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Planning for future sea-level rise in Swedish municipalities

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A warmer climate leads to rising sea levels. Despite uncertainties about how rapid and substantial future sea-level rise (SLR) will be, society needs to prepare and adapt. This study examines the state of planning for future SLR in Sweden by surveying 33 coastal municipalities in southern Sweden and interviewing local, regional and national authorities with relevant accountability. The results reveal that there are considerable gaps in current planning for SLR. Almost one-third of municipalities lack guiding planning documents for SLR, and more than two-thirds do not discuss SLR beyond 2100. We argue that the prevailing uncertainty and ambiguity in assessments of future SLR is problematic within a traditional "predict-then-act" paradigm, and that robust approaches, such as scenario planning, can reduce many of these problems.

Keywords: sea-level rise; uncertainties; planning; climate change adaptation

Introduction

Adapting to climate change calls for considerable efforts by many municipal authorities (e.g. Glaas *et al*. 2010, Aal *et al*. 2012). Rising sea levels are an important consequence of climate change, and it can have a major impact on dwellings, transport, drinking water and sanitation (Nicholls *et al*. 2007). Adapting to rising sea levels requires a long-term perspective and involves coping with the inherent uncertainties in how fast sea levels will rise as well as by how much. Such uncertainties must be handled by local planners facing demands for new housing along coasts or development of freshwater resources.

In recent years, the risk of accelerated and long-term sea-level rise ("SLR") has become more pertinent. One reason is the surprisingly large mass loss from the great ice sheets in Greenland and Antarctica observed over the last two decades (Shepherd *et al*. 2012). Also anthropogenic emissions of greenhouse gases have continued to increase, making climate change mitigation more difficult (International Energy Agency 2013). As a consequence, high-end global warming and SLR scenarios are now being taken more seriously (Nicholls *et al*. 2011). Moreover, there is an increased understanding in the scientific community that SLR will likely continue for centuries, even with forceful climate change mitigation (Meehl *et al*. 2012).

Climate change and SLR are global phenomena that have local impacts, and approaches to manage them are also mostly local. Consequently, adaptation to SLR varies significantly

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between different countries and regions (Nicholls and de la Vega-Leinert 2008, Wilby and Keenan 2012) and empirical knowledge on how adaptation to SLR works in reality is lacking (Tol *et al*. 2008).

Our focus here is on the use of assumed levels and time frames for future SLR in spatial planning of local governments, which is commonly recognised as a critical element in adaptation to climate change (Hurlimann and March 2012). While there are many other elements of spatial planning that are important in the context of climate change adaptation, the increased risk of accelerated and long-term SLR makes assumed levels and time frames for future SLR particularly important.

Our aim in this study is to investigate how coastal municipalities in Sweden plan for future SLR. The study addresses the following research questions:

(1) Do the municipalities address future SLR in their planning documents?
(2) If so, what levels of future SLR do they plan for?
(3) What time horizons do they apply in planning for SLR?
(4) How do they cope with uncertainties in projections of future SLR?

Background

Future SLR is uncertain (Willis and Church 2012). The Intergovernmental Panel on Climate Change (IPCC) provided a range of 0.18–0.59 m global mean SLR by the end of the twenty-first century (relative to the end of the twentieth century) in its fourth assessment report (IPCC 2007). However, this range did not include potential future changes in the dynamics of the great ice sheets on Greenland and Antarctica, and thereby excluded the greatest source of uncertainty in future SLR (Alley *et al*. 2005). The inability of the IPCC (2007) to assess the future contribution to SLR from Greenland and Antarctica triggered novel approaches in making SLR projections. Recent assessments based on these novel approaches suggest that 2 m SLR by 2100 is possible (Nicholls *et al*. 2011, Parris *et al*. 2012) and even higher figures have been suggested (e.g. Tol *et al*. 2006, Lowe *et al*. 2009, Hansen and Sato 2012).

Most SLR projections focus on the end of the twenty-first century, but longer-term projections have also been published. For example, one study found that even a low-emissions scenario (RCP3-PD) could yield 1–3 m SLR by 2300 (Schaeffer *et al*. 2012). Another found that a high-emissions scenario (RCP8.5) could yield 2–12 m SLR by 2500 (Jevrejeva *et al*. 2012). For longer time frames, analogues with paleoclimatic history suggest even higher SLR; Foster and Rohling (2013) showed that the present concentration of carbon dioxide in the atmosphere (around 400 ppm) has historically been associated with sea levels 9–31 m above present.

