The impacts of methodological choices on the outcome of climate change vulnerability assessments: an example from the global fisheries sector

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Abstract:	Climate change vulnerability assessments have been receiving increasing attention from policy-makers and academics. Given scarce funds for adaptation, the UNFCCC Secretariat has suggested that eligible countries be prioritized for support based on their vulnerability to climate change. National-level fisheries sector climate change vulnerability assessments as well as other overall vulnerability assessments to date have lent support to the idea that Least Developed Countries (LDCs) are more vulnerable to climate change than Small Island Developing States (SIDS) and other coastal countries. We demonstrate that these perceived differences in vulnerability among country groups are partly due to methodological choices made during these assessments. We argue that national-level vulnerability assessments, and particularly those dealing with the fisheries sector, often suffer from four main methodological shortcomings: 1) an inconsistent representation of countries belonging to each group; 2) use of socio-economic indicators that are not scaled to population size; 3) use of a small number of indicators; and 4) lack of accounting for potential redundancy among indicators. Building on a previous framework, we show that by addressing the four aforementioned methodological shortcomings, the ranking in fisheries sector vulnerability among SIDS, LDCs and other coastal countries is altered significantly. Our results underscore that the

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Titles

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Abstract:

Climate change vulnerability assessments have been receiving increasing attention from policy-makers and academics. Given scarce funds for adaptation, the UNFCCC Secretariat has suggested that eligible countries be prioritized for support based on their vulnerability to climate change. National-level fisheries sector climate change vulnerability assessments as well as other overall vulnerability assessments to date have lent support to the idea that Least Developed Countries (LDCs) are more vulnerable to climate change than Small Island Developing States (SIDS) and other coastal countries. We demonstrate that these perceived differences in vulnerability among country groups are partly due to methodological choices made during these assessments. We argue that national-level vulnerability assessments, and particularly those dealing with the fisheries sector, often suffer from four main methodological shortcomings: 1) an inconsistent representation of countries belonging to each group; 2) use of socio-economic indicators that are not scaled to population size; 3) use of a small number of indicators; and 4) lack of accounting for potential redundancy among indicators. Building on a previous framework, we show that by addressing the four aforementioned methodological shortcomings, the ranking in fisheries sector vulnerability among SIDS, LDCs and other coastal countries is altered significantly. Our results underscore that the vulnerability of SIDS was partially concealed in previous assessments and suggest that SIDS are in fact the most vulnerable group. Although this study focuses on assessing the vulnerability of the fisheries sector to climate change in SIDS, LDCs and other coastal countries, the implications also apply to other sectors and country groupings.

Keywords: climate change, fisheries management, LDCs, methodology, SIDS, vulnerability assessments

Contents

1. Introduction

Climate change could potentially interrupt progress of Least Developing Countries (LDCs) and Small Island Developing States (SIDS). Climate change and climate variability are expected to worsen poverty, exacerbate inequalities, trigger new vulnerabilities and provide some opportunities for individuals and communities (Olsson *et al*. 2014). As climate change is expected to impede the ability of nations to alleviate poverty and achieve sustainable development, adaptation to climate change in LDCs and SIDS has been highlighted as a high priority.

Given the scarcity of funds currently available for adaptation, the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat has suggested that prioritization among eligible countries should be based on their vulnerability to climate change (Hinkel 2011; Klein

2009). Convention Article 4.4 of the UNFCCC calls on the developed country parties to "assist the developing country parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation" (UN 1992). This has triggered a significant amount of research that assesses the vulnerability of different regions, countries, sectors, communities and groups of people (Hinkel 2011). Vulnerability assessments are based on a range of biophysical and socio-economic indicators have become the dominant method to establish who and what is vulnerable to the negative effects of climate change (Klein 2009; Tschakert *et al*. 2013). They are considered to be particularly relevant now that the impacts of climate change are increasingly being observed (Hinkel 2011). Climate change vulnerability assessments have, as a result, been receiving increasing attention in policy and academic circles (Klein 2009; Khazai *et al*. 2014).

A comparative approach using the country or state as the unit of analysis can be used to identify particularly vulnerable groups of countries. These national level vulnerability assessments can help guide appropriate climate change adaptation policies (Brooks, Adger and Kelly 2005; Allison *et al*. 2009). Vulnerability assessments and the ranking of countries can have both political and practical consequences. However, the choice of methodological approaches to vulnerability assessments can influence the outcomes, resulting in discrepancies among assessments. The main critiques of many existing indices of vulnerability assessments to climate change to date relate to conceptual, methodological and empirical weaknesses including lack of focus, lack of sound conceptual framework, methodological flaws, large sensitivity to alternative methods for data aggregation, and limited data availability (Füssel 2009; Park, Howden and Crimp 2012). Partly as a result of this there is little agreement regarding which countries are the most vulnerable (Eriksen and Kelly 2007).

Given the serious implications of vulnerability assessment outcomes for adaptation, in this study we seek to illustrate how simple, yet sound, methodological choices in the implementation of these types of assessments can substantially change the perceptions of which groups of countries are most vulnerable to climate change. We do this by systematically comparing the vulnerability outcome of three groups of countries, i.e. SIDS, LDCs and 'Other Coastal Countries' (OCCs) as we undertake six sequential methodological steps in our analysis, ultimately leading to what we believe is a robust vulnerability assessment.

LDCs and SIDS are recognized to be very vulnerable to the adverse effects of climate change by the UNFCCC. LDCs are considered to be vulnerable to extreme weather events, and climate variability and change are expected to exacerbate this; further these countries are expected to lack the adaptive capacity needed to respond to climate change due to their fragile economies (Bruckner 2012; Soares, Gagnon and Doherty 2012). SIDS are also considered to be highly vulnerable to climate change as many are low-lying, small, often remote, and economically vulnerable. Moreover, most SIDS are located in the tropics and sub-tropics where changes in weather patterns due to climate change are expected to be most pronounced (Guillotreau, Campling and Robinson 2012; Nurse *et al*. 2014).

There is increasing concern over the direct and indirect impacts of climate change and climate variability on marine capture fisheries (Brander 2010; Cheung *et al*. 2010; Mora 2013). Climate change impacts such as sea surface temperature increases, ocean acidification, increased intensity of storms, and sea level rise are expected to trigger a series of biophysical and socio-economic impacts on national fisheries (Mahon 2002; Brander 2007; Allison *et al*. 2009; Cheung *et al*. 2010; Nurse 2011; Mora 2013; Pörtner *et al*. 2014). Increasing frequency and strength of extreme events such as tropical storms, hurricanes and droughts also pose significant threats to coastal zones, maritime areas and economies. Direct (usually ecological) and indirect (both social and ecological) pathways exist between climate change or variability and the potential impacts on the fisheries sector. Understanding where the impacts of climate change on the fisheries sector have greatest social and economic significance is crucial as fisheries are important for food security, livelihoods and employment and the generation of foreign exchange for national governments globally (Allison *et al*. 2009; Allison 2011). While there have been numerous fisheries vulnerability assessments at the local and community level (Marshall and Marshall 2007; Park *et al*. 2012; Cinner *et al*. 2012, 2013;), only Allison *et al*. (2009) and Barange *et al*. (2014) have undertaken vulnerability assessments at the national level.

Allison *et al.* (2009) identified LDCs as most vulnerable to climate change, shown, *inter alia*, by the fact that LDCs were disproportionately overrepresented in their final list of most vulnerable countries. Indeed, although LDCs represented approximately only 20% of the total number of countries examined by the study, they accounted for most (57%) of countries listed as highly vulnerable. In contrast, SIDS represented about 8% of the total number of countries examined (whereby the two SIDS which are also LDCs are grouped under SIDS), yet they accounted for only 3% of countries listed as highly vulnerable, implicitly suggesting that SIDS fisheries were not particularly vulnerable to climate change (Allison *et al*. 2009).

We argue that interpretation of the outcome of national-level vulnerability assessments to date warrants caution. For example, a review of available national-level vulnerability assessments based on studies carried out 1) over the past decade; 2) related to climate change (or an aspect thereof) and/or the fisheries sector; and 3) based on freely accessible data, revealed ten assessments (Table 1). All these assessments seem to suffer from one or more of four main methodological shortcomings. The first shortcoming is an inconsistent representation of countries belonging to each group, with SIDS in particular being very poorly represented in comparison to LDCs. The second is the use of socio-economic indicators that are not scaled to take into account the existing large differences among countries in human population size. Allison *et al*. (2009), for example, use total national fish catch (metric tonnes) and total number of fishers without scaling them to population, while Kreft and Eckstein (2013) use total national number of deaths as a result of natural disasters and total national monetary loss. We recognize that in some cases there may be sound arguments for including indicators that are not scaled to population size. However, we argue that failing to scale some indicators to population size has the potential to under-estimate the vulnerability of smaller nations. Of these ten studies (Table 1), five included indicators that are based on total national numbers, rather than on estimates scaled to population size (per capita estimates), and thus potentially conceal the true vulnerability of smaller nations. The third shortcoming is the use of a rather small number of indicators, raising concerns about the sensitivity of the results to the inclusion or exclusion of any particular indicator. Whereas we recognize the need for a small number of simple composite indicators as final outputs of the analysis for policy making, we believe that the complexity of the different aspects that make up vulnerability will be more robustly captured by the use of a diverse range of indicators as inputs in the analysis. Eight of the 10 studies had no more than eleven indicators overall (Table 1). The fourth shortcoming is the lack of accounting for potential redundancy among indicators, which might lead to a disproportionate effect on the final vulnerability ranking by aspects of vulnerability that might be overrepresented with indicators. We examine how accounting for indicator redundancy using multivariate analysis affects the vulnerability ranking of the country groups.

