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Developing a framework to quantify potential Sea level rise-driven environmental losses: A case study in Semarang coastal area, Indonesia

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ABSTRACT

Climate change triggers major alterations to coastal zones worldwide. Quantification of these adverse impacts to coastal ecosystems is often done on a coarse scale of global regions. Consistent local scale estimates of physical impacts on ecosystems and monetary assessment of associated losses are scarce, especially in developing countries. With aim of facilitating such assessment, which is increasingly required, here we propose a coherent three-step framework and subsequently apply it to quantify potential sea level rise-driven alterations in the monetary value of ecosystem services in the coastal area of Semarang in Indonesia. Within this framework, we (1) quantify the present value of coastal ecosystem services by using economic valuation techniques; (2) identify the potential impacts of relative sea level rise (RSLR)-induced inundation on ecosystem services (for the year 2100 inundation scenarios); and (3) monetize these impacts by developing a novel scenario-based approach. The results show that full inundation (scenario A with 4 m RSLR) poses a median loss of 90% (US$ 2.8 – 3.5) and 25% (US$ 90 – 113) to the present art and fishery values per hectare, while amenity service is expected to lose upto 50% (US$ 3700 – 5400) of its present value. Additionally, recreation value of the coastal ecosystems in three selected sites (Marina and Maron beaches, and Plumbon estuary) will decrease by 70% (US$ 15,460 – 19,820) per hectare. However, in scenario B (RSLR of 1.1 m) with a 50% inundated area, these losses are estimated approximately 40% less than for scenario A. It is expected that researchers and policy makers may apply this approach in their areas of interest to gain a better understanding of the likely costs of sea level rise-driven environmental damages along coasts, ultimately contributing to the sustainable management of coastal environment in Indonesia and possibly in other developing countries.

1. Introduction

Climate change (CC) threatens coastal areas globally. Intensifying coastal hazards escalate damages to social, economic and environmental systems. Apart from social and economic losses, the coastal environment will undergo major physical changes triggered by coastal hazards (e.g. coastal recession, inundation, formation and closure of small tidal inlets) and CC impacts (Wong et al., 2014). The socio-economic wellbeing of coastal communities and their resilience rely considerably on the services that coastal ecosystems provide. Importantly, quantitative fine-scale physical and monetary assessments of CC driven losses – including ecosystem losses – form the basis for estimating global climate change related damages in Integrated Assessment Models. These climate science models integrate a description of greenhouse gas emissions and their associated impacts on temperature, showing how changes in temperature will affect the economic value of welfare (Pindyck, 2013). In addition, Integrated Assessment Models are used to estimate the social cost of carbon by modelling the growing change in global economic output caused by 1 t of anthropogenic carbon dioxide emissions (Sterncalls, 2016).

Available CC impact assessment studies have mostly explored the first order CC impacts on coastal and marine areas such as changes in sea level, ocean conditions and biogeochemistry, without monetizing these impacts on the services provided by ecosystems (Daw et al., 2009; Cochrane et al., 2009; Mohanty et al., 2010; Sumaila et al., 2011; Cheung et al., 2011). A few studies have performed quantitative

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analysis of physical impacts of CC on coastal ecosystem services (CES). For example, Cheung et al. (2011) demonstrated that ocean acidification (i.e. 30% reduction in oxygen demand as the H + ion concentration in the ocean doubles) in the North Atlantic reduces the growth rate of fish, resulting in a decrease of 20%–30% in potential catch.

Kuhfuss et al. (2016) conducted a valuation of CC-driven changes in CES in France, showing that a 1 m sea level rise (SLR) scenario in 2100 helps to gain additional territory to the regional coastal wetlands due to retreat of agricultural and urban areas. In this study, the transformations of ecological habitats, depending on their distance from salt water, were examined by assuming proportionality between the surface area and CES. This scenario-based approach resulted in a projected increase of total CES value (i.e. ecotourism, biodiversity, flood drainage, etc.) between €10,790,000 and €16,188,000 (2010 prices) due to 1 m of SLR by 2100 (relative to 2010) depending on different adaptive strategies considered. In a large scale study, Roebeling et al. (2013) projected coastal erosion patterns in Europe under IPCC-SRES scenarios (B1 and A1Fi), by using the Dynamic and Interactive Vulnerability Assessment (DIVA) data base, in combination with a benefit transfer approach. According to this study, SLR-induced erosion with total territory losses between 3700 km^2 and 5800 km^2 in different land cover types (coastal wetlands, agricultural areas, forests and semi natural areas) resulted in annual damages (by 2050) of approximately € 2.9 billion to associated CES. The outcomes of these studies are very diverse and sometimes conflicting, adding to the uncertainty related to the potential costs of adverse climate change impacts.

Despite the few applications mentioned above, little is still known about quantitative CC driven impacts on diverse CES. While most of available valuation studies have estimated the present value of CES in local case studies, this strand of literature has not explicitly quantified the changes in the value of different CES due to CC impacts (Mehvar et al., 2018a). Such quantifications are especially problematic in developing countries due to: a) a general lack of data even to asses physical impacts and associated losses (Bosello et al., 2012; Farmer et al., 2015; Burke et al., 2016); b) field work can be difficult to arrange and/or is expensive; c) willingness to pay (WTP) or willingness to avoid environmental damages (WTA) are difficult to extract in lower-income countries, especially for assessments of losses for a far-way future, while current needs are already difficult to meet. Indeed, most of the current assessments are carried out in developed countries, making it difficult to transfer these valuations into the context of developing countries. Yet, it is in fact developing countries that are likely to suffer most, given that local population is often dependent on CES to survive and adaptive capacity is low.

To fulfil this knowledge gap, particularly in the developing country context, the present study aims to quantify potential changes in the value of CES for the year 2100 inundation scenarios in Semarang coastal area, located in Central Java Province in Indonesia. The novel scenario-based approach used in this study represents a new methodology compared to previous studies by presenting a link between potential impacts of relative sea level rise (RSLR)-induced inundation with CES associated attributes. In addition, this approach bridges the potential impacts of inundation on CES with economic concepts (consumer and producer surpluses), providing a straightforward method that can be generally applied in situations where ecological and economic model simulations may not be possible due to data scarcity or other limitations.

Our study area choice is driven by the fact that Semarang provides diverse CES and large nursery habitat for coastal flora and fauna, while the area is already suffering from coastal inundation and CC impacts (KPP Nasional, 2014). To achieve the overarching objective of this study, we seek to answer the following specific questions: (1) what is the present monetary value of CES in Semarang?; (2) to what extent can climate change impacts, represented here only by RSLR (summation of mean sea level rise and land subsidence rate)-induced inundation affect the services provided by coastal ecosystems of Semarang in the year 2100?; and (3) how can the identified impacts be monetized?

The article follows three consecutive steps. Firstly, using economic valuation methods, we estimate the present monetary value of CES which is currently provided by mangrove swamps, beach, dune and pelagic systems. Secondly, by considering a ‘‘what if scenario’’ approach, we identify the potential impacts of RSLR-induced inundation on the (pre-valued) ecosystem services for different year 2100 inundation scenarios. Thirdly, these changes in CES – which could be losses or gains – are monetized using the pre-estimated values in step 1.

The outcomes of this study are expected to aid international research efforts on mapping monetary valuations of CES and RSLR impacts on CES through the quantitative assessment of a number of ecosystem services it provides within a developing country context.

2. Methods

2.1. Study area

Semarang with population of about 1.57 million people and an area of 374 km^2 (BPS, 2014) is the capital of Central Java Province in Indonesia. The whole coastal area of Semarang constitutes of 4,575 Ha (DKP, 2008). Marina and Maron beaches comprising about 33 Ha in total, and Plumbon estuary with an approximate area of 23 Ha, were selected as the study sites located in the lowland of Tugu and Semarang Barat districts (Fig. 1). The coast of Semarang mainly comprises volcanic terrain (Datema, 1989), and the soil types are generally alluvial due to fluvial sedimentation (Rahmawati et al., 2013).

There are different types of CES in the study area. Mangrove swamps mostly cover the Tugu district where the Plumbon estuary is located, while beach and dune systems are the dominant ecosystems in Maron and Marina areas. In addition, Java Sea represents another ecosystem constituting a pelagic system.

2.2. Methodology

To estimate the value of potential changes to CES, here, we develop a framework consisting of three methodological steps (Fig. 2). Firstly, we focus primarily on assessing the value of ecological services provided by coastal ecosystems (hazard impact to urban developments and infrastructure is excluded). Here we apply the available economic valuation methods to estimate the present monetary value of CES derived from the original field work. Secondly, we identify the potential impacts of RSLR-induced inundation on CES in 2100. Therefore, we use a particular scenario-based approach grounded in expert knowledge and in secondary data from literature review. Finally, we quantify the resulting losses to CES for year 2100 inundation scenarios by combining the pre-estimated monetary values with anticipated changes in quantity and quality of CES.