A variety of ranges of future SLR have been used in different national assessments. For example, in the Netherlands the Delta Commission defines an "upper limit scenario" of global mean SLR of 0.55–1.10 m by 2100 (Delta Commission 2008). The United Kingdom Climate Impacts Programme bases their assessments on a global mean SLR by 2100 of 0.18–0.59 m and a "H ++ scenario", which is based on a global mean SLR of 2.5 m by 2100 (Lowe *et al*. 2009).

The main responsibilities of planning for SLR vary between different countries and across all levels of the legislature (Tol *et al*. 2008). For example, the main responsibility of coastal defence lies with the national government in the Netherlands (VanKoningsveld *et al*. 2008), state governments in Germany (Sterr 2008) and counties in Ireland (Devoy 2008).

In Sweden, municipalities have a considerable degree of autonomy as well as independent powers of taxation (SKL 2013). They are responsible for a larger share of public services than in most other countries including planning and building issues, health and environmental protection, refuse collection and waste management, water, sewerage, emergency services and emergency preparedness. Coastal planning decisions taken by municipalities are highly dependent on assumptions about future SLR. Currently, there is pressure on municipalities to allow development of areas close to the sea.

Previous studies of climate change adaptation in Sweden have shown that SLR is a problematic issue for municipalities (Carlsson-Kanyama *et al*. 2013). A case study on local coastal zone management in Sweden (Storbjörk and Hedrén 2011) found a lack of continuity in policy-making, planning and decision-making and points to the importance of manifest planning and decision-making structures, arenas and regulatory frameworks.

In this study, we have focused on coastal municipalities' comprehensive and detailed planning with regard to future SLR, since comprehensive and detailed planning are key processes in adapting to climate change. The detailed plan regulates land use and construction, and it is legally binding. It is also a policy document guiding future development plans (Eliasson 2000). The County Administrative Boards (CABs) supervise and advise local planning, and national authorities such as the Swedish Meteorological and Hydrological Institute (SMHI) and the National Board of Housing, Building and Planning provide expertise (Storbjörk 2007). Sweden's Planning and Building Act (1987, p. 10) states that flooding and erosion risk should be considered in municipal detailed planning and when issuing building permits (Gov. Bill 2006/07, p. 122). Hence, coastal municipalities' comprehensive and detailed planning is our focus.

Finally, it should be noted that local (or "relative") SLR differs from the global mean SLR due to factors such as changes in salinity and ocean currents, rates of sedimentation, plate tectonics and postglacial land uplift (Nicholls 2011). For the Baltic Sea region the postglacial uplift is particularly important for local SLR (see Figure 1). The BALTEX Assessment of Climate Change in the Baltic Sea Basin writes that "land uplift and the global average sea level rise … seem to be the dominant contributions to the future changes of mean sea level in the Baltic Sea" (BACC author team 2008, p. 197). What levels of global mean SLR are assumed in local planning is therefore of specific interest. In what follows all numbers for SLR refer to the global mean if nothing else is specified.

Methods

Two main methods were used in the study: (1) A survey of municipal planning documents dealing with SLR. (2) Qualitative interviews with those responsible for SLR planning in selected local, regional and national authorities, and a consultancy firm who works with local and regional governments.

The selection of studied municipalities was based on the criterion that they all experience only limited postglacial land uplift. We selected all coastal municipalities in Swedish counties that are transected by the 1 mm/year uplift contour (see Figure 1). This resulted in a selection of 33 coastal municipalities in the southern Swedish counties of Halland (5 municipalities), Skåne (16), Blekinge (4), Kalmar (7) and Gotland[1] (1) (see Table 1 and Figure 2). The vulnerability to future SLR varies between the 33 municipalities, as each location has its own local geological conditions (soil etc.) and local weather conditions (precipitation, hydrological discharge in local watercourses and estuaries, wind and wave conditions, etc.). Coastline length also varies from 800 km in Gotland to less than 1.5 km in Burlöv.