The sensitivity of vulnerability assessments to methodological choices is rarely examined in studies focusing on climate change. We assess how the outcome of national-level vulnerability assessments of the fisheries sector to climate change is altered as we overcome the main methodological shortcomings mentioned above. We do this by using the conceptual framework proposed by Allison *et al*. (2009). The study by Allison *et al.* (2009), with more than 500 citations at the time of our study, has been influential in both the international policy-making arena and in the redistribution of international funding available to countries for adaptation to climate change.

Table 1

2. National level fisheries sector vulnerability assessments

Allison *et al*. (2009) followed the commonly applied definition of vulnerability used in the Third Assessment Report of the IPCC (2001) to build their vulnerability framework (see Figure 1). In this interpretation the vulnerability of any sector to climate variability or change is a function of (a) the degree of exposure to the threat; (b) the sector's sensitivity: the degree to which a system is affected (either adversely or beneficially); and (c) the capacity of the sector to cope with or adapt to the threat, to take advantage or create opportunities, or to cope with the consequences (Smit and Wandel 2006). In the Fifth IPCC Assessment report (AR5) the interpretation of vulnerability altered with a new focus on climate change risks (Field *et al.* 2014). However, during this research the AR5 was not yet available and as we are comparing and building on to the original Allison *et al*. (2009) framework we have adapted the original framework as discussed in the Third Assessment Report (IPCC 2001), which has also been used by a number of other vulnerability assessments (Bell, Johnson and Hobday 2011; Cinner *et al.* 2012).

Fig. 1

Exposure is defined as the degree of climate stress upon a particular unit of analysis; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events (IPCC 2001). Both slow-onset changes (e.g. sea surface temperatures, ocean acidification) and an increased number of extreme-weather events and intensity thereof are expected to impact fisheries worldwide (Brander 2007). Allison *et al.* (2009) used a single indicator for the exposure component, raising concerns about the sensitivity of the results to indicator choice. In addition, the indicator chosen (projected air surface temperature change by 2050) is expected to show the largest difference in the higher latitudes and thus gives the impression there is only relatively low impacts of climate change in the lower latitudes (sub-tropical and tropical countries). Other exposure indicators such as sea-level rise, ocean acidification and sea surface temperature change have a more direct link with fisheries sector vulnerability.

Sensitivity is usually defined as the degree to which biophysical, social and economic conditions are likely to be influenced by extrinsic stresses or hazards due to climate change, including beneficial and harmful effects. Allison *et al.* (2009) considered sensitivity to be represented by the fisheries dependency of a nation, for which five socio-economic indicators related to the fisheries sector were used. Of these five indicators, two are not scaled to take into account the large differences among countries in human population size. Using the absolute number of fishers per country or fish catch, for example, conceals the importance of fisheries to smaller nations such as Kiribati in comparison to larger nations such as China.

Adaptive capacity relates to the capacity of a community or country to cope with, and adapt to, a variety of climate change impacts and is strongly influenced by several factors related to economic vulnerability, governance, education, and health. Adaptive capacity is thus context specific, related to both availability of resources, capacity to learn, and government measures (Gupta *et al*. 2010). Climate-induced shifts in ecosystems and fisheries production will create significant challenges to sustainability and management, particularly for countries with fewer resources and lower adaptive capacity, including many low-latitude and small island nations (Allison *et al*. 2009; Pörtner *et al*. 2014). Allison *et al*. (2009) used one adaptive capacity indicator (GDP) which was not scaled to take into account the large differences among countries in human population size.

Finally, each of the three components of vulnerability were calculated as the mean of the selected indicators, which were equally weighted, and overall vulnerability was calculated as the mean of exposure, sensitivity and adaptive capacity. However, the degree of redundancy among indicators within each component was not examined. Thus, there is a risk that some vulnerability subcomponents might have been overrepresented with indicators relative to other subcomponents for which fewer indicators were included.

3. General approach

The objectives of this research are addressed by comparing the outcome of six vulnerability assessments conducted sequentially, with each assessment along the sequence entailing a different, yet sensible and justifiable, methodological choice from that of the Allison *et al*. (2009) study. The sequence starts with the original assessment by Allison *et al*. (2009). Figure 2 provides a roadmap of the sequence of changes undertaken, starting from Allison *et al*.'s (2009) assessment (A1), which is based on their original data using 10 indicators and 107 coastal countries (excluding 25 landlocked countries that the original authors had included). Note, however, that in A1 and all subsequent assessments, we have opted to rank-transform all the indicators. This is different from the Allison *et al*. (2009) approach, where either log-transformations or the raw values were used for the indicators. We believe rank-transforming each indicator will yield more robust results as this approach allows for standardizing data across indicators independently of the shape of the distribution of values underlying each indicator, while minimizing the influence of extreme values in a consistent manner across indicators. In any case, rank-transforming all the data or using Allison's selective log-transforming approach made little difference to the results for the ranking of SIDS, LDCs and Other Coastal Countries (hereafter OCC) vis-à-vis one another obtained for A1.

Assessment two (A2) follows the same methods as A1, but uses indicators scaled to human population size where relevant. Assessment three (A3) uses the same indicators as A2, but is based on a more recent dataset, gathering the most up-to-date information available for the indicators used in A2. Thus, A3 does not imply any methodological change in the assessment sequence. We simply seize the opportunity to use the most up-to-date data sets. However, to ensure that the changes in outcome between A2 and A4 are not a result of the use of more recent data, we present the outcome of this step separately.

Assessment four (A4) uses the same recent data but incorporates an additional set of 66 countries (see Supplementary Information Table 1 for the list of countries for assessments A1-A3 and A4-A6). Assessment five (A5) adds an additional set of indicators to the vulnerability assessment analyses; we propose that all these new indicators are particularly relevant to assessing the vulnerability of SIDS (see Supplementary Information Table 2 for a list of indicators used for A5 and A6). For the final vulnerability assessment (A6), we account for potential redundancy among indicators within each vulnerability component (exposure, sensitivity, adaptive capacity) by means of Principal Component Analysis (PCA) on the ranked-transformed indicator data. This allows the identification of groups of redundant (correlated) indicators and facilitates ensuring an equal weighting of each of these groups within each vulnerability component.

Finally, for each assessment, differences in components and overall vulnerability between assessments (for exposure, sensitivity, adaptive capacity and vulnerability) and among country groups (i.e. SIDS, LDCs, OCC) have been assessed graphically by means of box-and-whisker plots. Kruskal-Wallis tests were used to compare: 1) between sequential assessments within country groups, and 2) among country groups within each assessment (see Supplementary Information Table 3a-b for further details on tests outputs). In section 1.3 we present the outcome for each individual country for every assessment in maps (10a-f).

Fig. 2

3.1 A1 to A2: use of unscaled indicators

The first methodological comparison is between indicators that are not scaled to take into account the large differences among countries in human population size and those which are, as we argue this could make a large difference in vulnerability ranking of country groups. The exposure component was unaffected as the indicator remained the same in A1 and A2. In the sensitivity component, Allison *et al.* (2009) used two indicators related to the number of fisherfolk. One is the absolute number of fisherfolk; the second uses the same data but as a percentage of the Economically Active Population. As the indicator using the absolute number of fishers per country was not scaled to take into account the large differences among countries in human population size we excluded this indicator in A2 and kept the second indicator, which was scaled to population. In the adaptive capacity component we changed two indicators (see Table 2): 1) total Gross Domestic Product (GDP) was changed to GDP per capita, and 2) Gross Enrolment Ratio in the education component was deleted and only literacy rate was used due to missing data. Rescaling the indicators altered the pattern of differences among country groups for sensitivity; with SIDS replacing LDCs as the most sensitive country group, although only by a margin (see Figure 3a-d). SIDS also became more vulnerable in adaptive capacity although the relative position of country groups did not change. These changes did not affect the existing pattern of differences among groups in overall vulnerability, with LDCs being the most vulnerable group and OCCs the least.

Table 2

Fig. 3

3.2 A2 to A3: use of most current data available

In this comparison we examined whether using more up-to-date data affects the outcome on country groups rankings. Updating the datasets did not alter in any substantial way the existing pattern of differences among country groups for any of the components and for overall vulnerability except for LDCs becoming less vulnerable in adaptive capacity (Figure 4).

