analysts, legal experts, and engineers, among other disciplines that are devoted to generating scientific information. Scientific knowledge historically carried a legitimizing force in the policy process (Weible, 2008), although it is increasingly recognized to be situated (Agrawal 1995). However, to the extent that local knowledge is generated through the same process as the research-based approach described above, it may very well fall within the boundaries of the scientific disciplines and conform to the definition of scientific knowledge used in this paper. As such, we did not explicitly distinguish between scientific and local expertise.

Here we present findings from a survey of city planners on how scientific expertise is integrated into local SLR adaptation plans, with the goals of summarizing the current state of the system and providing guidance on how scientists can best communicate research findings to assist in the planning process. Specifically, our research objectives were to:

(1) Test whether demographic and geographic characteristics of municipalities were associated with SLR planning. Adaptation planning is a function of adaptive capacity, which in turn may be influenced by local factors including education, population, and income (Brooks et al., 2005). Previous research has found (Pitt, 2010) or hypothesized (Cidell and Cope, 2014) that local voting behavior is associated with climate change-related policies. To the extent that populations that are most vulnerable to SLR accurately recognize and accept this vulnerability (Grothmann and Patt, 2005), we would expect to find a positive association between vulnerability to SLR and planning to mitigate this potential risk (Zahran et al., 2008).
(2) Identify expert disciplines currently represented in SLR adaptation planning and those for which there is a perceived shortage among local planners. If local governments are constrained in their capacity for planning to meet a multidimensional challenge like SLR (Moser and Ekstrom, 2010; Moser and Luers, 2008), we would expect local planners to under-utilize input from experts who are primarily affiliated with organizations outside of the local government, including academic institutions and other government organizations, such as state and federal government agencies.
(3) Identify which forms of involvement by scientific experts is most helpful in the planning process. Planners may find it valuable for scientists to explicitly incorporate planning-related questions into scientific research (Sarewitz and Pielke, 2007). In this case, we would expect for planners to place a high value on activities that help connect them to the scientific process, such as early involvement in research design, scientists conducting research at their behest or involving planners when authoring reports or co-analyzing data, and co-authoring reports. Alternatively, scientific experts may be more helpful later in process, playing a valuable role in interpreting scientific information in ways that are relevant for planners (Marshall et al., 2017; van Stigt et al., 2015). The role of the expert as a mediator between the scientific and planning processes may be enhanced if the expert becomes more involved in the broader planning process (i.e., by attending meetings in-person or maintaining regular communication with planners). We sought to determine which roles and activities of scientific experts are most useful for advancing adaptation planning to SLR.

2. Methods

To understand the role of scientific expertise in SLR adaptation planning for cities, we surveyed individuals involved in coastal planning in city governments from a sample of randomly selected coastal communities in the United States, stratified by population size and geographic region. Respondents were recruited via email and by referral, and the survey was implemented using *Qualtrics* software (Qualtrics, Provo, UT).

2.1. Coastal city selection

We selected US coastal cities via stratified sampling based on population size and geographic region. We compiled a list of cities and towns on the U.S. Census Bureau Government Integrated Directory that lie within coastal counties according to NOAA's Office for Coastal Management (https://coast.noaa.gov/htdata/SocioEconomic/NOAA_CoastalCountyDefinitions.pdf). These cities were divided into seven population size classes (Table S1) and five geographic regions (Table S2), and three cities were randomly selected from each population and region strata. Because not all cities in coastal counties are on the coast, we manually checked (Google Earth, https://www.google.com/earth/) that the selected cities contained lands with an elevation of 10 m or less and were within 15 km of a marine or tidal water body. When selected cities did not meet these criteria we resampled from the same population and region strata. In cases where there were no more cities in the given population and region stratum to sample from, we sampled from a different population size class in the same region. This resulted in a total of 92 selected cities.

2.2. Contacting city or town employees

For each municipality in our sample, we used the public directory information associated with each municipality's website to compile email addresses of individuals who might be involved with SLR adaptation planning. Generally, these individuals included employees within the Planning or Public Works departments of city governments. The governments of some smaller municipalities were not organized into individual departments; in such cases, we collected emails for the mayor and/or city council. Several municipalities did not list email addresses on their website. For these municipalities, we either called the phone number provided on the municipality's website to solicit email addresses or used website forms provided by the municipality to request contact with employees involved in city planning. We also included a question in our survey that asked individuals to identify other individuals who would be able to provide more information on city planning and then added these individuals to the sample.