2.2.1. Step 1: Valuation of CES (current status)

In the first step of this study, we apply three standard economic methods (i.e. contingent valuation, net factor income and hedonic price), to estimate the present value of CES in Semarang. Semarang coastal ecosystems offer a variety of direct and indirect services such as provision of fibre and raw materials, educational opportunities, storm protection and wave attenuation, shoreline stabilization and erosion control as well as climate regulation services. In this study we focus on the four services that provide direct use values; recreation or tourism and fishery - the dominant sources of income in Semarang, together with art and amenity value - the less analysed services in current valuation studies, while are nevertheless beneficial to human well-being. Valuation of other CES is beyond the scope of this study either due to the limited time and/or resources for data collection (e.g. wood production provided by mangroves) and/or because of extensive modelling and experimental requirements (e.g. wave attenuation service). However, excluding these services in this study does not necessarily

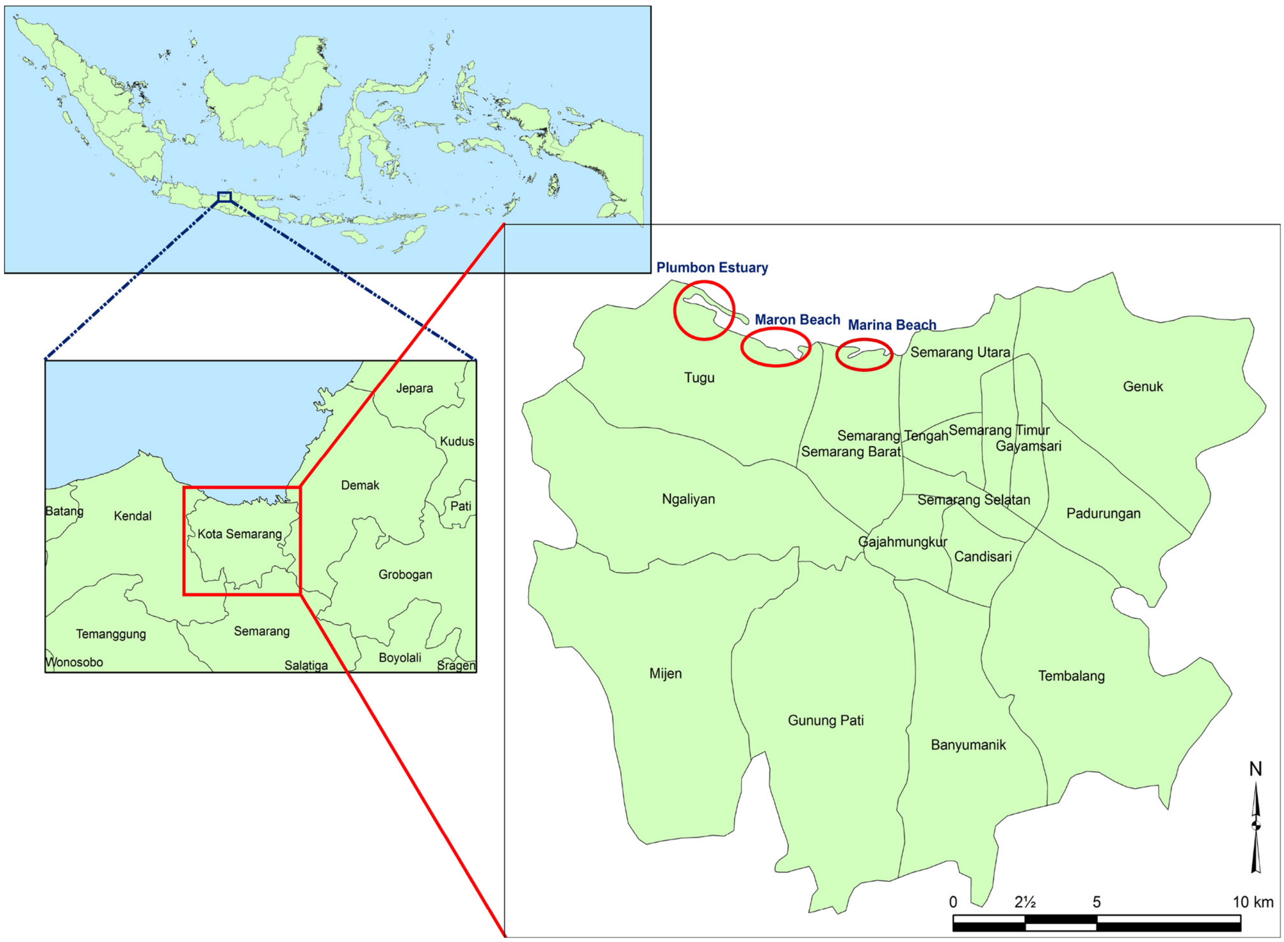

Fig. 1. Location of Semarang showing the study sites highlighted by red circles (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

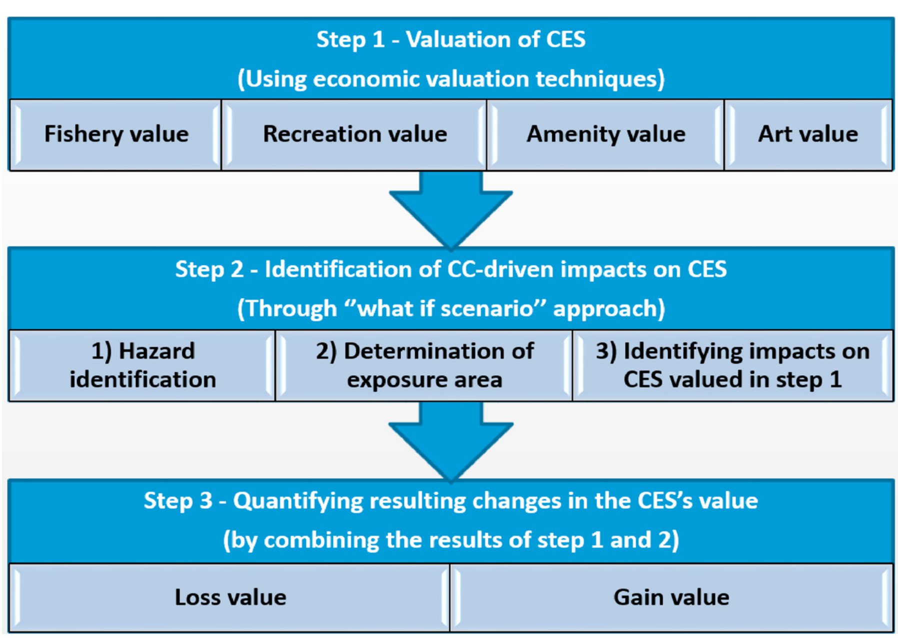

Fig. 2. Framework comprising three methodological steps adopted in this study.

mean that they do not provide any significant CES in the Semarang area.

In this study, monetary values of the four considered CES are estimated by using different valuation methods: net factor income and contingent valuation (for the recreation, and fishery values), net factor income (for the art value), and hedonic price method (for the amenity value).

Net factor income is one of the valuation techniques by which the net revenue earned by an ecosystem service is taken to represent its value. For example, the revenue earned through recreational activities of tourists, which directly or indirectly depend on the status of coastal ecosystems, is taken to represent the total tourism value of coastal ecosystems. Similarly, the net revenue earned from selling fish and other marine species in the market is taken to represent the total value of the fisheries service. Using this method, art value of coastal ecosystems is also estimated by considering the annual earnings from selling art works that either directly or indirectly captured the scenery associated with coastal ecosystems.

The Contingent valuation technique is the most applied method for both use and non-use values and is based on interviewing different stakeholders and recording their willingness to pay (WTP) to obtain an ecosystem service or to not lose it (Mehvar et al., 2018a). Here we used this method in valuation of tourism and fishery services by eliciting visitors and local community's WTP, respectively for benefiting from tourism-related attributes and for each kilo of fish or other marine species in the market.

The Hedonic price technique is used to capture the hedonic value of coastal nature represented by property prices. Conducting surveys among several local real estate agents, here information on property prices in Semarang is obtained and analyzed as a function of distance to the sea to estimate the amenity value of coastal ecosystems. Valuation of these CES and the estimates for each service are presented in detail in Appendix A in Supplementary material.

2.2.2. Step 2: Identifying potential impacts of RSLR-induced inundation on CES

In the second step of this study, we identify the hazard, its causes and affected area along the coast of Semarang. After identifying the hazard, we subsequently estimate how the associated impacts of identified hazard can potentially affect the target CES. Semarang has long been suffering from coastal inundation and CC impacts (KPP Nasional, 2014) mainly due to land subsidence and high tidal levels. Land subsidence in Semarang is primarily due to groundwater extraction (Marfai et al., 2008; Rahmawati, 2010; Kuehn et al., 2010; Soedarsono, 2011). While existing structural measures are not sufficiently developed to effectively protect affected areas (Marfai and King, 2008), CC impacts have been intensifying inundation in Semarang through rising sea level, changes in rainfall and increase of extreme weather (KPP Nasional, 2014).