Fig. 4

3.3. A3 to A4: inclusion of more countries

Inconsistent representation of countries belonging to the LDCs and SIDS groups could alter the results. SIDS were particularly poorly represented in the Allison et al. (2009) study with only 11 out of 52 included (Table 1). Data on SIDS are often excluded as a result of alleged data deficiency (Allison *et al*. 2009; Hughes *et al*. 2012). In order to partly overcome this we followed various routes. In the case of missing data we made a thorough search of secondary literature and/or establish direct contact with the countries involved. In some cases proxies were used for countries or missing data were filled with predictions using other datasets, which were correlated with the indicator datasets. Missing values in a given indicator were filled with the median value for that indicator. We acknowledge that filling in missing data or using proxies implies underlying assumptions which can have impacts on the final outcome. We expect that as more and more indicators become available for all countries in the world (including SIDS) results will be more robust in this regard in the long term._In A4 we present the results for the assessment including an additional 66 countries compared to A3. In A1-3 11 SIDS, 15 LDCs and 81 OCC were included. In A4-A6 51 SIDS (and an additional 7 overseas territories) (the nine SIDS which are also LDCs are grouped under SIDS as their outcomes were most consistent with those of the other SIDS), 22 LDCs (all remaining coastal LDCs) and 93 OCCs were included. We re-scaled A4 so that the maximum values are the same for both assessments. The country group rankings show broadly similar patterns between the different assessments. However, SIDS show a lower vulnerability when more countries were added as a result of lower vulnerability in adaptive capacity. A larger representation of countries within the SIDS and LDC groups tended to reinforce the pattern of differences among country groups established in A3 for all three components and the overall vulnerability ranking.

Fig. 5

3.4 A4 to A5: using a larger set of indicators

For A5 we used 8 indicators used by Allison et al. (2009) and included an additional 27 indicators. Based on a literature review we initially found data for 107 indicators (Figure 6). We faced several limitations in finding data for the desired indicators at a global scale and many potential indicators identified were not yet available. Of the 107 indicators for which data were available, we excluded 69 from further analysis for the following reasons: >10% missing data (41), redundancy (15) with similar indicators in the analysis covering the same topic, or uncertainty if different datasets covering the same topic gave different results (13) (Figure 6). Of the 35 final indicators included in A5, three are based on projected data (e.g. sea level rise and maximum potential yield change in fisheries by 2050; 'end-point' indicators) while the remainder are based on current status ('start-point' indicators).

Fig. 6

Expanding on the existing work on vulnerability assessments and the fisheries literature we thus present a broadened set of indicators for assessing the vulnerability of the fisheries sector to climate change. Broadening the set of indicators will allow the identification and isolation of interpretable subcomponents within each of three vulnerability components. This should better reflect the complex nature of these components.

There is no objective, independently derived measures of exposure, sensitivity or adaptive capacity, so their relevance and interpretation depend on the scale of analysis, the particular sector under consideration and data availability. For the three key elements of vulnerability the derivation of each indicator is detailed in the Supplementary online information Table 2.

<u>Exposure</u>

In A5 we used four exposure indicators for which data were available at the global scale. The original indicator used by Allison *et al*. 2009 (air surface temperature change) was omitted and we used four main climate stressors affecting fisheries: 1) sea surface temperature change; 2) sea level rise; 3) ocean acidification; and 4) UV radiation.

Sensitivity

Sensitivity is usually defined as the degree to which biophysical, social and economic conditions are likely to be influenced by extrinsic stresses or hazards due to climate change, including beneficial and harmful effects. Allison *et al*. (2009) assessed sensitivity solely using fisheries dependency indicators. In this study we consider sensitivity to consist of three elements: *fisheries dependency, coastal vulnerability* and *fisheries health*.

Fisheries dependence is represented by four indicators comprising: 1) fisheries production per 1,000 people (landings); 2) contribution of fisheries to employment by number of marine fishers as a percentage of total economic population; 3) export income as fish exports as % of total exports; and 4) food security as % of animal protein coming from fish. *Coastal vulnerability* is calculated from six indicators related to the percentage of population, land and assets projected to be exposed to coastal risks. *Fisheries health* relates to the ability of fisheries to remain viable in the face of climate-induced changes and to bounce back when there are short-term events (including indicators on exploitation of fished stocks and habitat and biodiversity health).

Adaptive capacity

The capacity of a community or a nation to cope with, and adapt to, a variety of climate change impacts is strongly influenced by several factors related to economic vulnerability, governance, education, and health. Climate-induced shifts in ecosystems and fisheries production will create significant challenges to sustainability and management, particularly for countries with fewer resources and lower adaptive capacity, including many low-latitude and small island nations (Allison *et al*. 2009; Pörtner *et al*. 2014). In this study adaptive capacity consists of three sub-components: socio-economic adaptive capacity of a country, economic vulnerability, marine governance and fisheries resilience.

The main differences between assessments A4 and A5 are seen in the exposure component (Figure 7a-d). A4 used only air surface temperature as an indicator of exposure due to lack of global availability for sea surface temperature data per country and used the underlying assumption that warming-related impacts (both positive and negative) upon physical and biological variables affecting fisheries production and fishery operations will be greater in areas where projected air temperature changes are greater (Allison *et al*. 2009). Geographical patterns of projected atmospheric warming, however, show greatest temperature increases over land (roughly twice the global average temperature increase) and at high northern latitudes, and the least warming over the southern oceans and North Atlantic (Barange and Perry 2009). SIDS therefore showed low levels of exposure in A1 through A4, whereas LDCs and OCCs showed much higher levels of vulnerability.

We have argued in the introduction that a small number of indicators and the particular choice of indicators can raise concerns about the sensitivity of the results to the inclusion or exclusion of any particular indicator. In A5 we omitted air surface temperature change and used sea level rise, sea surface temperature change, ocean acidification and UV radiation which we expect to have more direct and profound impacts on the fisheries sectors. As a result, SIDS were found to be much more vulnerable in exposure, closely followed by LDCs, whereas the median exposure of OCCs was the lowest of the three groups (see figure 7a-d). Using a larger and different set of indicators thus altered the pattern of differences among country groups for exposure. It did not alter existing differences among country groups for sensitivity and adaptive capacity showing the choice of more indicators in these components has thus only slightly altered the ranking of country groups. However, the choice for indicators more suited to explain differences in vulnerability of the fisheries sector for the exposure component have had a large influence on overall vulnerability ranking of country groups. Due to this change, whereas LDCs were ranked most vulnerable in A4, they were classified as having medium vulnerability in A5, and whereas SIDS appear to be *least* vulnerable in A4, they actually appear *most* vulnerable in A5.

Fig. 7

3.5 A5 to A6: Accounting for potential redundancy among indicators

For the final vulnerability assessment A6, we used principal component analysis (PCA) to identify groups of correlated indicators (i.e. subcomponents) within each vulnerability component (exposure, adaptive capacity, sensitivity – one PCA was conducted per component). This allowed implementing an equal weighting across subcomponents within a vulnerability component, rather than across all individual indicators. Each PCA was based on a correlation matrix and was followed by varimax rotation of the principal components (PCs) to help interpret indicator loadings. Only principal components (PC) corresponding to eigenvalues ≥1 were retained (Legendre and Legendre 2012). Each PC represented a specific interpretable dimension, or subcomponent, of a vulnerability component. To interpret each PC, only indicators with relatively high loadings (≥0.6) on that PC were considered. Second, for each vulnerability component, the country ranking on the retained PCs were extracted, rank-transformed, and averaged to yield an overall country ranking for that vulnerability component. Thus, each retained PC contributed equally to the final country ranking for a given vulnerability component, even though the PCs might have differed in the amount of total variance (and number of high loading indicators) that they captured. Finally, the three component rankings (one for exposure, one for adaptive capacity, one for sensitivity) were averaged to yield the overall vulnerability ranking. SIDS is the only country group that showed changes between A5 and A6, becoming more vulnerable in exposure but less vulnerable in sensitivity, yet not affecting their rank in overall vulnerability. Although we believe that an approach where indicator redundancy is taken into account is more conceptually sound it did not affect the final results in this specific study, with little differences observed between A5 and A6 (Fig 8a-d).

Fig. 8

3.6 A1 to A6: from start to finish

Fig. 9

For the final comparison we compared the results between A1 and A6 directly, with focus on the differences in ranking among country groups. Our results clearly indicated that although SIDS were the least vulnerable overall in the initial assessment (A1), they were the most vulnerable in the last (A6), followed by the LDCs (Fig 9d). Examining each of the vulnerability components separately revealed that the reversal in SIDS overall vulnerability is driven by changes within the exposure and sensitivity components, with SIDS now ranking highest in both components and LDCs and OCCs exhibiting similar but lower ranks (Fig 9a-b). In contrast, in adaptive capacity, the relative ranking among country groups changed little (Fig 9c).