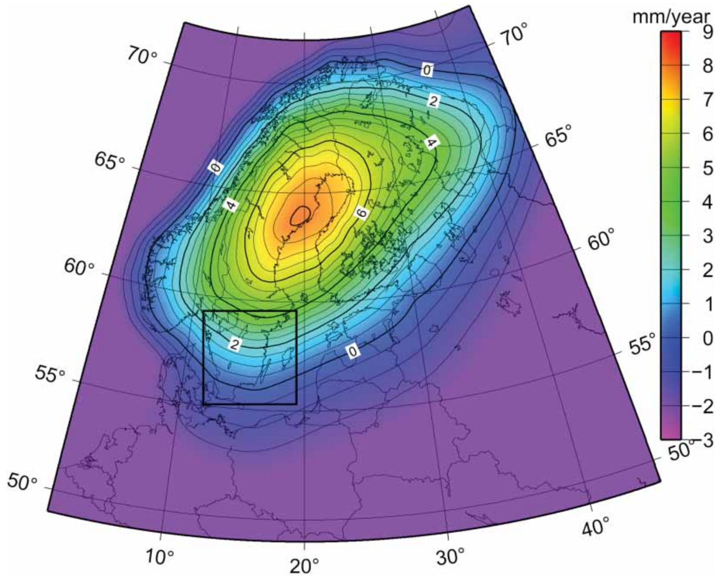

Figure 1. Contour lines for the apparent uplift (change relative to the mean sea level) for Fennoscandia based on the model from Ågren and Svensson (2007). The black rectangle shows the approximate area of Figure 2.
Source: Modified from: Lantmäteriet, Sweden.

Survey of municipal planning documents dealing with SLR

We began by surveying the websites of the 33 municipalities to identify documents guiding their planning for SLR. The documents were primarily municipal comprehensive plans,[2] climate strategies, climate memoranda, climate and vulnerability analyses and in some cases other documents (protocols etc.). In all cases, whether planning guidelines were found or not, we telephoned those responsible for SLR planning at the municipalities to ask about the primary guiding documents used for local SLR planning. This enabled us to confirm whether the municipalities could identify guiding documents or whether they had no planning documents for SLR. We then built a database with information for each municipality on:

- Guiding planning documents on SLR
- Estimated future SLR
- Time horizon for SLR planning
- Original sources of estimates of future SLR.

Qualitative interviews

Twelve qualitative interviews were conducted with desk officers at six municipalities, three CABs,[3] Halland, Kalmar and Skåne, the Swedish Civil Contingencies Agency (MSB), the SMHI and a consultancy firm (WSP). Our selection criteria follow. A third of the municipalities studied (i.e. 11) were randomly selected for interviews. Six agreed to be interviewed, one declined and four did not respond. All five CABs were contacted and three responded. We were able to reach one out of three consultancy firms identified as the main providers of SLR documentation to municipalities (DHI, Sweco and WSP).

Table 1. Counties and municipalities studied.

Municipality	Planning document	Local SLR by 2100	Global SLR by 2100	Source (reference)
Halland County				
Falkenberg	2012	?	?	–
Halmstad	2012	"about 1 m"	"about 1 m" (levels from 0.6 to 2 m also mentioned)	SMHI (2010), MSB (?)
Kungsbacka	2009	0.8 m	?	IPCC (?)
Laholm	N/A	–	–	–
Varberg	2010	0.4–1 m	?	IPCC (2007)
Skåne County				
Ängelholm	N/A	–	–	–
Båstad	2008	0.22–0.66 m	?	SMHI (2007), IPCC (2007)
Bromölla	N/A	–	–	–
Burlöv	N/A	–	–	–
Helsingborg	2012	"about 1 m"	"about 1 m" (levels from 0.18 to 1.6 m also mentioned)	SMHI (?), Rummukainen and Källén (2009), The Copenhagen Diagnosis (2009)
Höganäs	2012	0.89 m	"about 1 m"	SMHI (2010)
Kävlinge	2009	0.7 m	0.6 m	SMHI (2007), IPCC (2007)
Kristianstad	2011	0.8 m	?	SMHI (2007)
Landskrona	2012	"about 1 m"	?	SMHI (?)
Lomma	2011	0.66 m	?	SMHI (?)
Malmö	2008	0.22–0.66 m	?	IPCC (?)
Simrishamn	2008	?	?	–
Skurup	N/A	–	–	–
Trelleborg	2010	0.32–0.92 m	?	SMHI (?), IPCC (?)
Vellinge	2011	"about 1 m"	"about 1 m" (levels from 0.5 to 1.4 m also mentioned)	Rummukainen and Källén (2009), The Copenhagen Diagnosis (2009)
Ystad	2011	0.32–0.92 m	?	SMHI (2007)
Blekinge County				
Karlshamn	N/A	–	–	–
Karlskrona	2003	?	0.4–0.8 m	SMHI (?)
Ronneby	2008	0.32–0.92 m	0.18–0.59 m	SMHI (?), IPCC (?)
Sölvesborg	2011	0.22–0.9 m	?	SMHI (2007)
Kalmar County				
Borgholm	2010	0.2–1.22 m	?	IPCC (?)
Kalmar	N/A	–	–	–
Mönsterås	2012	?	?	–
Mörbylånga	N/A	–	–	–
Oskarshamn	N/A	–	–	–
Torsås	N/A	–	–	–
Västervik	2012	0.2–1.3 m	0.18–0.59 m	SMHI (?), IPCC (?)
Gotland County				
Gotland	2010	0.1–0.6 m	Several levels used at the same time: 0.18–0.79 m and 0.6–1.2 m	SMHI (2008), SMHI (?)