2.3. Survey design and pilot study

We sought to examine expert involvement in SLR adaptation, broadly construed, and therefore the definition of SLR that we used in the survey is necessarily broad. We defined 'SLR adaptation planning' for our survey participants as "any preparation or policy related to SLR, variability, and storm surge, including: comprehensive master plans, departmental plans, coastal resiliency plans, or plans for specific policies or programs such as infrastructure investment, coastal management, set back limits or other zoning changes." This definition has the additional benefit of including local planning processes that may have the effect of SLR adaptation planning even if the local political environment prevents 'SLR' or 'climate change' more generally from being explicitly discussed. We did not ask respondents to distinguish what terminology (i.e. "SLR" or "storm surge") or which plans or policies of the broad definition above were used in their local planning process. For simplicity, in the "Results" section we refer to all positive responses as "SLR adaptation planning", although the term "SLR adaptation" may not appear explicitly in plans for these communities.

Survey questions were written to correspond to our stated research objectives. We first sent a draft survey to relevant individuals in several cities not included in our random sample. Based on responses from these individuals, we revised the survey before sending it to other individuals within our targeted towns and cities. A complete list of final survey questions, with answer choices where applicable, is provided in Supplementary Materials (Appendix B). The final survey was initiated in July of 2016 and closed in October 2016. This extended survey period allowed for survey responses from contacts referred to us by original survey participants.

2.4. Data analysis

We included in our analysis all responses for each question in the survey, though not all respondents completed the entire survey. We used as many of the responses from the survey as possible and did not require consensus among or average responses across respondents from the same municipality. When aggregating responses by municipality, if individuals from the same municipality differed in response to the same question, we used the positive response for yes or no questions: for example, we assigned positive scores for SLR adaptation planning if a single respondent from a specific city indicated that planning was occurring or had occurred. For other questions aggregated by city, we used the largest numbers reported for quantities (such as how many experts of each discipline were involved at the city level), the earliest date for the start of adaptation planning, or the furthest-along category for the stage of planning. The affiliations of experts, the planning stages at which they were involved, and questions relating to the characteristics of experts were evaluated at the level of individual respondents and not aggregated by municipality.

We compiled a series of predictor variables, including demographic characteristics and vulnerability to SLR of each city, to be used in statistical tests (described below). Population density, median income, the percentage of housing units occupied by owners, and the percentage of residents with a college degree were obtained from the American Community Survey (ACS) for 2008–2012. County-level political orientation is drawn from the proportion of the two-party voting in the 2012 election (The Guardian, 2012). Data concerning vulnerability to SLR were obtained from http://riskfinder.climatecentral.org/. These data combine local SLR projections and a tidally-adjusted approach to quantify low-lying coastal land, housing, and population relative to local mean high water levels (Strauss et al., 2015). The local SLR predictions are derived from global estimates empirically fit to long-term records at 55 tide gauges located around the U.S. (Tebaldi et al., 2012). Because of the large uncertainties in local projections derived directly from climate models and the potential dominance of isostatic rebound or subsidence to local sea level change, this is a valid approach over limited time scales. However, SLR has been accelerating in recent decades (IPCC, 2013) and therefore past trends in SLR are very likely to be underestimates of future SLR. We used two measures of vulnerability for each city: the total population living on vulnerable lands, and the property value of those lands.

We performed a series of univariate and multivariate statistical tests to evaluate whether the presence of a plan or incorporation of expert knowledge by cities was associated with vulnerability or demographic variables. We constructed two sets of alternative general linear mixed-effects models, using a binomial response variable and a logit link function, to determine if demographic variables or vulnerability were related to these two response variables. In the first analysis, we tested whether these predictors were associated with the existence of an adaptation plan. In the second, we examined whether experts were involved in adaptation planning. We initially included population size class as a random effect, because cities ranged from very small to very large population sizes, and we wanted to study the effects of these predictors after accounting for differences due to population size. However, the estimated variance of this random effect was zero. Consequently, we used fixed effects models only. We removed the demographic parameter of median income from our set of predictors, because it was correlated with population density and slightly correlated with the percentage of housing occupied by owners. We used

Akaike's information criterion (AIC) weight to determine which model was best supported by the data.