In this study, we only consider RSLR (summation of SLR and land subsidence) as a key CC impact and subsequently focus on the coastal inundation resulting from RSLR in Semarang coastal area. As a result, two inundation scenarios are considered; Scenario A in which the whole study area is considered to be permanently inundated due to a projected 4 m RSLR by the year 2100 (relative to the present). This projection is computed by considering the rate of SLR (7.8 mm per year) and average land subsidence (4 cm per year) in Western Semarang reported by ISET (2010) and Abidin et al. (2013), respectively. In Scenario B, 50% of the area is considered to be permanently inundated due to a hypothetical, but not unlikely, 1.1 m of RSLR by 2100, which could result due to, for example, combination of a lower end SLR projection with a lower land subsidence rate over time. By using the Digital Elevation Map (DEM) of Semarang with a spatial resolution of 30 m (U.S. Geological Survey, 2017), the topography of the study area is considered and the resulting inundated areas corresponding to scenarios A and B are determined by using ArcGIS software and using a bath tub approach (for more details, see Appendix B in Supplementary material). The subsequent identification of resulting potential impacts on CES is described below.

2.2.2.1. Potential impacts of RSLR induced inundation on CES. To identify the potential impacts of inundation on CES, we first define ecosystem-related attributes and analyse how RSLR-induced inundation can potentially affect each of these attributes. For this purpose, depending on the scenario and attributes, the impacts are quantified by assigning a percentage range of change for each attribute, resulting in changes in CES value for scenarios A and B. These quantitative ranges are indicated by positive or negative impact indications (+ or – sign) representing a 20% increase or decrease for each positive or negative sign, respectively. This implies four ranges of 20%–40%, 41%–60%, 61%–80% and 81%–100% corresponding to the assigned impact indications from one (+/–) to four signs (+ + + +/– – – –), respectively.

Assignation of these impact indications is based on consultation with local experts and a ''what if scenario'' approach depending on the individual CES, its attributes and the 2100 inundation scenario considered. This implies that for two of the services (fishery and art), the local fishermen and experts who deal with art works are interviewed to elicit their points of view regarding the likely future changes of these two services. For the two other services (tourism and amenity) we use a ''what if scenario'' approach in which we assume that the full inundated area will result in potential losses of tourism and amenity value in the ranges of 81–100% and 41–60% for scenario A, and 41–60% and 20–40% for scenario B with 50% inundated area. Due to unavailability of literature nor similar application in Indonesia, in this study we have not considered the temporal rate of degradation, and landward migration (providing lateral accommodation space) for the considered ecosystems. It should be noted that in this study, similar to other applications (i.e. Payo et al., 2016), we have assumed that the MSL (as zero elevation reference) is the lowest elevation upto which coastal ecosystems such as mangrove swamps of Plumbon estuary can develop and provide services. Therefore, no future expansion and recovery is considered for the submerged ecosystems below MSL. This assumption is necessary as it is at present impossible to predict the resilience of the coastal ecosystems in Semarang to RLSR and their resulting potential future ecological behavior due to data/knowledge scarcity.

Potential impacts of RSLR-induced inundation on CES in Semarang is described below in detail for each ecosystem service considered.

2.2.2.2. Impacts on recreation/tourism service. Changes in the value of recreation or tourism service are estimated by assessing the potential impacts of RSLR-induced inundation on consumer and producer surplus values[1]. The impacts on consumer surplus of visitors are determined through the direct answers that interviewees provided for the damage-related questions in the custom-designed questionnaire developed for this study. Here, respondents to the interviews are asked to state their WTP to avoid losing 100% and 50% of the recreational attributes related to coastal ecosystems of Semarang. Selection of these attributes is based on the visitors' preferences derived from the interviews, showing that tranquillity, shore water quality and diversity of birds and coastal species are the most important recreational factors that draw tourists to the Semarang coast. Thus, our questionnaire elicits variations in WTP due to potential future changes in such attributes, resulting in different values of consumer surplus for the two considered inundation scenarios.

To identify impacts on the producer surplus of the local providers of recreational services for tourists (accommodation, boats, food), visitors

[1] Total tourism value is calculated by summing the consumer surplus (CS) referring to the willingness to pay (WTP) to obtain a recreational benefit stated by the visitors and the producer surplus (PS) representing the net revenue generated by the visitors (see more details in Appendix A in Supplementary material).

are asked to indicate an approximate contribution level of their expenditures for the pre-stated recreational attributes which draw them to the study area. Then by using scenarios of likely inundation impacts, loss percentages of 81–100% and 41–60% are respectively assigned to the three considered attributes, when the entire area (scenario A) and 50% of it (scenario B) is considered to be inundated. The hypothetical assignation of the impact indication here, is due to the unavailability of data or a sound approach/application for quantifying inundation driven losses of such attributes. Therefore, our assessment as done here could be considered as being scenario based.

2.2.2.3. Impacts on fishery service. To quantify how fishery could be affected by inundation, we rely on secondary data from the literature. This literature provide the basis to identify different fishery-related variables, which can be potentially affected by CC impacts and RSLR-induced inundation. These variables comprise changes in primary and secondary fish production, distribution or migration pattern, food web, fish abundance, size of nursery area, health conditions of species and changes in fish pond structures and fishery facilities.

Selection and analysis of theses variables are based on fishermen's opinions and using the available literature in which CC impacts (i.e. ocean acidification, increase in water temperature, extreme flood events, etc.) have been analyzed on fishery industry. For example, Pörtner and Knust (2007); Sumaila et al. (2011) and Mohanty et al. (2010) showed that climate change may potentially affect distribution pattern, species abundance and pose damages to fish habitats. These studies conducted an economic assessment of CC impacts on fishery, suggesting that (for example) damages to fish habitat due to flooding are likely to decrease catch potential, resulting in an increase of both fish market price, and fishing/adaptation costs. In addition, Williams and Rota (2011) and MAB (2009) reported that flooding of low lying areas due to SLR may create ideal conditions for fish farmers due to expansion of salt water areas (if the negative impacts such as flooding related damages to aquaculture ponds were to be excluded).

CC impacts on fish communities can also be grouped into changes in phenology (Cochrane et al., 2009), which is excluded from our analysis due to the consideration of inundation impacts on coastal ecosystems over a long time span, thus no cyclic phenomena (seasonal change) are considered in our analysis. Reviewing the study conducted by Cochrane et al. (2009), we also assess potential RSLR-induced inundation impacts on other fish/fishery related variables such as fish productivity, abundance and food web, for which changes in vertical mixing and nutrient supply may be relevant.

Notably, the literature used here, mostly present analysis of CC impacts on fishery, and do not specifically assess the likely impacts of SLR-induced inundation on fishery. For this reason, we used this secondary data and adapted it to the Semarang case study by developing our analysis on inundation-related fishery variables. This consideration led us to add other inundation-related variables such as ''health status'' and the physical structure of ''fish ponds''. However, changes in some variables due to inundation (such as distribution pattern of species) was found to be difficult to analyse, because of interaction among different factors such as temperature, salinity and wind driven circulation.

Ultimately, the potential impacts shown in Table 2 were determined by combining the knowledge gleaned from the aforementioned literature with fishermen's opinions elicited from the interviews with a group of 20 local fishermen. For example, interviews with fishermen highlighted damages to fish ponds as a serious effect of inundation on fishery compared to other variables such as reduction of health condition of species due to higher probability of having diseases caused by inundation. Thus, assignation of the potential impacts and the role of these variables in consumer and producer surplus values are qualitatively assessed employing both secondary data and experts opinions aforementioned.

Subsequently, the quantitative impacts of future inundation on these attributes and the value of fishery service are assessed, which will ultimately change the fishery value provided by the Java Sea in Semarang.

2.2.2.4. Impacts on amenity service. Amenity value of coastal ecosystems in developing countries has been poorly studied and thus little is known about this service. Using the aforementioned impact indications, the impact of inundation on the visual amenity of the beaches and ocean view is determined by assigning a range of negative impacts on the current amenity value. This impact identification is dependent on the average property prices as well as the considered inundation scenarios. This assignation is scenario based, since amenity value is subjective and there is no accepted principle for a definitive quantitative assessment of this impact.

2.2.2.5. Impacts on art service. To quantify changes in the art value of CES due to inundation, first the art-related attributes affecting the art value of coastal ecosystems are determined. These attributes include marine and coastal landscape, and coastal flora and fauna. Further, we present a range of scenarios of negative impacts[2] of inundation (with the ranges defined before) to experts who deal with art work (paintings, photos, books, etc.). Through this scenario-based approach – e.g. considering whether the whole area (scenario A) or 50% of it (scenario B) is inundated – we elicit expert opinion on likely quantitative changes in art-related attributes of CES and further we assign the impact indications for each attribute.