3.7 Maps of global coastal nation's fishery sector vulnerability by assessment

Figure 10a-f presents maps illustrating the relative rank of vulnerability (from very low to very high) of the 107 individual countries as inferred from the sequence of assessments 1 to 6 (panels a to f, respectively). We shaded each country's EEZ rather than landmass to make small islands nations more visible. The sequence of maps of the six assessments show the changes in vulnerability ranking of the countries involved. The general pattern of change from A1-A6 is that tropical and subtropical countries, including SIDS, are shown to be more vulnerable in the latter assessments in comparison to the initial ones. This is clearly illustrated in Figure 10g, which shows the change in ranks between A1 and A6 for all countries included in both assessments (n=107). The results showed that particularly Australia and islands in the Pacific Ocean, the Caribbean, Chile, northern Europe, the Middle East and some islands in the Indian Ocean became much more vulnerable in A6 (advancing in rank by at least 20 ranks) while North America, Russia, and parts of Asia and Africa became less vulnerable (dropping more than 20 ranks). While for comparisons between some assessments no significant difference was observed between SIDS, LDCs and OCCs, these maps show that at an individual country level, differences can indeed be observed.

Fig. 10

4. Discussion and Conclusion

Climate change vulnerability assessments of different sectors and at different scales have been gaining ground in academia and policy circles. At the national level, different country groups can be expected to express differences in vulnerability due to their level of exposure, sensitivity and capacity to adapt. When assessing the vulnerability of the fisheries sector, SIDS and LDCs are both expected to be highly vulnerable to climate change. However, assessments to date have provided support to the assertion that LDCs are more vulnerable than SIDS. We have argued in this paper, however, that the underlying reasons for this conclusion can partly be found in methodological choices that are made when assessing vulnerability of different nations.

To the best of our knowledge, this is the first study to have systematically analysed the effect of differences in methodological choices in vulnerability of the fisheries sector to climate change between SIDS, LDCs and OCC. Based on earlier work (Allison *et al*. 2009) in which vulnerability of the fisheries sector in the face of climate change was seen as a function of exposure, sensitivity and adaptive capacity, we presented six cumulative changes based on sensible methodological choices to show how different methodological choices can lead to different outcomes between SIDS, LDCs and OCCs. Changes between each assessment were necessarily carried out sequentially, resulting in a series of cumulative impacts on the final outcome. This makes it difficult to identify which methodological choice contributed the most to alter the final difference between the first and last assessment. Nevertheless, we can still draw some overall conclusions.

Comparing SIDS, LDCs and OCCs based on the Allison *et al*. 2009 data, we found that LDCs came out strongly as the most vulnerable country group, with SIDS as the least vulnerable group. Rescaling the indicators in Assessment 2 altered the pattern of differences among country groups particularly for sensitivity, with SIDS replacing LDCs as the most sensitive country group. Updating the datasets with the most up-to-date data in Assessment 3 did not alter in any substantial way the existing pattern of differences among country groups for any of the components and for overall vulnerability. This suggests the data followed a similar trend in all country groups over the time period between the different datasets. Including a much larger set of countries in Assessment 4 accentuates the differences between the country groups in exposure and adaptive capacity, yet there is little difference in sensitivity and final vulnerability ranking. Using a large set of indicators, and particularly the choice of different exposure indicators that are most suitable to assessing fisheries sector vulnerability, has accentuated the differences in final vulnerability outcome more strongly, increasing the relative vulnerability outcome of SIDS. We have noted that the results for exposure and sensitivity were radically different as a result of the choice of indicators and of the rescaling of indicators to population size. These results between A4 and A5 also showed that despite adding 27 indicators across the components of sensitivity and adaptive capacity, the ranking of SIDS and LDCs differed only marginally. However, just as between A2 and A3, at the individual country level the differences in country rankings were noticeable as can be seen in Figure 10a-f.

For the final vulnerability assessment A6, we combined the indicators in each of the subcomponents using PCA and thus accounted for potential redundancy among indicators, which might lead to a disproportionate effect on the final vulnerability ranking by those specific aspects of vulnerability that are overrepresented with indicators. Giving equal weight to underlying themes rather than individual indicators, however, had very little impact on the final outcome. We argue, nonetheless, that accounting for potential redundancy among indicators (e.g. by means of PCA) should still be preferred over weighing each indicator equally for any vulnerability assessment as it is more conceptually sound.

Overall, our results showed that SIDS were reported to be the least vulnerable in the initial assessments, consistent with the findings of Allison *et al.* (2009), but were the most vulnerable in the later assessments. Methodological choices thus have a significant impact on the vulnerability rankings of individual countries and groups of countries, a conclusion that we have emphasized in this work. From this study we can conclude that the absence or inclusion of particular countries, the use of indicators based on total versus relative numbers, and the choice of indicators is crucial to the outcome of vulnerability rankings for particular country groups in fisheries sector vulnerability assessments. These factors can conceal or highlight the relative vulnerability of particular country groups.

Our study also argues for a more adequate inclusion of SIDS in fisheries sector climate change vulnerability analyses as their exclusion has concealed their actual vulnerability. The under-representation of SIDS in previous vulnerability assessments can have widespread consequences for SIDS in the climate change debate, given that the results of national level vulnerability assessments are used to help determine the allocation of adaptation resources under various international governance mechanisms. Although in this comparison we specifically focused on the vulnerability of national fisheries sectors to climate change, the effects of methodological aspects highlighted here will apply similarly to any vulnerability assessment at the national level.

The disparities in results between the different assessments illustrate the difficulty in 'measuring vulnerability'. As we are building on the work of Allison *et al*. (2009) we have followed the IPCC definition of vulnerability, representing the average of exposure, sensitivity and adaptive capacity, with each component exhibiting similar weights. However, how much weight should be allocated to each of the three components (and for that matter, to each of their individual sub-components (PCs) in our study), is also subject to debate, as it can potentially affect the ultimate outcome.

In conclusion, our study shows that the outcomes of indicator-based vulnerability assessments are unavoidably affected by methodological choices, yet these are often not explicit in the literature. In that line, vulnerability assessments would greatly benefit from sensitivity analyses aimed at assessing the impact of different methodological choices. This is an area that should be further pursued in follow-up studies, although we recognize that the nature of such sensitivity analyses will depend on the specific conceptual, analytical and data framework used by a given vulnerability assessment. We suggest that methodological choices should be made much more transparent when discussing the selected methodology because these studies are likely to drive policy and thus have clear socio-economic implications for adaptation.

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References

Allison, E. H. (2011) *Aquaculture, fisheries, poverty and food security. WorldFish Working Paper* 2011-65, Penang, 61 pp.

Allison, E. H., Perry, A. L., Badjeck, M.-C., Adger, N. W., Brown, K., Conway, D., Dulvy, N. K. (2009) Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries 10* (2), 173–196.

Atkins, J.P., Mazzi, P. and Easter, C.D. (2000) A Commonwealth Vulnerability Index for Developing Countries: The position of Small States. In: *Small States in the Global Economy.* D. Perets, R. Faruqi, and E. Kisanga, eds. Commonwealth Secretariat, London, pp. 53-92.

Barange, M., and Perry, R. I. (2009) Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and. In: *Climate change implications for fisheries and aquaculture: Overview of current scientific knowledge*. K. Cockrane, C. De Young, & T. Bahri, eds. *FAO Fisheries and Aquaculture Technical paper* No. 530, Rome, pp. 7–43.

Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., Jennings, S. (2014) Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change* 4, 211-216.

Bell, J.D., Johnson, J. E., and Hobday A.J. (eds) (2011) Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community, Noumea, New Caledonia.

Brander, K. M. (2007) Global fish production and climate change *Science 104*(50), 44–46.

Brander, K.M. (2010) Impacts of climate change on fisheries. *Journal of Marine Systems* 79 (3-4), 389–402.

Brenkert, A., and Malone, E. (2005) Modelling Vulnerability and Resilience to Climate Change: A Case Study of India and Indian States. *Climate Change 72*(1-2), 57–102.

Brooks, N., Adger, N. and Kelly, P. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change 15*(2), 151–163.

Bruckner, M. (2012) Climate change vulnerability and the identification of least developed countries, *CDP Background Paper* No. 15 ST/ESA/2012/CDP/15. Economic and Social Affairs, United Nations, 27 pp. http://www.un.org/en/development/desa/policy/cdp/cdp_background_papers/bp2012_15.pdf (Accessed 7 April 2014)

Cheung, W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., and Pauly, D. (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology 16*(1), 24–35.

Cinner, J., McClanahan, T., Graham, N., Daw, T., Maina, J., Stead, S., Bodin, Ö. (2012) Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. *Global Environmental Change 22*(1), 12–20.

Cinner, J. E., Huchery, C., Darling, E. S., Humphries, A. T., Graham, N. A., Hicks, C. C., McClanahan, T. R. (2013) Evaluating social and ecological vulnerability of coral reef fisheries to climate change. *Public Library of Science One*, *8*(9): e74321. doi:10.1371/journal.pone.0074321

Eakin, H., and Luers, A. L. (2006) Assessing the Vulnerability of Social-Environmental Systems. *Annual Review of Environment and Resources 31*(1), 365–394.

Eriksen, S. H. and Kelly, P. M. (2007) Developing Credible Vulnerability Indicators for Climate Adaptation Policy Assessment. *Mitigation and Adaptation Strategies for Global Change 12*(4), 495–524.

Field, C., Barros, V., Mastrandrea, M., Mach, M., Abdrabo, M., Bilir, T., White, L. (2014) Summary for Policy makers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. V.R. Barros, C.B. Field, D.J. Dokken, et al. eds. Cambridge University Press, Cambridge, pp. 1–44.