To assess the composition of expert disciplines involved in planning, we used non-metric multidimensional scaling (NMDS) to visualize and qualitatively compare the expert composition among cities. We then tested if expert composition varied by vulnerability, geographic region, population size, stage of planning, or the year planning initiated, using multivariate permutational analysis of variance (PERMANOVA, Anderson 2001) based on Bray-Curtis dissimilarities and 999 permutations, which allows for comparison of multivariate data relative to predictor variables. PERMANOVA was performed in R using the vegan package (Oksanen et al., 2013).

3. Results

3.1. Survey response

Responses indicated planning was common in coastal communities, and the presence of a SLR planning process has increased dramatically since 2012. We received 174 responses from 71 city governments. Respondent job profiles included mayors, council members, city commissioners, planners, and employees in the departments of zoning, economic development, parks and recreation, public works, ports, emergency management, and coastal restoration. Of the 71 cities surveyed, 47 (66%) reported engaging in SLR adaptation planning, 19 (27%) did not, and for 5 cities (7%) the respondents did not know if planning had taken place (Fig. 1). One city in our sample began SLR planning in 1985. From 2005–2010, several other cities began SLR planning each year. Between 2012 and 2015 SLR planning grew quickly, increasing to a maximum of 8 cities that began planning in 2015 (Fig. 2). The city plans we surveyed varied in stage of development, spanning preparation (22%), writing (14%), implementation (27%), and review or revision (27%). The most common planning actions respondents reported were comprehensive city plans (38%), other (26%), and coastal management (13%). Less common planning actions respondents reported were regional or state plans (8%), transportation infrastructure (7%), coastal armoring (5%), and re-zoning and setbacks (3%). Areas of SLR planning that respondents categorized as other included hazard mitigation planning, general vulnerability assessments, planning for specific projects or developments, wastewater utility planning, overarching strategy documents, flood plain development regulations, waterfront revitalization, and critical infrastructure.

Fig. 1. Location of coastal cities sampled. Blue points indicate cities that have engaged in SLR planning, green points represent cities than have not, and red points represent cities in which respondents were unsure if SLR planning has taken place (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

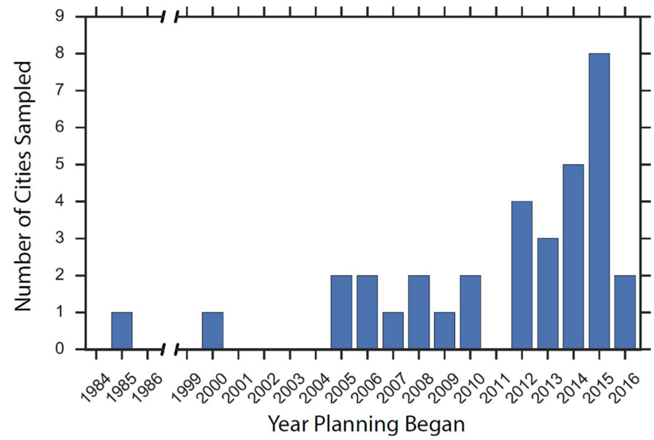

Fig. 2. Earliest year that each city initiated SLR adaptation planning.

3.2. Expert involvement

Expert involvement in planning was common; among cities that had engaged in SLR planning (38), 87% involved experts in the planning process. The most common expert disciplines used by (31) cities are urban planners (87%), engineers (77%), biologists and ecologists (55%), and legal experts (55%). When asked which disciplines they would like more involvement from, 24 respondents most frequently cited atmospheric scientists (38%), urban planners (38%), oceanographers (33%), geologists (33%), and economists and political scientists (33%). The experts that were most frequently rated highly valuable were urban planners (78%), oceanographers (69%), atmospheric scientists (67%), and biologists and ecologists (63%). To compare these three measures (i.e. for each discipline: were experts in this discipline involved, did cities want more involvement from experts in this discipline, were experts of this discipline considered most valuable) of expert involvement, we ranked expert types by responses from each city for these three questions and scaled the rankings from 0 to 1 (Fig. 3). The result indicates that atmospheric scientists, oceanographers, economists and political scientists, and geologists are currently underutilized, according to planners.

Institutional affiliation of experts showed distinct patterns among disciplines (Fig. 4). Legal experts and urban planners predominantly came from local government (58 and 49%, respectively). Oceanographers, atmospheric scientists, biologists and ecologists, and geologists were mainly from other governmental (29, 34, 28, 39%, respectively) and academic institutions (43, 34, 28, 22%, respectively). The stages in the planning process at which experts were involved also varied among expert categories (Fig. 5). Economists and political scientists, geologists, atmospheric scientists, and sociologists and anthropologists were primarily involved during preparation for planning. Urban planners and engineers were approximately evenly involved across all stages of the planning process (Fig. 5).