2.2.3. Step 3: Quantifying monetary value of the identified changes to CES

After the potential impacts are identified, the corresponding loss or gain value of ecosystem services is estimated by incorporating the pre-estimated monetary value of ecosystem services and the identified impacts.

3. Results

The results of this study are presented below as distinct parts: (1) monetary value of CES in their present state; and (2) changes in these values due to losses or gains in CES resulting from RSLR-induced inundation by the year 2100.

3.1. Present-day value of CES in Semarang

Table 1 summarizes the results of valuation of different CES in Semarang. The total value per hectare is presented in Indonesian Rupiah (IDR) as well as US Dollars. Notably, the estimated value per hectare is based on the area size for which the services have been considered. Thus, except the recreation value which is estimated specifically for the two selected beaches and estuary, and amenity value which is computed for the coastal area upto a 5 km landward distance from the shoreline, all other values are estimated per hectare of the whole coastal area of Semarang. This consideration is due to the fact that the fishery value is mostly provided by the pelagic system (Java Sea) and no clear boundary can be defined for the marine area associated with pelagic system. Similarly, art works (books, photos, etc.) including picturesque scenery of coastal ecosystems in Semarang cannot be explicitly distinguished in terms of representing a specific coastal area. Therefore, the value of art and fishery services is consistently considered for the entire coastal area of the Semarang. With respect to the

[2] This hypothetical assumption (i.e. the current landscape is aesthetically more attractive than the future inundated landscape) had to be inevitably used here due to two reasons; (1) the data for such potential losses are currently unavailable; (2) landscape evolution of coastal environment due to RSLR-induced inundation can occur in a multitude of ways, and several stages may be recognizable in formation of a new environmental landscape, as reported by Razjigaeva et al. (2018).

Table 1
Summary of the present value estimated for the CES of Semarang.

Ecosystem service	Economic valuation method	Area considered (Ha)	Estimated value (mln. IDR)	Estimated value (mln. IDR)/Ha	Estimated value* (US$)/Ha
Art	Net factor income	4575	213	0.046	3.5
Fishery	Contingent valuation & net factor income	4575	23,331	5.1	380
Recreation/ tourism (beaches)	Contingent valuation & net factor income	33	19,000	575	43,000
Recreation/ tourism (estuary)	Contingent valuation & net factor income	23	400	17	1,300
Amenity **	Hedonic price	–	122	–	–

* Exchange rate of US$/IDR = 0.000075.
** Total value is estimated for CES upto 5 km landward distance from the shoreline.

Table 2
Different fish/fishery-related variables potentially affected by RSLR-induced inundation in the two inundation scenarios A and B. NK: Not known, NE: No effect. Source: Literature Based; Expert opinion.

Fish / fishery related variable	Potential impact of RSLR-induced inundation*		Remark
	Scen. A	Scen. B	
Primary & secondary production	+ +	+	Vertical mixing is increased leading to more nutrient supply. Larger nursery area is provided for breeding and oviposition.
Distribution/ migration pattern	NK	NK	Unknown due to interaction of diverse variables such as water temperature, salinity, vertical mixing rates and wind driven circulation.
Abundance	+ +	+	Larger water body and nursery area are provided causing more nutrient supply.
Phenology	NE	NE	No phenological and seasonal change due to projected RSLR-induced inundation.
Health status	- -	- -	Increased turbidity, higher probability of having diseases for species.
Food web	+ +	+	Increased zooplanktons and nutrients supply.
Nursery habitat	+ +	+	Providing larger (natural) water bodies.
Fish ponds	- - - -	- -	Highly important variable for Semarang's fishery Industry. Probability of considerable damage to the fish ponds when inundation occurs.

* Each (+) and (-) represents a quantitative impact as defined in section 2.2.2.

period in which the valuation is done, all the values are estimated in the period of 2014–2015 with a resulting annual value given in 2015 prices.

3.2. Changes in the value of CES due to climate-driven RSLR-induced inundation

3.2.1. Change in the fishery value

Table 2 shows the potential impacts of RSLR-induced inundation on fish and fishery in Semarang for scenarios A and B. The magnitude of likely impacts was assigned for each selected fish/fishery related variable (derived from the literature mentioned in Section 2.2.2) by interviewing a group of 20 local fishermen and eliciting their opinions regarding the likely impacts of RSLR-induced inundation on each variable (as an average magnitude, rounded off to our impact indication ranges). Interviews with fishermen highlighted damages to the fish ponds as the most serious threat to fishery with a likely impact stated in the range of 81–100%, and 41–60% for the two inundation scenarios A and B, respectively. In addition, for the ‘’health status’’, the negative impact was estimated in likely ranges of 41–60% and 20–40% for Scenarios A and B respectively, since the interviews showed that inundation may result in higher probability of having disease for species with low tolerance to the turbidity caused by inundation. This may cause some species to disappear altogether, leading to a reduction of total catch volume.

For other variables such as primary and secondary production, abundance, food web, and nursery habitat, the interviewees stated an approximate positive impacts of 41–60% and 20–40% for scenarios A and B respectively. The main reasons of having such positive impacts (Table 2, “Remarks” column) are the likely increase in provision of nutrient supply and the formation of larger water bodies and nursery areas due to RSLR-induced inundation.

In order to estimate the quantitative change in fishery value, we relate the impacts of inundation to its monetary value by analysing the role of each assumed impact on the consumer and producer surpluses. Thus, we analyse how changes in each variable (identified in Table 2), may potentially alter the catch volume, market price as well as fishing and adaptation costs. By identifying these changes and considering the producer surplus (net revenue) and consumer surplus (difference between market price and WTP), the changes in the value of fishery service is estimated. Importantly, we assume that WTP is constant and does not change over time. This assumption is a necessity, since there is no data about how inundation may affect people’s WTP. For example, increase of the primary and secondary fish production results in more catch volume and lower market price that would lead to an increase in consumer surplus. However, producer surplus is expected to remain constant, because of the reverse effect of gross revenue and costs which will neutralize each other. Thus the net revenue is likely to not be affected (see Table 3).

Table 3 shows the final results indicating how fishery value in Semarang is potentially affected by the positive and negative impacts of RSLR-induced inundation in 2100. In consultations with local fishermen, a constant contribution level of 10% is assigned for most of the fishery related attributes, while nursery habitat and fish ponds are weighted higher (25%) than other attributes, and therefore contribute more to the affected value.[3] Change in the fishery value is finally calculated for each variable by applying ‘potential impact indications’ derived from Table 2, multiplied with ‘contribution to the affected value (%)’ and changes of the’ affected value’ (whether it is consumer or

[3] This contribution level for fish ponds can be less than that considered here for other applications where the fishery industry is not as aquiculture-dependent as it is in Semarang.

Table 3
Changes in the fishery value of CES of Semarang for the two 2100 RSLR-induced inundation scenarios. CS: consumer surplus, PS: producer surplus, F: Fishing, A: Adaptation, NK: Not known, NE: No effect.
Source: Literature Based.

Fish / fishery related variables	Catch volume	Market price	Cost		Affected value		Contribution to the affected value	Change in fishery value (mln. IDR)	
			F	A	CS	PS		Scen. A	Scen. B
Primary & secondary production	↑	↓	↓	↑	↑	NE	10%	+ (34 – 50)	+ (17 – 33)
Distribution/ migration	NK	NK	NK	NK	NK	NK	10%	NK	NK
Abundance	↑	↓	↓	↑	↑	NE	10%	+ (34 – 50)	+ (17 – 33)
Phenology	NE	NE	NE	NE	NE	NE	NE	NE	NE
Health status	↓	↑	↑	↑	↓	↓	10%	- (956 – 1398)	- (466 – 933)
Food web	↑	↓	↓	↑	↑	NE	10%	+ (34 – 50)	+ (17 – 33)
Nursery habitat	↑	↓	↓	↑	↑	NE	25%	+ (86 – 126)	+ (42 – 84)
Fish ponds	↓	↑	↑	↑	↓	↓	25%	- (4724 – 5832)	- (2391 – 3500)
Total gain								**188 – 276**	**93 – 183**
Total loss								**5680 – 7230**	**2857 – 4433**
Net change								**- (5492 – 6954)**	**- (2764 – 4250)**

Table 4
Different tourism/recreational attributes potentially affected by RSLR-induced inundation, for different potential impacts for inundation scenarios A and B in Semarang.
Source: Survey Based (SB).