Füssel, H.M. (2009) Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts. *Development and climate change - Background note to the World Development Report 2010*. Potsdam Institute for Climate Change Research, Potsdam, 34 pp.

Guha-Sapir, D., and Hoyois, P. (2012) *Measuring the Human and Economic Impact of Disasters*. Centre for Research on the Epidemiology of Disasters (CRED), University of Louvain School of Medicine, Brussels, 49 pp. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/286966/12-1295-measuring-human-economic-impact-disasters.pdf (Accessed 5 November 2014)

Guillotreau, P., Campling, L., and Robinson, J. (2012) Vulnerability of small island fishery economies to climate and institutional changes. *Current Opinion in Environmental Sustainability 4*(3), 287–291.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, S., Jong, P. (2010) The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science and Policy 13*(6), 459–471.

Hinkel, J. (2011) Indicators of vulnerability and adaptive capacity: Towards a clarification of the science–policy interface. *Global Environmental Change 21*(1), 198–208.

Hughes, S., Yau, A., Max, L., Petrovic, N., Davenport, F., Marshall, M., Cinner, J. E. (2012) A framework to assess national level vulnerability from the perspective of food security: The case of coral reef fisheries. *Environmental Science and Policy* 23, 95–108

IPCC (2001) *Climate change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken and K. S. White, eds. Cambridge University Press, Cambridge, 1032 pp.

Khazai, B., Kunz-Plapp, T., Büscher, C., and Wegner, A. (2014). VuWiki: An Ontology-Based Semantic Wiki for Vulnerability Assessments. *International Journal of Disaster Risk Science 5*(1), 55–73.

Klein, R. J. (2009). Identifying Countries that are Particularly Vulnerable to the Adverse Effects of Climate Change : An Academic or a Political Challenge ? *Carbon and Climate Law Review* 1, 283–291.

Kreft, S., and Eckstein, D. (2013) *Global Climate Risk Index 2014* http://germanwatch.org/en/download/8551.pdf. (Accessed 3 February 2015).

Legendre, P. and Legendre, L. (2012). *Numerical Ecology*. 3rd English Edition. Elsevier, Science BV, Amsterdam.

Mahon, R. (2002) *Adaptation of Fisheries and Fishing Communities to the Impacts of Climate Change in the CARICOM Region.* Mainstreaming Adaptation to Climate Change (MACC) of the Caribbean Center for Climate Change (CCCC), Organization of American States, Washington, D. C., 33 pp.

Malone, E., and Brenkert, A. (2009) Vulnerability, Sensitivity, and Coping/Adaptive Capacity Worldwide. In: *The Distributional Effects of Climate Change: Social and*

Economic Implications. M. Ruth & M. Ibarrarán, eds. Elsevier Science BV, Dordrecht, 8-23 pp.

Marshall, N., and Marshall, P. (2007) Conceptualizing and Operationalizing Social Resilience within Commercial Fisheries in Northern Australia. *Ecology 12*(1), 1.

Mora, C. (2013) The projected timing of climate departure from recent variability. *Nature 502* (7470), 183–187. doi:10.1038/nature12540

Nurse, L. (2011) The implications of global climate change for fisheries management in the Caribbean. *Climate and Development* 3(3), 228–241.

Nurse, L.A., McLean, R.F., Agard,J. et al. (2014) Small islands. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. V.R. Barros, C.B. Field, D.J. Dokken, et al., eds. Cambridge University Press, Cambridge, pp. 1613-1654.

Olsson, L., Opondo, M., Tschakert, P. et al. (2014) Livelihoods and Poverty. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* C.B. Field, V.R. Barros, D.J. Dokken, et al., eds. Cambridge University Press, Cambridge, pp 793-832.

Park, S., Howden, M., and Crimp, S. (2012) Informing regional level policy development and actions for increased adaptive capacity in rural livelihoods. *Environmental Science & Policy 15*(1), 23–37.

Park, S., Marshall, N., Jakku, E., Dowd, A., Howden, S., Mendham, E., and Fleming, A. (2012) Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change 22*(1), 115–126.

Peduzzi, P., Dao, H., Herold, C., & Mouton, F. (2009) Assessing global exposure and vulnerability towards natural hazards: the Disaster Risk Index. *Natural Hazards and Earth System Science* 9(4), 1149–1159.

Pörtner, H.-O., Karl, D.M., Boyd, P.W. et al. (2014) Ocean systems. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. C.B. Field, V.R. Barros, D.J. Dokken et al., eds. Cambridge University Press, Cambridge, pp. 411-484.

Smit, B., and Wandel, J. (2006) Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16(3), 282–292.

Soares, M. B., Gagnon, A. S., and Doherty, R. M. (2012) Conceptual elements of climate change vulnerability assessments: a review. *International Journal of Climate Change Strategies and Management* 4(1), 6–35.

Tschakert, P., van Oort, B., St. Clair, A. L.,and LaMadrid, A. (2013) Inequality and transformation analyses: a complementary lens for addressing vulnerability to climate change. *Climate and Development 5*(4), 340–350.

Yohe, G., Malone, E., Brenkert, A., Schlesinger, M., Meij, H., Xing, X., & Lee, D. (2006) *A Synthetic Assessment of the Global Distribution of Vulnerability to Climate Change from the IPCC Perspective that Reflects Exposure and Adaptive Capacity*. Center for International Earth Science Information Network, Columbia University. http://sedac.ciesin.columbia.edu/mva/ccv/ (Accessed 15 May 2014)

United Nations (UN). 1992. *United Nations Framework Convention on Climate Change. FCCC/INFORMAL/84 GE.05-62220 (E) 200705.* 24 pp. https://unfccc.int/resource/docs/convkp/conveng.pdf

(Accessed 14 August 2013)

Tables and Figures

Table 1: Inclusion of Small Island Developing States (SIDS) and Least Developed Countries (LDCs) in global climate indices

Topic	# of 52 SIDS (%)*	# of 49 LDCs (% of total LDCs)	# absolute indicators / total number of indicators	Total number countries in analysis	References
Fisheries sector vulnerability to climate change	11 (21)	26 (53)	3/10	132	Allison et al. (2009)
Impacts of climate change on marine ecosystem production	5 (10)	14(29)	0/4	63**	Barange et al. (2014)
National-level vulnerability assessment: food security in fisheries	4 (8)	7(14)	0/10	27	Hughes et al. (2012)
Combined Vulnerability to Food Security Threats from Climate Change and Ocean Acidification	18 (35)	18 (37)	0/11	50	Oceana (Huelsenbeck, 2012)
Coasts at Risk	31 (60)	27 (55)	0 /29	139	Beck 2014
Analysis of the Impacts of Acidification on the Countries of the World	38 (73)	45 (92)	1/4	187	Oceana (Harrould-Kolieb et al., 2009)
Vulnerability Risk to climate change	5 (10)	16 (33)	2/16	100	Brenkert and Malone (2005); Yohe et al. (2006)
Vulnerability-Resilience Indicators Model *(VRIM)*	14 (27)	38 (78)	2/16	160	Malone and Brenkert (2009)
Global Climate Risk Index 2013	33 (63)	42 (86)	2/4	174	Kreft and Eckstein (2014)
Disaster Sensitivity Index	46 (88)	46 (94)	0/3	201***	Guha-Sapir and Hoyois (2012)

* The 9 SIDS that overlap with LDCs have been counted both for LDCs and SIDS groups,

** Plus 12 dependent territories

*** including several dependent territories

Table 2 Comparison between the indicators used in the Allison et al. (2009) (Assessment 1) and indicators used in Assessment 2 (where necessary, indicators were reversed to ensure that high outcomes implied high vulnerability, these are marked with *).

Components	Assessment 1 (Allison et al. (2009), 107 coastal countries)	Assessment 2 (9 modified indicators: 107 coastal countries)
Exposure	Air surface temperature change B2 scenario	Air surface temperature change B2 scenario
Sensitivity	Fisherfolk	-
Sensitivity	Fisherfolk/ Economic Active Population	Fisherfolk/Economic Active Population
Sensitivity	Fish export as % of total export	Fish export as % of total export
Sensitivity	Fish catch (metric tonnes)	Fish catch (capture) (metric tonnes)/population
Sensitivity	Fish as % animal protein	Fish as % animal protein
Adaptive capacity	Health (Healthy Life Expectancy) *	Health (Healthy Life Expectancy)*
Adaptive capacity	Education (Literacy rate and Gross Enrolment Ratio)*	Education (Literacy rate)*
Adaptive capacity	Governance Index*	Governance Index*
Adaptive capacity	Gross Domestic Product*	Gross Domestic Product per capita*

Figure legends:

Figure 1 Vulnerability assessment framework of the fisheries sector

Source: Allison et al. 2009

Figure 2 Sequence of assessments (from 1 to 6) showing the additional methodological step conducted in each assessment

Figure 3a-d Box-and-whisker plots showing the distribution of country mean rank scores for exposure, sensitivity, adaptive capacity and overall vulnerability for Small Island Developing States (SIDS, n=11), Least Developed Countries (LDC, n=15) and Other Coastal Countries (OCC, n=81), as inferred from Assessment 1 (dark grey) and Assessment 2 (light grey) (including the p-values < 0.05).