Notes: For each municipality, the following information is provided in the columns: (1) planning document from year or N/A, if no planning document was available, (2) local SLR by 2100 specified or question mark, if no figure was found, (3) global SLR by 2100 specified or question mark, if no figure was found, (4) source for SLR figures (year, if reference provided, or question mark, if no reference provided).

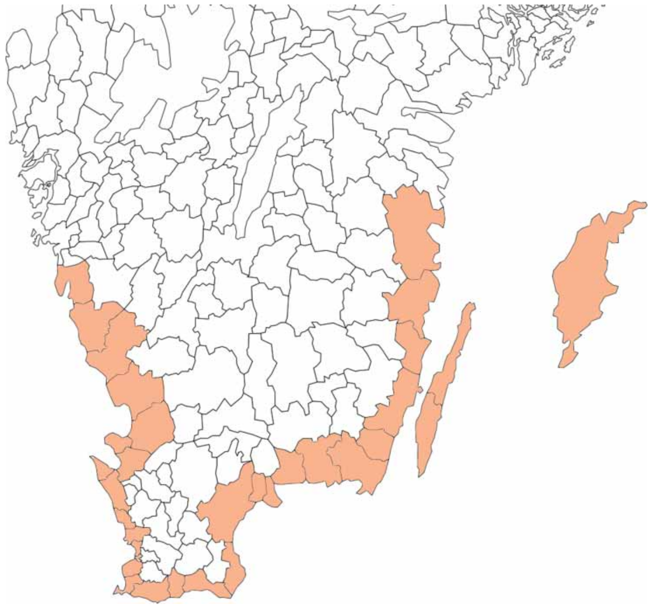

Figure 2. The 33 municipalities chosen for the study.
Source: Modified from: SCB, Sweden.

We believe the interviewed municipalities and CABs are representative in terms of diversity of location and variety of size; however, we note that none of the selected municipalities in Kalmar county could be interviewed. MSB was selected as it is the national agency responsible for emergency and crises preparedness and prevention, including flooding, and SMHI as it is the government agency providing knowledge and decision support about weather, water and climate data, and WSP since it is a main provider of outsourced reports on issues related to SLR for CABs and municipalities. The interviews were conducted by telephone in a semi-structured way (Kvale 2007) between 30 May and 19 June 2012 (for interview questions see the appendix). The interviews were recorded[4] and transcribed, then analysed thematically (Miles and Huberman 1994, Kvale 2007). The interviewees were then given an opportunity to review and clarify their quotes. Quotes from the interviews below have been anonymised so that CABs are randomly but consistently called CAB A, B, C, and municipalities are called Municipality 1, 2, 3, etc. Quotes from published reports are not anonymised.

Results

This section is structured around the four research questions set out in the Introduction: (1) Do municipalities plan for SLR or not? (2) If so for what levels? (3) What time horizons do they plan for? (4) How are uncertainties handled?

Do the municipalities address future SLR in their planning documents?

Twenty-three of the 33 studied coastal municipalities identified a guiding planning document on SLR. Thus almost one-third (10/33) of the municipalities lacked such documents. Of the 23 municipalities that included future SLR in their planning, comprehensive plans were the main guiding documents. Thematic supplements to comprehensive plans, such as climate memos, climate analyses and more specific action plans, were also used.

In practice, municipal planning for SLR notably involved the definition of a lowest floor elevation ("LFE"), below which buildings may not be constructed. We found that the LFE ranged from 2.0 to 2.8 m (nine municipalities) to 3.0–3.5 m (11 municipalities), while one municipality used a differentiated level, depending on location (2 or 5 m). Two municipalities did not identify any LFE, despite discussing SLR in a general guiding document. In most cases, it was not clear how the estimated LFEs used were related to assumptions of local or global SLR levels (see below).