Tourism/ recreational attributes	Potential impact of RSLR-induced inundation		Remark
	Scen. A	Scen. B	
Tranquillity (in terms of storminess)	- - - -	- -	Visiting the beach or estuary is less pleasant if tranquillity is affected by inundation. Less impact is expected when the area is less inundated.
Shore water quality	- - - -	- -	Turbidity caused by inundation affects the shore water quality. Less impact is expected when the area is less inundated.
Diversity of birds and coastal species	- - - -	- -	Considerable impact on the diversity of species expected while inundation occurs. Less destructive impact is expected when the area is less inundated.

*Each (+) and (-) represents a quantitative impact as defined in Section 2.2.2.

producer surplus, or both). The results show a losses of 5492–6954 million IDR (US$ 412,000–520,000) and 2764–4250 million IDR (US$ 207,000–318,000) for scenarios A and B, respectively.

3.2.2. Change in the recreation/tourism value

Table 4 shows analysis of the potential inundation impacts on recreation value for the two inundation scenarios. Here, depending on the scenario, different impact percentages (similar to the fishery value analysis) are assigned to the tourism-related attributes. These impact indications are related to the attributes, for which the visitors in the interviews stated their WTP for enjoying 100% and 50% of such recreational attributes.

Similar to the previous section, to quantify the changes in tourism value, we relate the assumed impacts of inundation to the consumer and producer surpluses and then analyse its influence on these values. For the analysis of consumer surplus (WTP), the results of interviews are directly used. We found that when a larger area is inundated, consumer surplus increases correspondingly since the respondents stated higher WTP to avoid having higher percentage of loss for the recreational attributes considered in our survey (see Table 5). The total stated WTP is divided by the number of respondents (giving the average WTP per visitor) and multiplied by the annual number of visitors[4] to obtain the total annual value of this attribute corresponding to scenarios A and B, respectively.

However, producer surplus is expected to decrease, since the hypothesis is that when the whole beach area is inundated, tourism will severely be affected due to the fact that there would not be any opportunity for visitors to visit the beaches and enjoy the tranquillity, water sports, and watching birds or other coastal species. This would result in much fewer number of visitors and lower revenue. However, the inundated area might still provide recreational value even after inundation occurred, which is not known for certain. Therefore, as shown in Table 2, we considered a conservative scenario of upto 81–100% loss in the tourism value for the worst case scenario of full inundation (scenario A), and a relatively lower loss (41–80%) when half of the area is inundated (scenario B). Presenting losses in a range of 20% is due to uncertainty of potential losses, justifying our hypothesis used in this study.

[4] According to 'Badan Pusat Statistik (BPS) Kota Semarang, 2014' 252,840 and 13,200 visitors were recorded in 2014 for the selected beaches and estuary, respectively.

Table 5
Changes in the recreation value of CES of Semarang for the two year 2100 RSLR-induced inundation scenarios A and B.

Tourism / recreational attributes	Affected value		Average WTP* stated for the loss percentage (mln. IDR)		Contribution to the PS	Change in annual tourism / recreation value (mln. IDR)	
	CS	PS	100%	50%		Scen. A	Scen. B
Tranquility (in terms of storminess)	↑	↓	660	317	60%	- (7642 – 9590)	- (3885 – 5832)
Shore water quality	↑	↓	557	289	20 %	- (2210 – 2860)	- (1111 – 1761)
Diversity of flora and fauna	↑	↓	1070	603	20 %	- (1697 – 2346)	- (797 – 1446)
Total gain						**0**	
Total loss						**11,550 – 14,800**	**5,790 – 9,040**

*Calculated for the total number of visitors in 2014.

To establish the link between producer surplus and recreational attributes that are likely to be affected by inundation, we rely on the stated importance of each attribute as reported by the respondents in the survey. This importance is represented by ranking the most enjoyed recreational aspects while visiting the beaches and estuary. According to the interviews, tranquillity of the beaches and estuary is the most important attribute (stated to be 60% in our survey, thus contributing to 60% of the total producer surplus) followed by the shore water quality (20%) and the diversity of flora and fauna (20%). Changes in the producer surplus is calculated by multiplying 'potential impact indications' (derived from Table 4) with 'contribution of changes to the PS (%)' and 'producer surplus' estimated before.

Total change in the tourism value is estimated by summing the changes in 'consumer surplus' and 'producer surplus' (Table 5). While summing the values, it should be noted that for all the recreational attributes, inundation increases the consumer surplus (as higher WTP is indicated in the interviews), whereas the producer surplus is expected to decrease. The final results indicated a total annual losses of 11,550 – 14,800 million IDR (US$ 866,000–1,110,000) and 5790 – 9040 million IDR (US$ 434,000–678,000) for inundation scenarios A and B, respectively.

3.2.3. Change in the art and amenity values

As described in section 2.2.2, potential impacts of RSLR induced inundation on art related attributes are quantified by eliciting expert opinions on likely changes to art related attributes of CES due to predeveloped inundation scenarios of A and B. Therefore, in the survey conducted in 20 art-related shops, (photo, book, and painting shops) more than 30 people (who deal with art works) were interviewed and asked to indicate their opinions for likely inundation-induced changes to coastal and marine landscape, and to the coastal flora and fauna of Semarang. Moreover, a range of potential changes in five different classes of 1 (0–20%), 2 (21–40%), 3 (41–60%), 4 (61–80%), and 5 (81–100%) was presented to the respondents, and depending on whether the entire coastal area or 50% of it is inundated, an approximated impact was identified by the interviewees for each inundation scenario. According to the results, the respondents stated that average losses in art value of CES in Semarang are likely to be similar for the two related attributes (landscape, flora and fauna) in classes of 5 (81–100%), and 3 (41–60%) for inundation scenarios A and B, respectively.

Table 6-a shows the total loss value calculated by multiplying the loss percentage derived from the survey with the estimated current value, and summing up the resulting loss value of two attributes. The results indicate that RSLR-induced inundation will lead to an annual potential losses of the art value of CES equivalent to 172–213 million IDR (US$ 13,000–16,000) and 87–128 million IDR (US$ 6500 – 9600) for scenarios A and B, respectively.

With respect to the change in amenity value, Semarang coastal area is expected to lose its visual amenity depending on the extent of the inundated area. While the property price in Semarang correlates with the coastal amenities level, proximity to the coast also increases the risk of inundation, leading to high uncertainty when determining losses or gains in amenity value. Similar to the tourism service, a ''what if scenario'' approach is considered here, assuming that although the area will be fully inundated, the new landscape and the Sea view may still provide a picturesque scenery affecting the price of properties along the coast. Thus a conservative loss value in the range of 41–60% is assigned for scenario A with full inundation, while a lower range of 20–40% loss is assigned for scenario B when half of the area is inundated. Compared to the obviously large impact of inundation on tourism value, here we assumed a lower impact range for the amenity value with the hypothesis that amenity provided by the Sea view is likely to be less affected by inundation.

The important point considered here is that the impacts on the amenity value were only considered for the closest distance range of 0–5 km from the coast, where the value (most likely) will decrease due to the reduction of property price affected by inundation. The reason for excluding the impact quantification for greater distances from the coast is mainly due to the uncertainties associated with future SLR and consequently with inundation/erosion impacts on property prices that may or may not result in a reduction of property value at some location. This is however impossible to ascertain without a detailed numerical modelling study that is able to provide robust estimates of the likelihood of coastal inundation and recession in future, inclusive of uncertain quantifications (see for e.g. Ranasinghe et al., 2012; Jongejan et al., 2016).

The results show a total losses of 50–73 million IDR (US$ 3700 – 5400) and 24–49 million IDR (US$ 1800 – 3600) of the amenity value for scenarios A and B, respectively. This low estimation is due to the relatively low property price in the coastal area of Semarang.

3.2.4. Overview of the changes in the value of CES in Semarang

Table 7 summarizes the estimated changes in the value of CES in Semarang coastal area for the two year 2100 RSLR-induced inundation scenarios A and B. It should be noted however that a number of factors such as development of coastal protection structures, changes in WTP on both consumer and producer surpluses, changes in elasticity, and even in social norms will be likely occurred by 2100, affecting the

Table 6
Changes in the art (a) and amenity value (b) of CES of Semarang for the two year 2100 RSLR-induced inundation scenarios A and B.

a)

Art related attributes	Estimated value (mln. IDR)	Potential impact of RSLR-induced Inundation		Change in art value (mln. IDR)		Remark
		Scen. A	Scen. B	Scen. A	Scen. B	
landscape	115	- - - -	–	- (93 – 115)	- (47 – 69)	Destructive impact is expected to increases when the coastal area is inundated.
Flora & fauna	98	- - - -	–	- (79 – 98)	- (40 – 59)	
Total gain				**0**		
Total loss				**172 – 213**	**87 – 128**	

b)

Amenity	Estimated value* (mln. IDR)	Potential impact of RSLR-induced Inundation		Change in amenity value (mln. IDR)		Remark
		Scen. A	Scen. B	Scen. A	Scen. B	
Based on property price	122	- -	- -	- (50 – 73)	- (24 – 49)	Aesthetic pleasure is expected to decrease in coastal area, depending on the extent of the inundated area.
Total gain				**0**		
Total loss				**50 –73**	**24 –49**	

* Considered for upto 5 km landward distance from the shoreline.