3.3. Expert characteristics

Attributes of individual experts who were most influential in the SLR planning process included: bringing relevant research to the attention of planners, attending meetings in person, participating in formal partnerships, and developing planning recommendations based on scientific research (Fig. 6). Effective experts were also more likely than other experts to make scientific knowledge more accessible to planners and present specific relevant research. Experts in disciplines that planners considered more relevant for the planning process were also reported to be more effective, suggesting the expert's discipline may have influenced their perceived usefulness (Fig. 7).

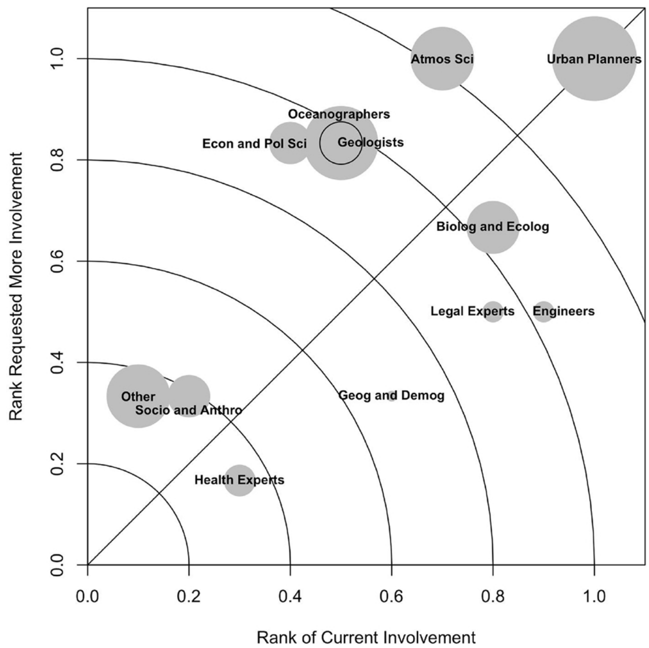

Fig. 3. Value of expert disciplines according to scaled rankings of current involvement (x-axis) and scaled ranking of requests for more involvement in planning (y-axis). The size of each point is scaled to the ranking of how valuable experts from that discipline have been to planning. Disciplines are increasingly utilized and requested with distance from the origin. Disciplines above the 1:1 line are underutilized compared with perceived needs.

3.4. Other information used

Experts were not the only source of scientific information respondents used during planning. Almost every city (93% of 29) used mapping tools, and most cities also used impact, risk, or vulnerability assessments (90%), existing reports (79%), and other adaptation plans (76%). Only a minority of cities used journal articles (34%). A majority (62% of 29) cities consulted existing plans during their planning process. When using existing plans as sources of information, the majority of cities (70% of 20) chose reference plans based on proximity, i.e. county or state plans from the area or region. However, some cities (25% of 20) looked to larger cities' plans (i.e. New York, San Francisco, Seattle, Boston, and New Orleans) for reference.

3.5. Cities without planning

Of the 26 cities that had not engaged in SLR planning, 50% said SLR planning is not a current planning priority, 25% said the city is not threatened by SLR, 22% cited funding limitations, and 22% said the city is not in a coastal area. About half (54%) of non-planning cities expect planning to occur in the future, 31% do not expect it to occur, and for 15% of cities, respondents within a city did not agree. Of those cities that do not expect to engage in planning in the future, 46% of respondents said their city was not threatened by SLR, 31% cited funding limitations, 23% said that it was not a future planning priority, and 8% said the city is not in a coastal area. Respondents from one city reported they are not threatened by SLR and cited scientific information supporting this claim.

3.6. Quantitative analyses

Whether or not a city had engaged in SLR adaptation planning was not related to any of the predictor variables examined, but whether or not experts were involved was related to some of the predictor variables. Although the model including the total vulnerable population for each city had the lowest AIC value, since this model was more complex, the difference in AIC between this model and the null model did not meet the threshold ($\Delta AIC < 2$) for including this variable as a predictor (Tables 1 and 2). Conversely, whether experts were involved in planning was related to two predictor variables. The percentage of city occupants with a college degree and the percentage of occupants living below the selected SLR level were chosen as significant predictors [had a lower AIC value] (Table 3) when examining the probability of expert involvement. Expert involvement increased with the amount of college-educated residents, but decreased when more occupants lived within dangerous levels of SLR (Table 4).