Figure 4a-d Box-and-whisker plots showing the distribution of country mean rank scores for exposure, sensitivity, adaptive capacity and overall vulnerability for Small Island Developing States (SIDS, n=11), Least Developed Countries (LDC, n=15) and Other Coastal Countries (OCC, n=81), as inferred from Assessment 2 (dark grey) and Assessment 3 (light grey) (including the p-values < 0.05).

Figure 5a-d Box-and-whisker plots showing the distribution of country mean rank scores for exposure, sensitivity, adaptive capacity and overall vulnerability for Small Island Developing States (SIDS), Least Developed Countries (LDC) and Other Coastal Countries (OCC), as inferred from Assessment 3 (dark grey) and Assessment 4 (light grey). Note that number of countries included now differ between assessments with SIDS, LDC, OCC being 11, 15 and 85, respectively, in Assessment 3 and 58, 22, 93,

respectively, in Assessment 4. [Given the larger possible range of ranks in A4, values have been re-scaled so that the maximum value is the same as in A3] (including the p-values < 0.05).

Figure 6 Roadmap illustrating the selection process of the final set of indicators used in Assessments 5 and Assessments 6

Figure 7a-d Box-and-whisker plots showing the distribution of country mean rank scores for exposure, sensitivity, adaptive capacity and overall vulnerability for Small Island Developing States (SIDS, n=58), Least Developed Countries (LDC, n=22) and Other Coastal Countries (OCC, n=93), as inferred from Assessment 4 (dark grey) and Assessment 5 (light grey) (including the p-values < 0.05).

Figure 8a-d Box-and-whisker plots showing the distribution of country mean rank scores for exposure, sensitivity, adaptive capacity and overall vulnerability for Small Island Developing States (SIDS, n=58), Least Developed Countries (LDC, n=22) and Other Coastal Countries (OCC, n=93), as inferred from Assessment 5 (dark grey) and Assessment 6 (light grey) (including the p-values < 0.05).

Figure 9a-d Box-and-whisker plots showing the distribution of country mean rank scores for exposure, sensitivity, adaptive capacity and overall vulnerability for Small Island Developing States (SIDS, n=58), Least Developed Countries (LDC, n=22) and Other Coastal Countries (OCC, n=93), as inferred from Assessment 1 (dark grey) and Assessment 6 (light grey). [Given the larger possible range of ranks in A6, values have

been re-scaled so that the maximum value is the same as in A1] (including the p-values < 0.05).

Figure 10. Panels a-f. Maps showing the relative rank of an individual country (from very high to very low) based on the overall vulnerability scores, as inferred from the sequence of assessments 1 to 6 (panels a to f, respectively). Red, dark orange, orange and yellow shading represents countries in the fourth (very high), third (high), second (low) and first (very low) quartile, respectively (see Vulnerability legend). Each country is delineated by its Exclusive Economic Zone. Note that the number of countries included differ between assessments with SIDS, LDC, OCC being 11, 15 and 81, respectively, in Assessment 1-3 and 58, 22 and 93, respectively, in Assessment 4-6. **Panel g. Map showing the change between A1 and A6 in the relative ranks of individual countries for the 107 countries that were included in both assessments** (see Relative Change legend).

Figure 1

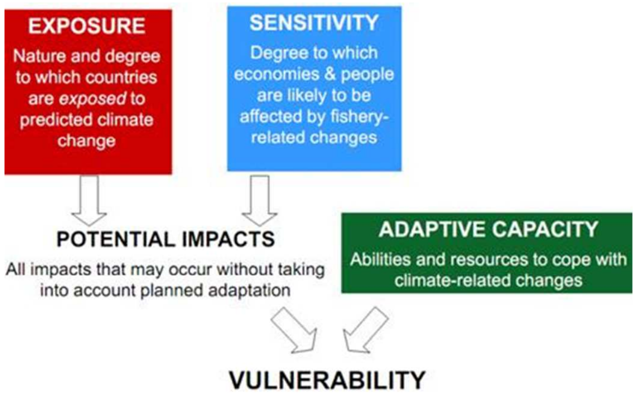

EXPOSURE
Nature and degree to which countries are *exposed* to predicted climate change
SENSITIVITY
Degree to which economies & people are likely to be affected by fishery-related changes
POTENTIAL IMPACTS
All impacts that may occur without taking into account planned adaptation
ADAPTIVE CAPACITY
Abilities and resources to cope with climate-related changes
VULNERABILITY

Figure 2

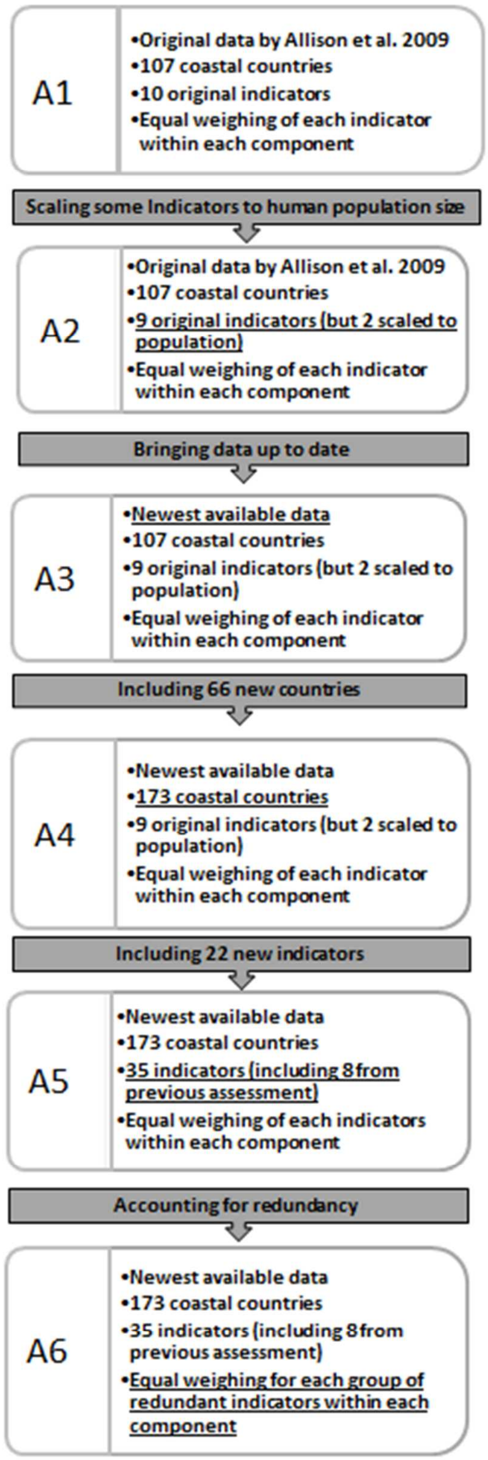

A1
•Original data by Allison et al. 2009
•107 coastal countries
•10 original indicators
•Equal weighing of each indicator within each component
Scaling some Indicators to human population size
A2
•Original data by Allison et al. 2009
•107 coastal countries
•9 original indicators (but 2 scaled to population)
•Equal weighing of each indicator within each component
Bringing data up to date
A3
•Newest available data
•107 coastal countries
•9 original indicators (but 2 scaled to population)
•Equal weighing of each indicator within each component
Including 66 new countries
A4
•Newest available data
•173 coastal countries
•9 original indicators (but 2 scaled to population)
•Equal weighing of each indicator within each component
Including 22 new indicators
A5
•Newest available data
•173 coastal countries
•35 indicators (including 8 from previous assessment)
•Equal weighing of each indicators within each component
Accounting for redundancy
A6
•Newest available data
•173 coastal countries
•35 indicators (including 8 from previous assessment)
•Equal weighing for each group of redundant indicators within each component