Table 7
Changes in the value of CES of Semarang coastal area for the two year 2100 RSLR-induced inundation scenarios A and B.

Ecosystem service	Estimated change in the value of CES (mln. IDR)		Estimated change in the value of CES (US$)/Ha *		Median change relative to present value	
	Scen. A	Scen. B	Scen. A	Scen. B	Scen. A	Scen. B
Art	- (172 – 213)	- (87 – 128)	- (2.8 – 3.5)	- (1.4 – 2.1)	−90%	−50%
Fishery	- (5492 – 6954)	- (2764 – 4250)	- (90 – 113)	- (45 – 70)	−25%	−15%
Recreation**	- (11,550 – 14,800)	- (5790 – 9040)	- (15,460 – 19,820)	- (7750 – 12,100)	−70%	−40%
Amenity***	- (50 – 73)	- (24 – 49)	- (3700 – 5400)	- (1800 – 3600)	−50%	−30%

* Exchange rate of US$/IDR = 0.000075.
** The total value estimated for the selected beaches and estuary.
*** The total value estimated for upto 5 km landward distance from the shoreline.

values estimated here. Consequently, the results presented here should be considered as being indicative of potential losses of CES due to RSLR-induced inundation assuming a constant WTP.

4. Conclusion

This study presented a coherent three-step framework to quantify the environmental losses due to the potential impacts of climate-driven changes, here represented by RSLR-induced inundation by the year 2100, in the Semarang coastal area in Indonesia. Changes in the monetary value of CES (recreation, art, amenity and fishery) provided by mangrove swamps, beach, dune and pelagic systems were estimated using standard economic valuation techniques and a ''what if scenario'' approach. This presents an opportunity to better understand and to improve quantitative assessment of the sea level rise-driven impacts on coastal ecosystem services, evidence for which is scarce in the current literature, especially in developing countries.

The results of our extensive field work show that complete inundation of the beach area due to 4 m RSLR in 2100 (scenario A) will considerably decrease the recreational service of coastal ecosystems by upto 70% of the current value, equating to US$ 15,460–19,820 per hectare of the selected sites in Semarang (Marina and Maron beaches and Plumbon estuary). For this inundation scenario, considerable losses are also shown in the value of art and fishery services (per hectare) with estimated decreases of 90% (US$ 2.8–3.5) and 25% (US$ 90–113), respectively, by 2100 relative to the present. The amenity service is expected to lose 50% (US$ 3,700–5,400) of its current value. For scenario B, where 50% of the coastal area is considered to be inundated (due to 1.1 m RSLR in 2100), these changes are relatively lower with estimated losses of 40%, 50%, 15%, and 30% for recreation, art, fishery, and amenity values, respectively (about 40% of the corresponding losses estimated for Scenario A).

It should be noted that the results of this study provide an approximation of the losses of CES as a value range, and not as single deterministic values of such ecological degradations. Thus, the approach used here should be conservatively considered given the uncertainties of the climate change impacts and likely ecological responses. The framework presented in this study can be used for a wide range of applications providing an approximate estimation of RSLR-driven impacts on CES value, especially in data-scarce environments such as developing countries for which it is not feasible to apply standard ecological and economic simulation methods. Outcomes of this study can also be useful for assessments of environmental risk which is an important topical area for researchers and policy makers.

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Appendix A

Valuation of CES (current status)

The economic value of ecosystem services is the value of services provided by nature that contribute to human well-being. Contemporary valuation techniques are based on eliciting the value that a person is willing to pay (WTP) in order to obtain the benefit of services or goods provided by ecosystems, or is willing to accept (WTA) to stop receiving it (Costanza et al., 1997; Barbier et al., 2011; Bateman et al., 2011; Russi et al., 2013; Barbier, 2013; Mehvar et al., 2018a). Table A1 summarizes the coastal ecosystems and ecosystem services considered and the methods used for valuing these services in this study.

Table A1
Coastal ecosystems and services considered and the methods used for economic valuation in this study.

Coastal ecosystem	Ecosystem service (direct use value)	Economic valuation method
- Mangrove swamps - beach and dune systems - pelagic systems	Recreation/tourism Fishery Art Amenity	Contingent valuation, net factor income Net factor income Hedonic price

To quantify the monetary value of selected coastal ecosystem services (CES), primary and secondary data is used. The secondary data, including ecological and hazard-related data, were collected via a literature review (Durand and Petit, 1995; Marfai, 2011; Rahmawati et al., 2013). The primary data were obtained to estimate the present value of CES of the Semarang study area through field observations, participatory discussions, surveys and interviews with a range of stakeholders. This field data were collected in July-August 2015 by interviewing tourists, artists, fishermen, and people who work in the real estate sector. Depending on the type of ecosystem services and target stakeholders, different questionnaires (eliciting environmental and socio-economic data) were designed. All interactions with local population were performed through a native language interviewer. Subsequently different valuation methods that are most suitable to assess the value of a particular CES were used (Table A1). In what follows we provide details of each data collection phase for each CES.

Recreation/tourism value

Contingent valuation and net factor income methods were used to estimate the value of recreation and tourism services provided by coastal ecosystems. Tourism value is estimated as a sum of consumer and producer surpluses based on the similar approach used by Van de Kerkhof et al. (2014b). Consumer surplus is estimated using the contingent valuation method. Following a scoping exercise, we designed a questionnaire to elicit the recreation value of beaches and dunes. In total 210 visitors on selected beaches and estuary were interviewed. Through this survey we determined recreational attributes such as beach tranquillity (in terms of storminess), shore water quality and diversity of birds and coastal species. The questions aimed to elicit visitors' WTP assuming they fully benefit from the present conditions of these attributes with no environmental loss considered. The total WTP (consumer surplus) is finally estimated by averaging the WTP stated by the respondents multiplied by the number of total visitors in 2014.

Producer surplus is estimated by using net factor income method. It considers the net income earned by the recreational activities dependent on coastal ecosystems. The resulting income include total direct and indirect average expenditures spent by the visitors in the selected sites. Direct expenditures are the values that are spent in recreational areas where coastal ecosystems provide direct benefits to visitors. These values are directly dependent on the quality and health conditions of coastal and marine ecosystems. On the contrary, indirect expenditures are the visitors' expenses for food, transportation, accommodation, entrance tickets, equipment rental etc., which are indirectly dependent on the status of the coastal ecosystems. Because of the data scarcity on the cost structure of the tourism industry in Semarang, we assumed that 25% of the average expenditure reflects the added value to the tourism industry (adapted from Schep et al., 2013). Also, the dependency level of the recreational activities on coastal ecosystems was assumed to be 25% and 60% for direct and indirect values, respectively (adapted from Van de Kerkhof et al., 2014b).

To estimate the net revenue generated by the visitors, direct and indirect average expenditures (per day) were summed and multiplied with the added value and the factor of ecosystem dependency. The total net revenue (producer surplus) was finally estimated by multiplying the resulted value with the number of total visitors recorded in 2014 (252,840 and 13,200 visitors for the selected beaches and estuary, respectively) and the average duration of stay of 1.4 days per visit per person (only considered for the beach area)[5]. It should be noted that consumer surplus captures the value that people receive from enjoying the natural benefits that the coast provides, while the producer surplus indicates the net recreational revenue generated by visitors. Thus, in using contingent valuation method, the questionnaire was designed carefully to avoid double counting of the same recreational aspects.

Fishery value

Fishing is an important source of income and livelihood in Semarang coastal and marine area creating the welfare basis for local coastal communities. Similar to the recreation service, the total value of commercial[6] fishery is estimated by adding up the consumer and producer surpluses as done by Schep et al. (2012).

Using the net factor income, the producer surplus was estimated to represent the net revenue generated by the ecosystem-related fishery. The revenue is the difference between gross revenue generated in the market and the production and maintenance fishing costs. These secondary data were collected from BPS (2014). The calculated value was then multiplied by the ecosystem dependency factor which was approximated based on a group discussion with local fishermen which indicated that fishery is approximately 40% dependent on the coastal ecosystems in Semarang.

[5] Tourist data is based on the tourist statistics 2014: ''Badan Pusat Statistik (BPS) Kota Semarang''.
[6] Recreational fishery is excluded in this study because of little importance for local population leading to data limitations.

Using the contingent valuation method, consumer surplus was obtained by asking the local community (20 respondents in this survey) the maximum amount they are willing to pay for each kilogram of fish. This WTP was then subtracted from what they actually pay in the market. Then by multiplying the obtained value with the total production in 2014, the annual consumer surplus was estimated.