3.7. Multivariate statistics

Multivariate analyses revealed no relationship between the composition of experts and predictor variables measuring city demographic characteristics and vulnerability to SLR. City governments from all regions and population size classes varied widely in terms of the number and range of expert disciplines they incorporated into adaptation planning. We found no significant differences in the composition of experts between cities at different planning stages, or with respect to population size, or the year in which planning began (Table 5). Multivariate dispersion was comparable between different categorical levels of region, population size, and planning stage (PERMDISP, psuedo-P > 0.05).

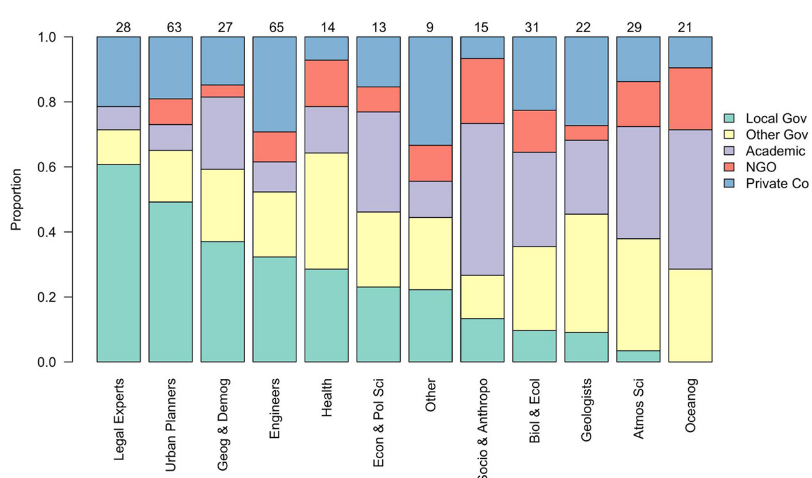

Fig. 4. Type of affiliation for experts in each discipline. Numbers at top of columns represent *n* number of responses.

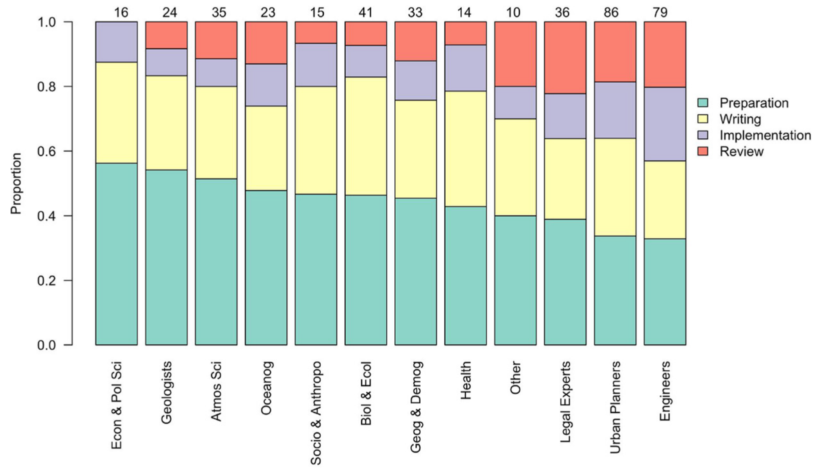

Fig. 5. Stage of planning process at which experts were involved in for each discipline. Numbers at top of columns represent *n* number of responses.

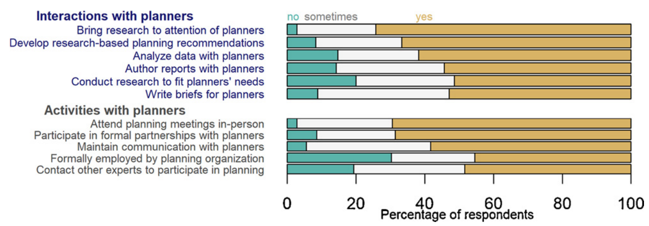

Fig. 6. Proportion of respondents identifying each characteristic of experts (i.e. interactions with planners [blue text] and planning-related activities [gray text]) that correlated with more effective experts. Gold refers to characteristics effective experts had, while teal refers to characteristics effective experts did not have (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

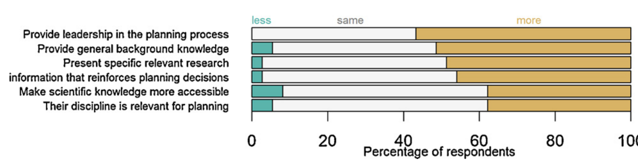

Fig. 7. Proportion of respondents identifying each action of experts that correlated with more effective experts. Gold refers to actions effective experts engaged in more often, while teal refers to actions effective experts engaged in less compared to less effective experts (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Table 1
Alternative logit link functions used to evaluate effect of predictor variables ($x_{i,j}$) on presence of plan and expert involvement (p_i) for coastal city *i*.