The finding that a significant portion of the municipalities in southern Sweden does not consider SLR in their planning documents is surprising. Tol *et al*. (2008) identifies four types of responses to SLR (for different European countries): (1) those that do not worry about SLR and should not as their coasts are not susceptible, (2) those that do not worry as they have more urgent problems, (3) those that do not worry but probably should, (4) those that do worry and have started to adapt. The municipalities in our study that did not consider SLR fall into one of the first three categories, some being more vulnerable to SLR than others. The remaining municipalities fall into the fourth category. We have not been able to categorise the municipalities, because this would require detailed assessments of local vulnerability to SLR, which is not always available. On a general level, it can be observed that all municipalities selected for our study experience very low postglacial land uplift (see Figure 1), and they are therefore potentially more exposed to SLR than most other municipalities in Sweden.

What levels of future SLR do they plan for?

Of the 23 municipalities that identified guiding planning documents for future SLR, three municipalities did not specify any levels of future SLR, but discussed planning in terms of LFE or extreme weather events. Of the 20 municipalities that explicitly provided levels for SLR by 2100, only nine specified the assumed maximum levels of global mean SLR; 0.6 m (three municipalities), 0.8 m (one municipality) and "about 1 m" (four municipalities). One municipality mentioned several different estimates (see Table 1).

In the cases where assumptions of global mean SLR were provided, the maximum has changed over time, from 0.8 m (2003), to 0.6 m (2008, 2009), to "about 1 m" (2011, 2012). These changes likely reflect the changing scientific views on SLR, and major assessments, such as the third assessment report of the IPCC (Church *et al*. 2001) and the fourth assessment report (IPCC 2007). Given the lack of scientific consensus with regard to future SLR, it is important that any major assumptions, such as global SLR, are made explicit to enable transparency.

What time horizon do they plan for?

Nine out of 33 municipalities discuss SLR beyond the year 2100 in their planning documents. Helsingborg discusses the situation in 2200 and specifies a "permanent sea level" of "+2–4 m" which would mean "+4.5–6.5 m above today's average level including extreme weather situations" (Helsingborgs kommun 2012, p. 11). The source of this figure was the Dutch Delta Commission (2008). Other municipalities use more vague statements when mentioning SLR beyond 2100 and do not include specific estimates. For example, Höganäs (2012) mentions that "sea levels most likely will continue to rise after

2100", while Landskrona states that "Thereafter [after 2100], the sea level will rise for a long time" (2012, p. 8). Kävlinge applies a 1000-year perspective: "New research shows that global SLR is unstoppable and is expected to last at least over the next 1000 years, whether carbon emissions end or not" (cited from NOAA 2009), but mentions no specific future levels (Kävlinge kommun 2009, p. 6).

The time perspective of planning for future SLR was raised in interviews and discussed by several central authorities, CABs and municipalities. SMHI's time perspective usually extends to 2100, but the interviewee at SMHI claimed that this is not far enough:

> [Planning for 2100] is what is requested, but . . . one must be aware that this is a short time frame for many things in society and that the sea will continue to rise ... when expanding a city it should stand for more than 100 years. This is particularly important because the ocean will continue to rise for a long time: the Dutch [Delta Commission] talk about two to four metres in 200 years. And we often mention this in these reports, especially the more recent reports.

The Climate Adaptation Coordinator at CAB C also noted that the focus on 2100 might be shortsighted:

> We do not have any predictions or scenarios that go beyond 2100 ... but we are quite clear in saying that climate change does not end in 2100, there is no end date.

Also CAB B, who uses 2100 as the time horizon in its scenarios, recognises the need for a much longer perspective:

> The life span of buildings, if one maintains the houses, can be about a hundred years, but then it is also true that ... when we actually claim land we will remain there for several centuries or actually for all future.

However, reasons for limiting planning to a time horizon of 100 years were also given by e.g. Municipality 1:

> Planning for a thousand-year perspective is not relevant, but we have to set a limit for what is a relevant perspective, and then one can contemplate the fact that many houses in coastal areas are perhaps one hundred years old, one has to take this into account at least.

The same interviewee added, "a human being can anticipate barely more than one life span". Another interviewee (Municipality 2) mentioned political trade-offs and argued that a time horizon beyond 2100 would be difficult to apply in practice:

> [The choice of time perspective depends on] what political mission you should carry out – what finally should be included in a document. There is a conflict between not so long-term development and housing construction and immigration, versus this several hundred year perspective . . . we still have not always, as I see it, found this golden mean between development and climate adaptation.