Art value

Ecosystems provide art value through picturesque landscapes and artistic views captured in art works. We used net factor income method to estimate the art value of coastal ecosystems in Semarang. To this end, we conducted an art-related survey with a specifically-designed questionnaire among 8 book stores, 4 painting and 8 photo shops to assess how coastal nature in Semarang is represented in the art works and in the annual earnings from selling art works that either directly or indirectly captured the scenery associated with coastal ecosystems in Semarang. The final annual value was estimated by summing the total revenue earned from all the art works sold in these shops in 2014. Since art-related shops were few in Semarang, we assumed that the 20 surveyed stores provided a reasonable representation of the art value of coastal ecosystems in Semarang. This approach was adapted from Van Beukering and Wolfs (2012) who presented a similar valuation study in Caribbean Islands.

Amenity value

The amenity value of Semarang coastal ecosystems for local residents was estimated by using the hedonic price method that traditionally aims to capture the hedonic value of coastal nature by considering property prices. The proximity of properties to the Java Sea is likely to capture the influence of ocean views on local properties prices, which indirectly represents the amenity value of coastal ecosystems. Following Fraser and Spencer (1998), we approximated the hedonic value of coastal amenity, primarily the ocean view, by using a scoring system and a proportional change in the sale price of residential property. To this end, we conducted survey among several local real estate agents to collect information on property prices. In total 35 properties (at different distances from the sea) were assessed. While this small sample does not allow a full scale hedonic analysis, the aforementioned scoring system, which identifies the proportional change in the sale prices, serves as a suitable alternative in such data-scarce environments. Thus, based on our survey we categorized the property prices in different groups based on proximity to the coast and assigned proportional percentages of the sea view/accessibility to each group. Subsequently, this assigned proportion (as a percentage) was multiplied with the corresponding mean sale price to estimate the final amenity value of coastal ecosystems for each distance-from-sea property category.

Results

Fishery value

This section presents the valuation results of the fishery service provided by the Java Sea and mangrove swamps in Semarang by estimating the consumer (Table A2) and producer surpluses (Table A3). Results show that the total value of fishery is primarily formed by the producer surplus,

Table A2
Consumer surplus of fishery value. Source: Survey Based (SB), Literature Based (LB).

No.	Fish type	Market price/kg (IDR) [SB]	Average WTP/kg (IDR) [SB]	Annual production in kg [LB]	Consumer surplus (mln. IDR)
1	Manyung	30,000	31,700	8781	14,9
2	Bawal Putih	20,000	29,600	4316	41,4
3	Belanak	23,000	24,600	3869	6,2
4	Beloso	15,000	25,500	1042	10,9
5	Cumi-cumi	40,000	29,300	31551	−337,6
6	Peperek	28,000	3100	72925	218,7
7	Tongkol Krai	25,000	44,600	893	17,5
8	Kembung	27,000	29,100	38695	81,2
9	Layur	15,000	22,600	43606	331,4
10	Rajungan	35,000	38,600	24854	89,4
11	Selar	23,000	24,800	7441	13,4
12	Tembang	25,000	25,600	82747	49,6
13	Tengiri	32,000	46,500	1935	28
14	Teri	45,000	49,600	101573	467,2
15	Udang Putih	60,000	51,600	22175	−186,2
Total					**845**

Table A3
Producer surplus of fishery value. Source: Survey Based (SB), Literature Based (LB).

No.	Fishing net method	Number of fishing gear/year [LB]	Cost/unit (mln. IDR) [LB]	Gross revenue/unit (mln. IDR) [LB]	Net revenue/unit (mln. IDR)	Ecosystem related factor [SB]	Producer surplus. (mln. IDR)
1	Payang seine	20	106,9	311,8	204,9	0.4	1639
2	Danish seine	16	114,5	379,7	265,2	0.4	1696
3	Beach seine	60	58,6	112,4	53,8	0.4	1291
4	Set gill	40	10,3	18,8	8,5	0.4	136
5	Trammel	36	265,5	1432	1166	0.4	16790
6	Boat/raft	12	17,7	108,9	91,2	0.4	438
7	Portable trap	17	20,7	93,8	73,1	0.4	496
Total							**22,486**

constituting 22,486 million Indonesian Rupiah (IDR) versus only 845 million IDR of consumer surplus. Therefore, the value of fishery service is dominated by the market price and fishing costs that affect the producer surplus. The much lower value estimated for consumer surplus (3.75% of the producer surplus) is due to the fact that local people are not willing to pay much higher than the market price for each kilogram of fish. By summing the two, we estimate that the value of fishery provided by the Semarang coastal ecosystems is 23,331 million IDR, which is equivalent to approximately US$ 1,750,000 annually, given the 2015 prices and the exchange rate at 15.07.2015 (note: these conversions were used consistently in this study).

Art value

Table A4 shows revenue generated by selling art works related to Semarang coastal ecosystems. The survey also revealed that 44% of art works depict coastal landscape, 38% depict coastal fauna, and 18% include coastal flora and marine area. Total annual art value of coastal ecosystems is estimated at 213 million IDR (US$ 16,000).

Recreation/tourism value

The tourist Information Centre of Central Java Province states that foreign visitors do not often visit the coastal area due to the lower quality and popularity of these environments compared to other coastal areas in the country. Interviews during this study confirmed this revealing that half of the visitors to the area originate from the suburban area, and the rest from other cities in Indonesia. Thus, the recreational value of coastal ecosystems in Semarang is primarily formed by the stated WTP (consumer surplus) and resulting net ecosystem benefit (producer surplus) of Indonesian visitors.

Table A5 shows the results of calculation of consumer surplus (estuary and beaches) based on the interviewees stated WTP for fully enjoying the present benefits of three considered ecosystem-related recreational attributes (with no loss considered). The results show a higher WTP for the Plumbon estuary compared to the beaches for the two attributes of shore water quality and diversity of birds and coastal species.

Table A4
Total annual art value of coastal ecosystems in Semarang. Source: Survey Based (SB).

Category	No. of sold pieces in 2014 [SB]	Annual revenue (mln. IDR)
Painting	411	129
Photo	184	3
Book/Journal/Poster	1462	81
Total		**213**

Table A5
Consumer surplus for estimating the recreation value of coastal ecosystems in Semarang. Source: Survey Based (SB).

Ecosystem-related attributes	Average WTP (mln. IDR) [SB]	
	Beaches	Estuary
Tranquility (in terms of storminess)	0.0025	0.0023
Shore water quality	0.0016	0.0116
Diversity of birds and coastal species	0.0037	0.0103
Total/person/day	**0.0078**	**0.0242**
Total *	**1,970**	**320**

* Annual value calculated based on the total number of visitors in 2014.

Table A6
Producer surplus for estimating the recreation/tourism value of coastal ecosystems in Semarang. Source: Survey Based (SB).

Values	Added value	Average expenditure/day (IDR)		Added value (IDR)		Factor Ecosystem dependency	Net ecosystem benefit (mln. IDR)	
		Beaches	Estuary	Beaches	Estuary		Beaches	Estuary
Direct values								
Boat rental	25%	4167	–	1041	–	25%	0.0002	–
Indirect values								
Entrance ticket	25%	4415	–	1103	–	60%	0.0006	–
Food/beverage	25%	42713	25600	10678	6400	60%	0.0064	0.0038
Transportation	25%	29979	17000	7494	4250	60%	0.0045	0.0025
Accommodation	25%	235833	–	58958	–	60%	0.0353	–
Buoys rental	25%	4375	–	1093	–	60%	0.0006	–
Mats rental	25%	2552	–	638	–	60%	0.0004	–
Total/day/person	–	324034	–	81005	–	–	**0.048**	**0.0063**
Total *							**17000**	**83**

*Annual value calculated based on the total number of visitors in 2014.

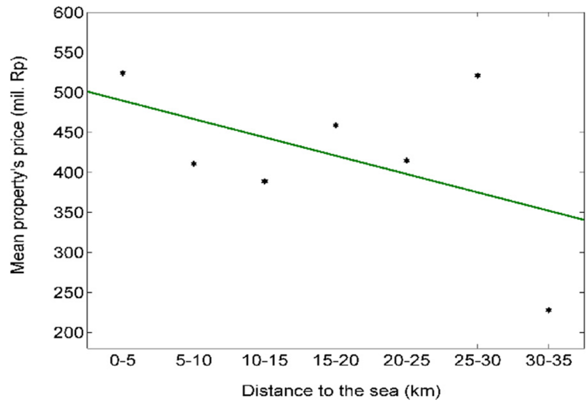

Fig. A1. Average price of the selected properties as a function of distance to the sea (km).

Table A7
Amenity value of coastal ecosystems in Semarang, based on mean property prices.
Source: Survey Based (SB).