Model name	Link function
Null	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0$
Percent occupants below selected level	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_1 x_{i,1}$
Property value below selected level	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_2 x_{i,2}$
Percent democratic voters	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_3 x_{i,3}$
Population density	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_4 x_{i,4}$
Percent housing occupied by owner	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_5 x_{i,5}$
Percent of population with college degree	$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_6 x_{i,6}$

Table 2
AIC values for alternative models predicting presence of SLR adaptation plan. Italicized model represents selected model.

Predictor variables	df	AIC
Vulnerable Population	2	93.86
Null	*1*	*94.15*
Property percentage below level	2	94.99
Percentage democratic voters	3	95.08
College education	3	95.65
Population density	3	95.89
Percent housing owner occupied	3	95.90

Table 3
AIC values for alternative models predicting expert involvement. Italicized model was selected.

Predictors	df	AIC
College and percentage below level	*3*	*76.31*
College education	2	81.36
Percentage below level	2	81.49
Population size class	2	84.98
Property value below level	2	85.14
Null	1	85.32
Percent democratic voters	2	87.02
Population density	2	87.25
Percent housing owner occupied	2	87.30

Table 4
Estimated parameters of chosen model relating predictors to expert involvement.

Parameter	Estimate	Std. error	p value
Intercept	−2.18	0.81	0.00724
Coefficient on percentage of population in vulnerable areas	−1050.68	556.12	0.05885
Coefficient on percentage of residents with a college degree	9.54	3.75	0.01099

4. Discussion

4.1. Use of science in the planning process

We found that coastal cities in the U.S. have engaged in SLR planning across a wide range of population sizes, geographic regions, and population characteristics. Assuming that our sample is representative of coastal cities around the U.S., we can infer that SLR planning is common. The rate of planning we observed (63%) is similar to a 2011

Table 5
Results from PERMANOVA tests used to compare the composition of expert disciplines included in sea level adaptation planning between cities in different regions, population size class, and planning stages, and relative to population size and the year in which adaptation planning was initiated.

Variable	df	F	Pseudo-P
Region	4	0.8148	0.692
Population size class	7	0.9137	0.593
Planning stage	4	0.755	0.780
Population size	1	1.669	0.119
Year initiated	1	2.0778	0.086

survey of 298 U.S. cities that were members of ICLEI-Local Governments for Sustainability reporting 59% had engaged in some sort of climate change adaptation planning (Carmin et al., 2012). Additionally, a 2017 survey of municipal planning documents found 12 out of 20 coastal cities had relevant planning documents addressing SLR (Fu et al., 2017). Our definition of SLR planning was purposefully broad to be inclusive of places where climate changed induced SLR is a politically charged topic and to characterize expert involvement in all aspects of planning. This broad definition may have contributed to how widespread we found planning to be. The widespread occurrence of planning also suggests that local governments will play a critical role in adaptation, because most costs and benefits of adaptation measures will be experienced at the local spatial scale.

Contrary to our expectations, the presence of SLR planning was not correlated with local SLR vulnerability estimates based on either vulnerability of the human population or property. The estimates of vulnerability we used in this study rely on current population distributions and do not consider future population growth. Therefore, they underestimate the impacts of future SLR but reflect the current state of each city. Including projections for population growth with SLR vulnerability predicts a nearly three-fold increase in the number of people at risk of inundation (Hauer et al., 2016).

The use of scientific expertise in SLR planning was widespread, with 87% of cities using experts in the planning process. This agrees with previous research that found local planners generally place high value on scientific involvement (van Stigt et al., 2015). We found a positive relationship between the involvement of experts in the planning process and the percentage of citizens with a college degree. This could suggest that localities with high educational capacity or high density of educational institutions have more access to experts, though it could also represent a greater perceived value of scientific involvement among a more highly-educated populace. Although there was no relationship between a city's vulnerable population size and whether or not they had engaged in planning, we found a weak negative relationship between the vulnerable population size and whether experts were involved. Taken together, these results could suggest that planning is seen as more urgent in highly vulnerable areas and consultation with experts is perceived to be time-consuming. However, due to the small sample size of our study, it is difficult to draw confident conclusions from correlations with these predictor variables.