Figure 3a-d

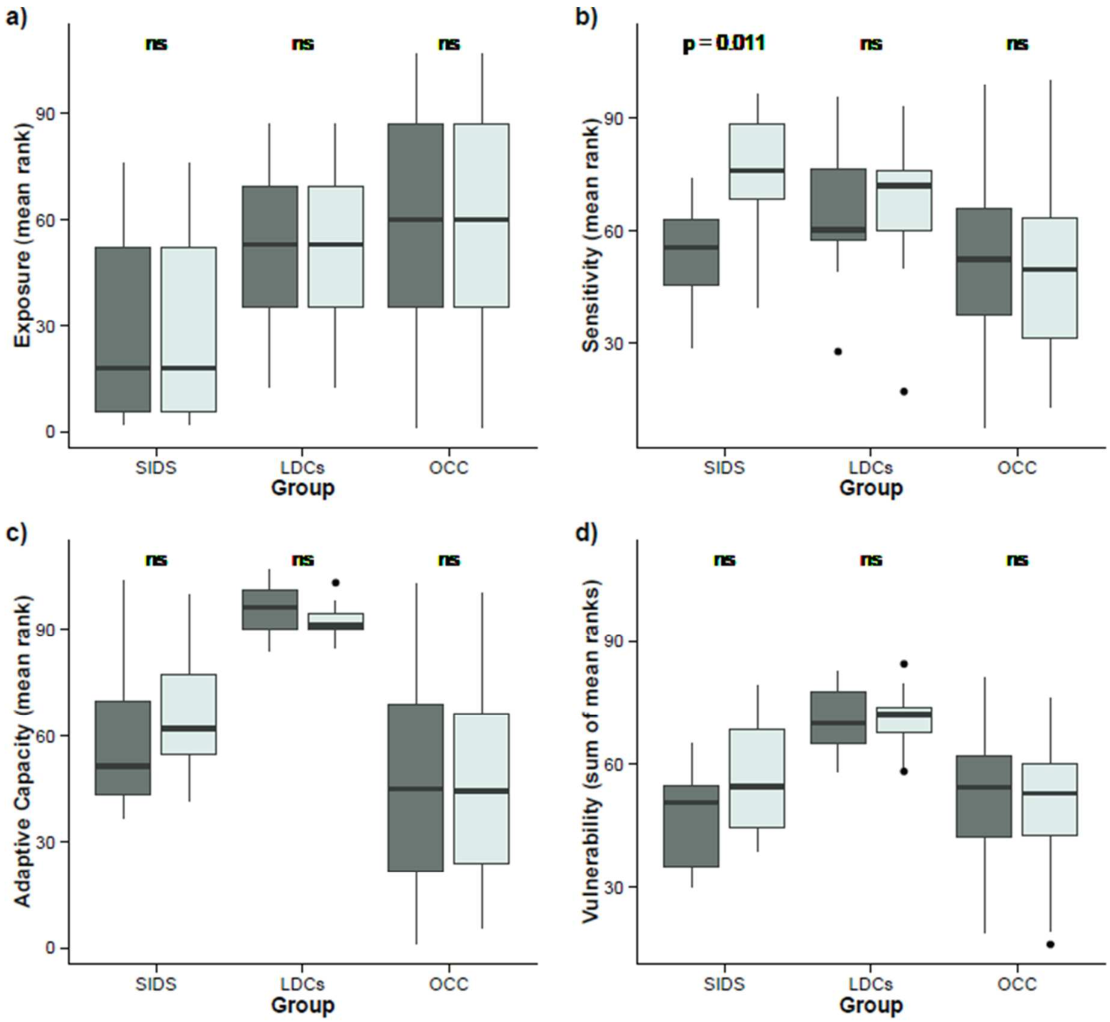

a)
ns
ns
ns
Exposure (mean rank)
0
30
60
90
SIDS
LDCs
OCC
Group
b)
p = 0.011
ns
ns
Sensitivity (mean rank)
30
60
90
SIDS
LDCs
OCC
Group
c)
ns
ns
ns
Adaptive Capacity (mean rank)
0
30
60
90
SIDS
LDCs
OCC
Group
d)
ns
ns
ns
Vulnerability (sum of mean ranks)
30
60
90
SIDS
LDCs
OCC
Group

Figure 4a-d

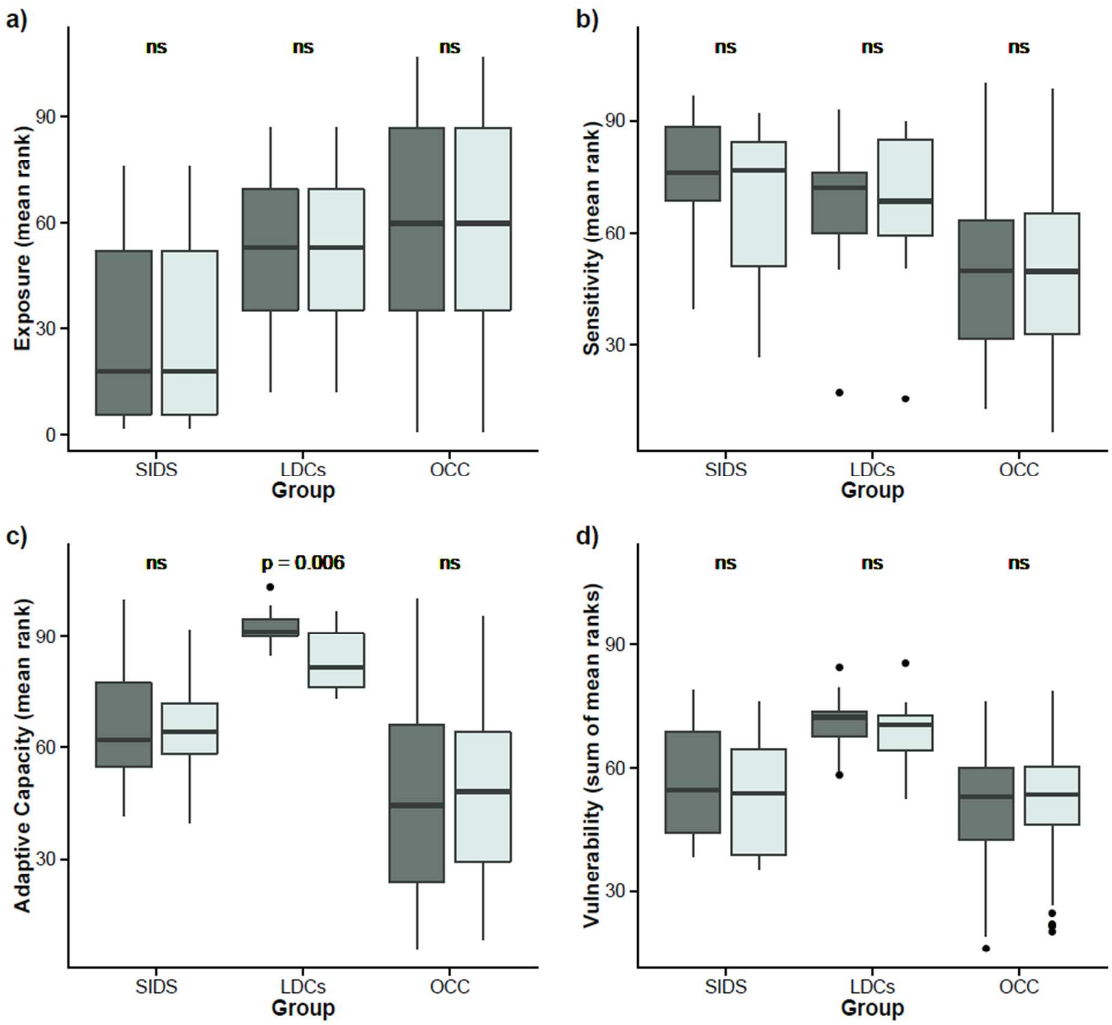

a)
ns
ns
ns
Exposure (mean rank)
0
30
60
90
SIDS
LDCs
OCC
Group
b)
ns
ns
ns
Sensitivity (mean rank)
30
60
90
SIDS
LDCs
OCC
Group
c)
ns
p = 0.006
ns
Adaptive Capacity (mean rank)
30
60
90
SIDS
LDCs
OCC
Group
d)
ns
ns
ns
Vulnerability (sum of mean ranks)
30
60
90
SIDS
LDCs
OCC
Group