There were also CABs who argued for a time perspective of 100 years because it seemed "reasonable". CAB C stated: "we should plan for the long-term and in that perspective 100 years is quite reasonable," and CAB A justified the choice of perspective thus:

> It can be a relatively graspable time to discuss ... 90 years ... there is a credible argument behind these numbers, and that's what we felt was most relevant.

Thus, planning for SLR beyond 2100 in the studied communities was rare and statements about SLR beyond this date were often vague. Opinions about what time horizon to plan for differed and reasons given for delimiting oneself to a time perspective of a century were mainly based on pragmatism.

The finding that long-term SLR (beyond 2100) was hardly discussed in planning documents is not very surprising. Municipal comprehensive plans in Sweden typically have a time frame of 20–30 years into the future, while spatial planning may have consequences 50–100 years into the future, and in some cases even longer (e.g. siting of new residential areas) (Hallegatte 2009). This mismatch between climate change impacts and planning horizons is a common problem in adaptation studies (Wilson 2006), but it is particularly pertinent for SLR. Planning for SLR beyond 2100 is probably rare; one notable exception is the Dutch Delta Commission (2008).

How do municipalities cope with uncertainties in projections of future SLR?

Our survey shows that municipalities apparently avoid using a span of SLR when provided with *one* estimate that they believe is suitable for their purposes. An example of the latter is that a number of municipalities and all the interviewees at the CABs use an SLR figure of "around one metre" (for 2100), taken from SMHI. The municipalities using this 1 m value do so in planning documents from 2011 (Vellinge) or 2012 (Halmstad, Helsingborg, Höganäs, Landskrona) while older documents, written before SMHI recommended one level, contain a span for future SLR levels.

For example, Municipality 3, drafting an ambitious climate memo on SLR and referring to a number of sources of SLR estimates, primarily follows the SMHI approach and uses SMHI as consultants because "they have the role of an authority and a follow-up responsibility too." The expected future SLR figure of "around one metre" in municipal planning documents was described by the Municipality 3 interviewee as the outcome of a process:

> In the beginning [SMHI] said 0.2 to 0.6, and then we had to add two decimetres for our situation, so 0.4 to 0.8, but now they say about one metre in general.

Municipality 1 has chosen to use SMHI values because they "feel relevant and reliable ... SMHI's one metre feels like a 'golden mean' in any case it is a quite up-to-date calculation".

The CABs also argue in a similar manner and say that SMHI is the government authority responsible for the issue (CAB B) and has the best and most up-to-date documentation (CAB B and C). According to the interviewee at CAB A, "around one metre" ... "felt like a credible argument and it is one of the more useful [figures]".

The SMHI figure of "around one metre" by 2100 has been used in background data for the Göta älv investigation (Bergström *et al*. 2011), for a proposed new regulation of Lake Mälaren at Slussen[5] in Stockholm (Andréasson *et al*. 2011), and verbally at a large number of public meetings and workshops with stakeholders. Many of the municipalities and CABs have been present at such meetings and some CABs have ambitious plans for visiting each municipality in their county to communicate plans for climate change adaptation.

Considering the clear emphasis municipalities and CABs put on the importance of the information provided by SMHI, we now address the SMHI estimate. According to the interviewee from SMHI, their approach is said to be pragmatic and based on IPCC material and then elaborated through extensive literature studies. The conclusion that "about one metre" is a good estimate is based on a comprehensive assessment "within and outside SMHI" and on an emphasis on the impossibility to assess SLR in detail. The interviewee also points out that:

> Around one metre is a pessimistic scenario – it presupposes that we fail in negotiations on reducing emissions of greenhouse gases.

The SMHI interviewee further argued that there is plenty of information, but that the certainty of assessments is questionable due to weaknesses in "knowledge of the Earth system", primarily in terms of what will happen with the inland ice sheets in Greenland and Antarctica, how fast they will melt and especially how fast they will slide into the sea. Thus, it is crucial to emphasise uncertainties:

> We always try to emphasize that there are significant uncertainties here ... but you can at least say something . . . which is better than saying nothing at all. I think that it is not question of seven metres in a hundred years, it is not zero metres, the assessments that have been developed so far in the world are located thereabouts [around one metre] ... Sometimes two metres is mentioned as an absolute upper limit by 2100.