4.2. Expert disciplines in the planning process

Our findings agree with previous research that has found that local planners value scientific knowledge, either for themselves or for their governing organization (van Stigt et al., 2015). Specific areas of knowledge required for SLR planning are more rarely reported but interdisciplinary groups involved in SLR planning include economists, engineers, spatial analysts, law and policy experts, and scientists (Langridge et al. 2014). Coastal managers regularly depend on a wide range of information including land-use, weather, socioeconomic, and geologic information (Tribbia and Moser, 2008), and similarly our results indicate a breadth of expertise is involved in SLR planning. One might expect that types of experts that are often consulted for many planning purposes (e.g., urban planners and engineers) would be more accessible and therefore included more often in SLR planning. On the other hand, because of the unique scientific issues involved with SLR, planners may be strongly motivated to seek out specific expertise, such as oceanographers and atmospheric scientists.

The responses from local planners regarding expert involvement suggest inter-organizational barriers to action could impede inclusion of relevant scientific expertise. For example, among the expert disciplines considered in this study, oceanographers and atmospheric scientists were ranked as highly valuable by local planners. At the same time, planners reported the desire for more participation in the planning process from experts in these two disciplines, as well as economists, political scientists, and geologists. When they were involved, experts from these disciplines were primarily affiliated with academic and other (non-local) governmental organizations, and were among the disciplines least employed by local governments. While connections between local governments and academic institutions certainly already exist, our findings suggest that there is still space to increase the exchange of information and expertise between local governments and academic and other (non-local) government organizations and to draw experts into the planning process. This agrees with a previous study that found universities and research laboratories were the most trusted sources of information and widely available, but that they are largely unused (Tribbia and Moser, 2008). Quantitative analysis revealed a positive correlation between education and involvement of expert disciplines in the planning process, which hints that some locations may be limited by the institutional capacity of the surrounding area. Legal experts, urban planners, and engineers were identified by respondents as more often involved in the planning process, whereas additional expertise in these areas was not desired as highly. These experts are more likely to be affiliated with local governments, suggesting that local governments are able to use their internal analytic capacity, but such capacity may be insufficient, on its own, to address a broad, interdisciplinary issue such as climate change.

4.3. Experts' activities

The most commonly identified trait among experts who are perceived as highly effective in the policy process is the ability to make scientific research more accessible for participants in the local adaptation planning process. This is consistent with prior research that has found a crucial role for scientists to bridge the gap between scientific research and the adaptation planning process by making research more salient for decision-makers (Bierbaum et al., 2013; Moser and Ekstrom, 2010; Moser and Luers, 2008). Scientists play key roles in translating research to make it more accessible for the planner and to describe the political implications of scientific findings (Marshall et al., 2017; van Stigt et al., 2015). The second-most common trait planners associated with highly effective experts is the ability to bring relevant research to the attention of planners. Planners value scientific information, but do not necessarily have the capacity to effectively recognize or use relevant information (Moser and Luers, 2008). There is an aspect of bounded rationality to the planning process that prevents planners from considering all planning-relevant knowledge, and planners may not know what they don't know. Only 34% of cities used published journal articles directly. By making scientific information more accessible to planners, experts reduce the barriers imposed by limited analytic capacity, thereby reducing the costs associated with assimilating and using the information effectively. Expert participation in planning can identify relevant existing research and increase policymakers understanding of their remaining information needs, thereby enhancing the intelligibility of scientific information across contexts (Jasanoff, 2004).

However, this does not mean that scientists should defer the responsibility for setting a research agenda to local planners and policymakers. We find that experts that were perceived as most effective did not necessarily conduct specific research for planners, nor were they necessarily employed by the planning organization. These findings agree with previous critiques of the 'demand-pull' model of science in which scientists surrender responsibility for setting a research agenda (Landry et al., 2001), as well other empirical research that has shown that while local policymakers have great interest in using research to inform policies, they have little interest in directing research (van Stigt et al., 2015). It is important to note that this does not necessarily mean that the most effective experts were not engaged in local, problem-oriented research that previous work on knowledge co-production has found to be valuable for legitimation and integration in local planning (Armitage et al., 2011; Lemos and Morehouse, 2005; Puente-Rodriguez et al., 2016). In fact, the activities associated with scientists viewed as most effective, outlined in the following paragraph, align with previous knowledge co-production work demonstrating the importance of building sustained relationships between scientists and policy-makers.