Distance range to the sea (km)	Mean sale price* (mln. IDR)	Proportion of mean sale price (%) **	Amenity value (mln. IDR)
0 - 5	490	25	122
5 - 10	467	20,8	97
10 - 15	444	16,6	73
15 - 20	421	12,5	52
20 - 25	398	8,3	33
25 - 30	375	4,1	15
30 - 35	352	0	0

* Derived from the regression line (Fig. A1).
** Adapted with modification from Fraser and Spencer (1998).

Table A6 shows the estimated producer surplus and total net ecosystem-related benefits generated from tourism in Semarang. Accordingly, ”boat rental” is the only source of income indicated for the direct value generated in the selected beaches of Semarang, since there is no diving, snorkelling or other marine-based recreational activities (swimming does not provide any monetary benefit). However, the net benefit obtained from the boat tours are not fully dependent on the ecosystems and could still be earned even if the shore water quality is not high (here we consider a 25% dependency level). The final estimated value for the annual producer surplus is 17,000 million IDR for the beaches and 83 million IDR for the estuary (US$ 1,275,000 and US$ 6,200, respectively).

Amenity value

Following hedonic analysis literature, here we assumed that people attached hedonic value to coastal amenities which will be reflected in property prices. Property prices in the coastal area are influenced by the presence of coastal ecosystems and more importantly, the visual amenity of ocean views. According to the collected data, properties in the area are private dwellings with rather similar structural characteristics such as size and year of construction. We considered a weighted average price by dividing the results into 7 price categories as a function of distance to the property from the sea. Fig. A1 illustrates these results showing an overall decrease when moving farther inland, but a considerable jump in the distance of 25–30 km from the sea, which may be due to the close proximity at that location to shopping, educational and welfare facilities.

To put a monetary value on the amenity value of the CES (mainly provided by the aesthetic value afforded the Java Sea) we necessarily had to rely on our small sample of housing price estimates and otherwise poor data available for the Semarang housing market. The amenity value captured in property prices was therefore estimated by considering a proportional percentage of the mean sale price starting from 25% for the closest distance range from the sea (within 0–5 km) decreasing to zero for the farthest distance range (30–35 km), (adapted from Fraser and Spencer, 1998). Table A7 shows that the largest share of 122 million IDR (US$ 9150) is captured in properties that are the closest to the sea (0–5 km).

Appendix B

Hazard identification

In this study we consider inundation due to relative sea level rise (RSLR) (summation of SLR and land subsidence). This is because that the hazard history in Semarang shows the occurrence of coastal inundation and the high importance of SLR impacts on the coastal area of Semarang. However, other CC-induced hazards such as coastal erosion, storm surges etc. also can result changes to the CES of Semarang, the evaluation of which is beyond the scope of this study.

SLR can substantially change the extent and nature of coastal wetlands and the important ecosystem services they provide (Kassakian et al., 2017). In the study area, SLR and land subsidence can potentially alter the CES provided by the Maron and Marina beaches, Java Sea and mangrove swamps in Plumbon estuary. For example, SLR driven beach loss and degradation of the mangrove swamps would result in changing CES such as recreation, fishery and amenity.

Here, we relied on secondary data from literature to determine the rate of land subsidence and SLR. These two quantities were then summed to obtain an estimate of relative sea level rise (RSLR). Different rates of land subsidence have been reported for the study area. Abidin et al. (2013) found that given temporal and spatial variations, this rate varies between 6–7 cm/year with a maximum of 14–19 cm/year at some locations in the Eastern part of Semarang. This high rate of land subsidence in the Eastern part has been also reported by Murdohardono et al. (2009), and Kuehn et al. (2009). In this study, we used the land subsidence data reported by Abidin et al. (2013) for the Western part of Semarang with an average level of 4 cm/year based on the subsidence rates derived from GPS measurements in the period 2010-2011. For SLR in Semarang, we used the 7.8 mm/year projection given by ISET (2010). Thus, a RSLR of 4m by 2100 (relative to present) was adopted for Semarang area in this study.

Developing Scenarios and determining the resulting inundation areas

In order to determine the area that will be inundated by the projected RSLR, we developed two scenarios in relation to the identified hazard. In scenario A, the area that will be inundated by the projected 4m of RSLR was determined using a bath tub approach in which a 30m resolution DEM (U.S. Geological Survey, 2017) was used (Fig. B1a). Thus, Scenario A presents a situation where all of the mangrove swamps, beach and dune systems including their flora and fauna are fully inundated.

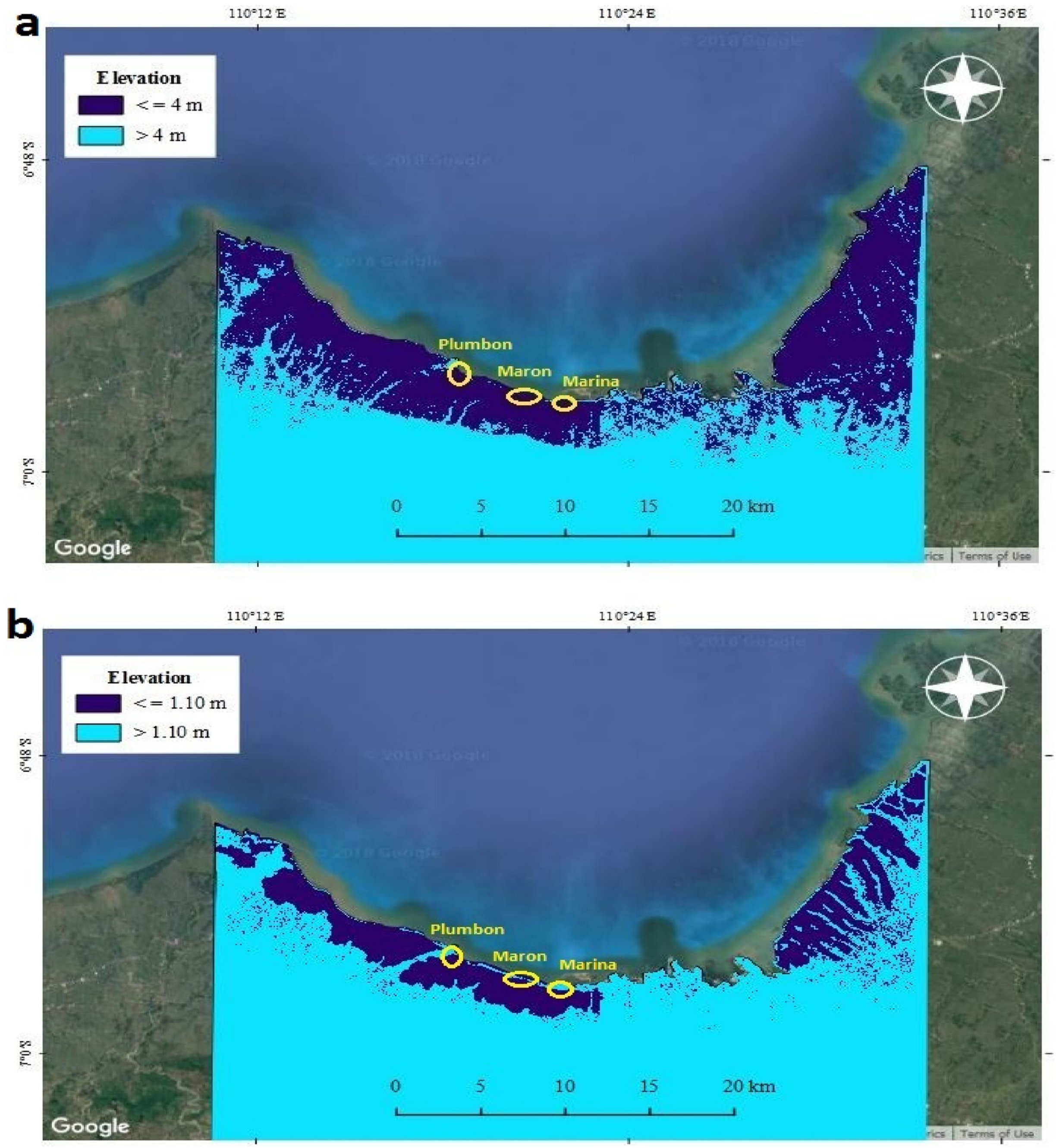

Fig. B1. Inundation areas (in blue) due to 4m RSLR by 2100 (relative to present) for the scenario A (a), and due to 1.10m RSLR by 2100 for the scenario B (b), showing that the three selected study sites will be completely (a) and 50% (b) inundated in 2100. This proportion is comparatively seen in the whole coastal area as well.

Scenario B represents a situation where the above inundation area is halved due to a RSLR of 1.10m by 2100 (Fig. B1b). Scenario B could arise due to many reasons such as SLR projection, a decreasing rate of land subsidence over time, or any adaptation measures that may increase the resilience of area, making it less exposed to inundation.

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