The SMHI interviewee further saw a risk with following "horror scenarios" that "paralyses the entire decision-making process" and emphasised that high credibility is crucial and that a "climate alarmist" or "exaggerated" perspective is dangerous: "It's serious enough as it is." The interviewee also attaches great importance to being balanced with the highest possible scientific credibility, but that:

> Would something scientific turn up pointing in a completely different direction than what we have said so far, we will change our stand immediately as soon as we are confident about it.

Despite the high trust municipalities and CABs give current SMHI estimates, several of the interviewed municipalities and CABs expressed concern about uncertainties in future SLR. For example, municipalities 1, 3 and 5 reported that they discuss the consequences of not taking the most extreme estimates of SLR into account, particularly in issue-based working groups. According to Municipality 1, planning for the worst-case scenario means that "a margin in planning" is needed, but:

> [There have been] newer and fresher calculations talking about six to eight metres . . . so the big ice sheets will perhaps melt, but it will not happen in a hundred years ... it is not reasonable to believe that we will get a six to eight metre rise in sea levels in a hundred years. Maybe we're talking 10,000 years in that perspective.

CAB A mentioned how very large low-lying areas could be affected and how many coastal areas could become uninhabitable in the future:

> In the end it's a question of whether it is appropriate even to build or have a town in this location. There are examples of these strategies one can talk about – attack and retreat and defence, it's not entirely wrong to discuss them.

Several interviewees believed that credible information is essential and agreed that there are major risks in excluding the most extreme estimates. According to Municipality 2, the best would be to apply a worst-case scenario and start from there, since it would mean taking the utmost care. But at the same time, the interviewee asked:

> What is the worst-case scenario? How long will the scientists believe that this is the worst-case scenario?

Several municipalities mentioned a lack of knowledge and an absence of clear guidance on what levels to plan for. Interviewed municipalities believed that SMHI should be the source of planning guidance, while SMHI emphasised the responsibilities of municipalities.

Information regarding future SLR is not only uncertain, it is also ambiguous in that there are many different reports and expert assessments that planners might take into account. Ambiguity is also apparent regarding the SMHI figure of "around one metre" SLR. In general, ambiguity may hinder actions or responses to climate change, as uncertainty about what is the right thing to do may arise (Brugnach *et al*. 2008).

The choice of ranges for future SLR assumed in planning was often motivated by "reasonableness", without further discussion. Municipalities, however, seem to have great confidence in SMHI, and simply used the estimates provided to them. Such cases in which trusted expert knowledge points in a specific direction, or presents a narrow scope of uncertainty, can be framed as "manufactured certainty", whereby trust in expert knowledge leads the municipalities to lack awareness of the uncertainties involved in future SLR.

Concluding discussion

We found considerable gaps in current planning for SLR in the studied municipalities. Almost one-third (10/33) of municipalities lack guiding planning documents for SLR, and more than two-thirds do not discuss SLR beyond 2100. A more detailed study of the reasons why SLR is not considered in the 10 municipalities would be very valuable for studying the perception of climate change and barriers to adaptation. Planners in the coastal zone must deal with ambiguity and uncertainty in how much and how rapidly sea levels will rise, and increasingly they must also take into account that sea levels will likely continue to rise for many centuries to come. However, this does not mean that they need to become paralysed until uncertainty has been reduced.

Recently a variety of decision-making strategies have been developed in order to manage ambiguous and uncertain scientific predictions, in particular related to climate change. This development can be summarised as a move away from the traditional "predict-then-act" paradigm, to what has been called "robust approaches" (Weaver *et al*. 2013).

The predict-then-act paradigm is characterised by a sequential order of first making scientifically based predictions, and then using the best available prediction to drive decision-making. In our study we found that municipalities perceived a lack of knowledge and an absence of clear guidance on what levels to plan for – the municipalities wanted SMHI to say what level they should plan for, but SMHI pointed to the planning responsibility of the municipalities. This is a nice illustration of how a presumed predict-then-act paradigm creates problems. Weaver *et al*. (2013) point out more problems associated with relying on predict-then-act approaches. First, it creates high demands on climate science and modelling to deliver precise results (e.g. quantitative characterisation of uncertainty). Second, it is biased towards well-characterised problems (e.g. by ignoring structural model uncertainties or surprises). Third, it causes problems of controversies among stakeholder (e.g. stakeholders may focus on results most consistent with their interests and worldviews).

In contrast, robust approaches are designed to deal with uncertain and diverse outcomes, and often start from the particular decision-making context. Furthermore, robust approaches are focused on seeking solutions that are acceptable across a range of possible scenarios in contrast to planning for a single projection (for recent reviews see Hallegatte 2009, Hallegatte *et al*. 2012).