Importantly, our data imply that the role of a scientist does not stop at the presentation of information, but extends to the interpretation and application of this information to the relevant policy subsystems and to developing research objectives with planning objectives in mind. This contrasts with the 'science push' model of scientific involvement in the planning process, where publication of research typically marks the end of responsibility for the scientist and published information may or may not be taken up by planners (Cash et al., 2006; Latour, 1998; van Kerkhoff and Lebel, 2006). Crucially, scientists can increase uptake of their information by deliberately avoiding insulating their research from the planning process (Sarewitz and Pielke, 2007). A crucial aspect of the role of experts, particularly with respect to SLR, is to provide information at the appropriate spatial scale to improve the usefulness of the information and increase the likelihood the information is utilized by planners (Poff et al., 2016; Rasmussen et al., 2017). With limited analytic capacity among government planning bodies, not only are scientists responsible for communicating their research to other scientists, but also for communicating with planners and policymakers such that their information is likely to be appropriately used by planners. Translating scientific knowledge for planners can be particularly valuable if it is presented in a way that explicitly links relevant information to the different policy options planners are considering (Poff et al., 2016; van Stigt et al., 2015).

Communication of scientific information can be most effective if scientists can place their recommendations within the context of stakeholder goals or otherwise adapt their information for the particular decision-making context. (Dilling and Lemos, 2011; Marshall et al., 2017; van Stigt et al., 2015). We find that developing research-based planning recommendations is one of the more common planning activities that experts who are perceived as most effective engage in. However, lack of knowledge among scientists about the planning process and political context – including the specific goals of planners and stakeholders and the constraints they face – presents a significant barrier to engagement (Marshall et al., 2017; Poff et al., 2016). In order to be effective, scientists must repeatedly interact with planners to build a mutual understanding of the policy subsystem and engender trust between the two groups (Marshall et al., 2017). Our findings agree with those of others that attending planning meetings in-person and forming formal partnerships between scientists and planners are effective means of engagement. These activities can help scientists familiarize themselves with the goals and limitations of the planning process, and allow scientists to make more effective recommendations for planners. Institutionalizing this relationship between experts and planners via formal partnerships or development of informal norms of information-sharing may reinforce communication between the two groups. Partnership activities may also help to promote a sense of collaboration and mutual respect which can increase the likelihood of successful adaptation planning (Burch, 2010). At the same time, formalizing relationships in this way can create substantial barriers to scientific involvement in the planning process, because it requires a significant investment of time and effort on the part of the scientists. Overcoming these barriers would be difficult to achieve without some institutional incentive for relevant experts to become involved in the planning process. The academic and government organizations that employ scientific experts could facilitate their involvement in a proactive way so that relevant experts could become involved at the beginning of the planning process in order to overcome these barriers and incorporate scientific expertise from the outset.

5. Conclusion

Using a survey of stratified randomly sampled coastal cities we study the extent to which scientific expertise is incorporated into local SLR planning, which expert disciplines are underutilized, and the perceived characteristics of effective scientific experts. Our results show 63% of responding cities engaged in SLR planning. While respondents reported high rates of utilization of scientific expertise, many reported a desire for additional involvement from experts: particularly from atmospheric scientists and oceanographers who are not widely employed at the municipal level. Barriers to using relevant scientific expertise could be institutional, financial, or attitudinal (Moser and Ekstrom, 2010; Porter et al., 2015). While the utilization of experts was weakly positively correlated with education of the municipal population, these results are consistent with many different possible barriers to expert utilization, and further research should further examine the variety of institutional contexts in which experts were employed and how relevant institutional barriers were overcome. Experts that cultivated an ongoing working relationship with planners and who were able to translate and apply scientific information to the planning context were perceived as most effective. However, this research does not explore how these partnerships were initiated. To the extent that climate adaptation is a thoroughly political process (Eriksen et al., 2015), further research should disentangle how scientific partnerships can be inserted into the political decision-making process, and how the effectiveness of scientific information depends on the political context in which it is received, adjudicated, and acted upon.

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Appendix A. Supplementary data

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