Municipalities and other local planners could use robust approaches to better manage the consequences of present-day decisions relating to uncertainty in future SLR. Scenario planning (Van der Heijden 2005) is one type of robust approach that can be used by societies to plan and prepare for a wide range of possibilities (Bell 2003). Recent examples include Sheppard *et al*. (2011), who developed local scenarios as a participatory capacity-building process and as a decision support for climate change adaptation in British Columbia. Carlsen *et al*. (2012) developed a method to construct and use tailor-made local scenarios for adaptation to climate change in Sweden. NOAA Coastal Services Center (Marcy *et al*. 2012) describes a scenario approach for planning for sea-level change impacts. Tompkins *et al*. (2008) studied coastal planning at the local level in the UK and found that uncertainties could be dealt with by stakeholders, who did not need precise scientific information to make decisions but could work with an envelope of possibilities. The Thames Estuary 2100 project (Reeder 2011) developed a range of measures to cope with SLR of up to 4 m and calculated response thresholds in order to propose flexible solutions to uncertainties.

Furthermore, it is interesting to note that robust approaches, such as scenario planning, create new demands on information from expert assessments (Weaver *et al*. 2013). Notably, they create a need for *exploring the limits of system behaviour*, meaning more focus on the tail ends of the probability distribution and on bounding and extreme cases. Moreover, they mean a change in focus *from making predictions to generating scenarios,* which creates a need for “sampling the outcome space” more comprehensively and collaborating with end-users to determine what aspects of modelling are important.

This implies a change in informational requirements on expert assessments. For example, a wider range of possible scenarios is more useful than a central or “likely” estimate. A recent example is the SLR scenarios for the US National Climate Assessment, where four scenarios for SLR by 2100 are defined; the lowest scenario is 0.2 m and the highest is 2.0 m (Parris *et al*. 2012). However, robust approaches are not only a matter of defining wider scenario ranges, but they also mean a focus on more interactive assessments, where experts and end-users collaborate for a particular application. Graham *et al*. (2013) argue that more comprehensive accounts of social values are needed when planning for SLR. An advantage of participatory assessments is that they enable a wider range of aspects of vulnerability, including social adaptive capacity (Jonsson *et al*. 2012).

In conclusion, we found considerable gaps in current planning for SLR in Swedish municipalities. A large fraction of the studied municipalities did not consider SLR at all in planning documents, and a large majority did not consider SLR beyond 2100. Furthermore, we found that the municipalities perceived a lack of knowledge of SLR and wanted more guidance on what levels to plan for. We argued that the prevailing uncertainty and ambiguity in assessments of future SLR is more problematic within a traditional “predict-then-act” paradigm. Robust approaches, such as scenario planning, reduce many of these problems, and provide a way forward to improve local planning for future SLR.

Notes

1. Since 1 January 2011 Gotland Municipality (Gotlands kommun) is called Region Gotland.
2. “Översiktsplaner”.
3. County Administrative Boards, i.e. the county government agencies responsible for coordinating development in line with national policies.
4. The recorded interviews are stored by the main author.
5. The locks between Lake Mälaren and the Baltic Sea in Stockholm.

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Appendix. Interview questions

Initial questions

- What sea levels are mentioned for the year 2100 (possibly later) and what document/what reference is the original source?
- What planning document is considered the guiding document of each municipality/CAB/etc.?

Interview questions

- Do you relate to rising sea levels in your planning? For what purposes?
- In what time frame have you considered the risks of SLR?
- How (on what grounds) and why have you chosen the levels and time horizons you have chosen?
- How have you acquired knowledge about expected sea levels, how have you looked for them, with what method? (via the IPCC, SMHI, MSB, CAB, literature searches?)
- Do you believe that there is sufficient and good information available? Why/why not?
- Have you deliberately omitted certain estimates of future SLR (low/high, has the "medium" level been selected)? Why/why not?
- Could there be a risk that you do not have enough information and therefore that you have inadvertently omitted certain estimates of future SLR?
- Are there any risks linked to omitting the most extreme estimates of future SLR? What might the consequences be if the selected estimates are faulty?
- Are these risks discussed within the municipality/CAB, etc.?
- Do you lack any kind of information and would you need any additional support to be able to deal with future uncertainties in terms of SLR?
- Where do you think the responsibility for producing knowledge, ensuring that there are good estimates of future sea levels and communicating these to you should lie? Who should take this responsibility?
- Would you like to add anything?