Figure 5a-d

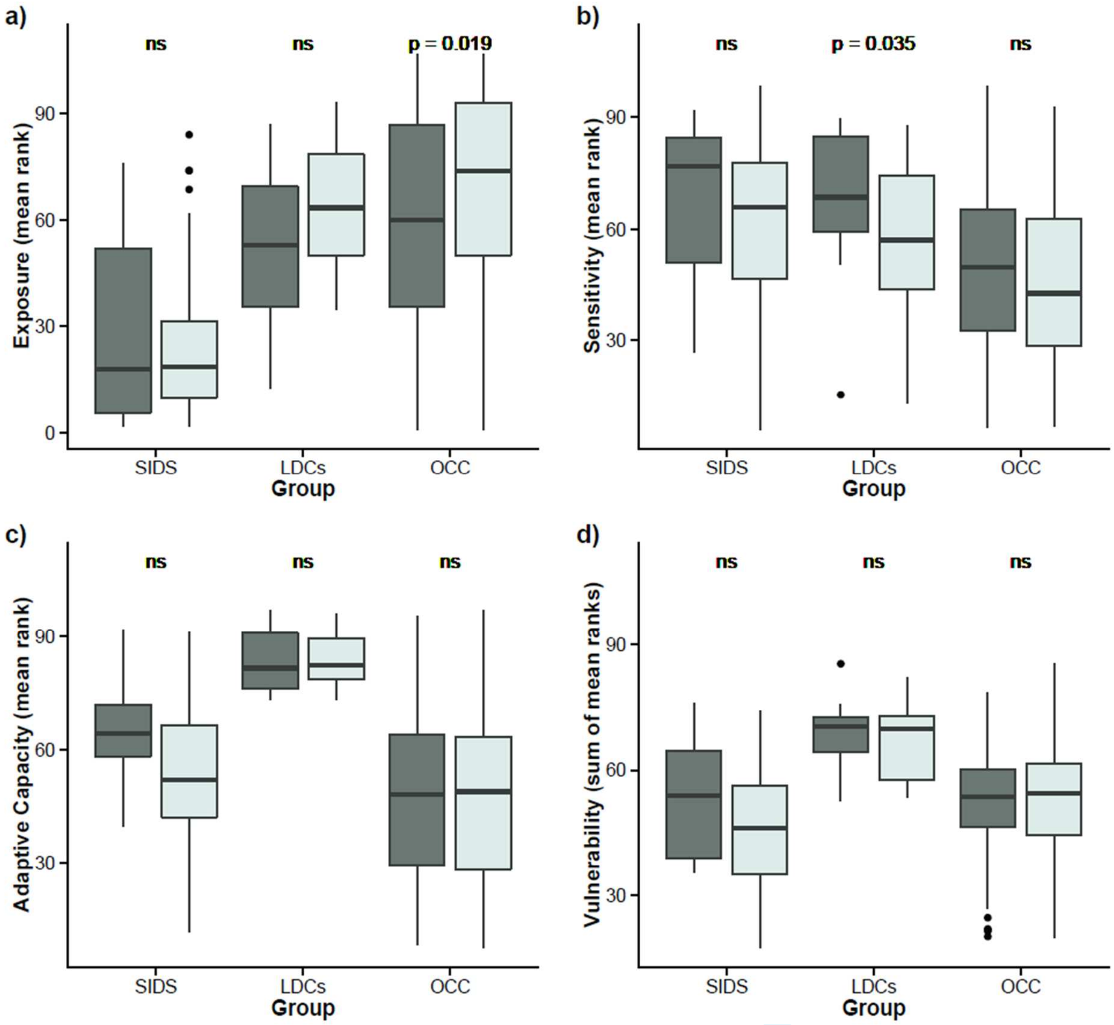

a)
ns
ns
p = 0.019
Exposure (mean rank)
0
30
60
90
SIDS
LDCs
OCC
Group
b)
ns
p = 0.035
ns
Sensitivity (mean rank)
30
60
90
SIDS
LDCs
OCC
Group
c)
ns
ns
ns
Adaptive Capacity (mean rank)
30
60
90
SIDS
LDCs
OCC
Group
d)
ns
ns
ns
Vulnerability (sum of mean ranks)
30
60
90
SIDS
LDCs
OCC
Group

Figure 6

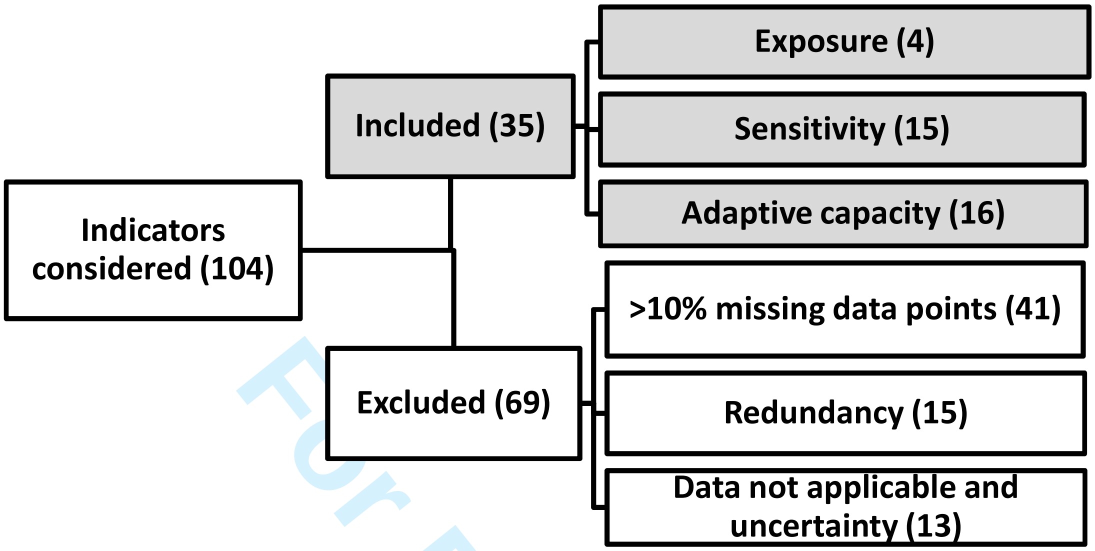

Indicators considered (104)
Included (35)
Excluded (69)
Exposure (4)
Sensitivity (15)
Adaptive capacity (16)
>10% missing data points (41)
Redundancy (15)
Data not applicable and uncertainty (13)

Figure 7a-d

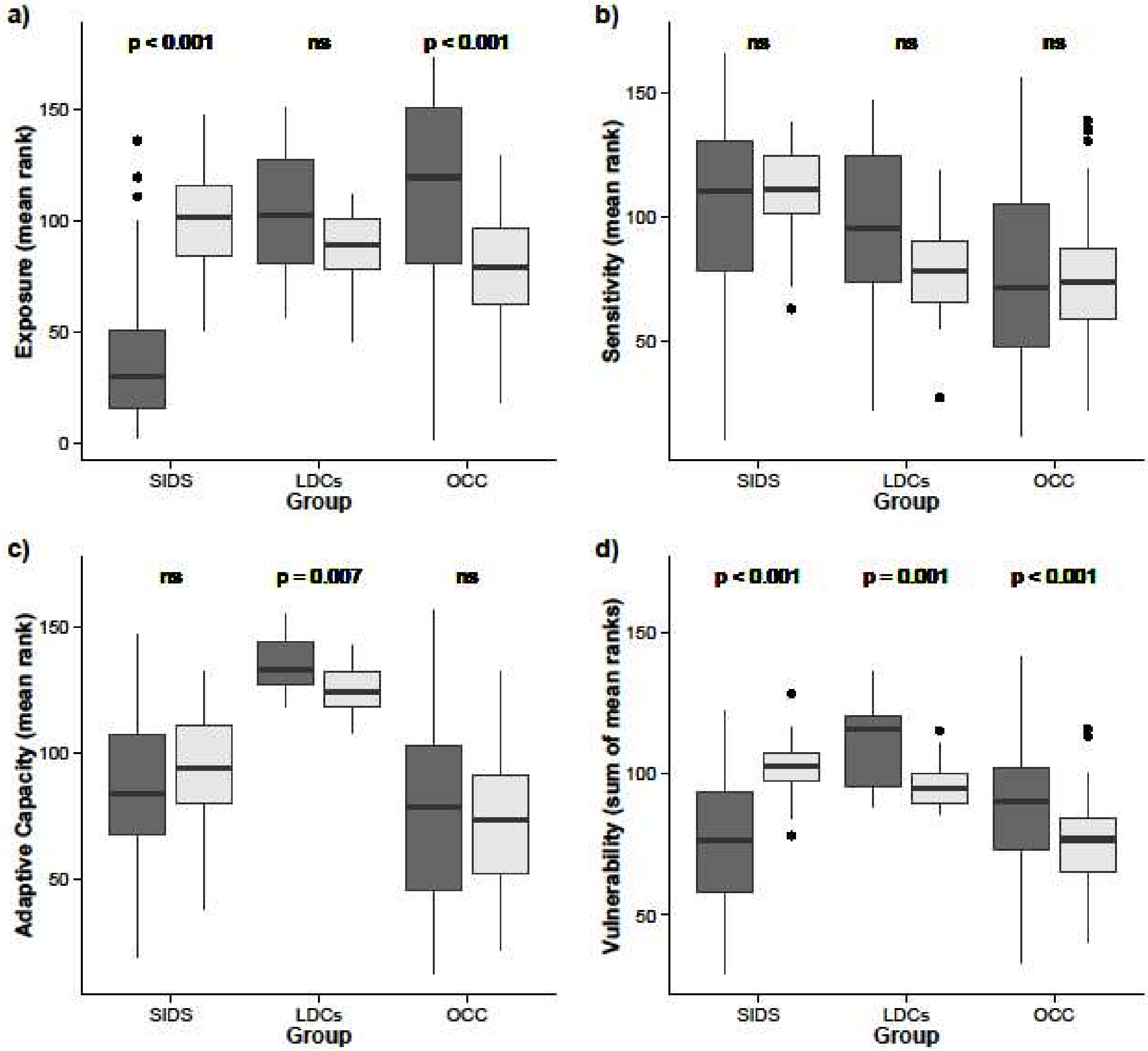

a)
p < 0.001
ns
p < 0.001
Exposure (mean rank)
0
50
100
150
SIDS
LDCs
OCC
Group
b)
ns
ns
ns
Sensitivity (mean rank)
50
100
150
SIDS
LDCs
OCC
Group
c)
ns
p = 0.007
ns
Adaptive Capacity (mean rank)
50
100
150
SIDS
LDCs
OCC
Group
d)
p < 0.001
p = 0.001
p < 0.001
Vulnerability (sum of mean ranks)
50
100
150
SIDS
LDCs
OCC
Group

Figure 8a-d

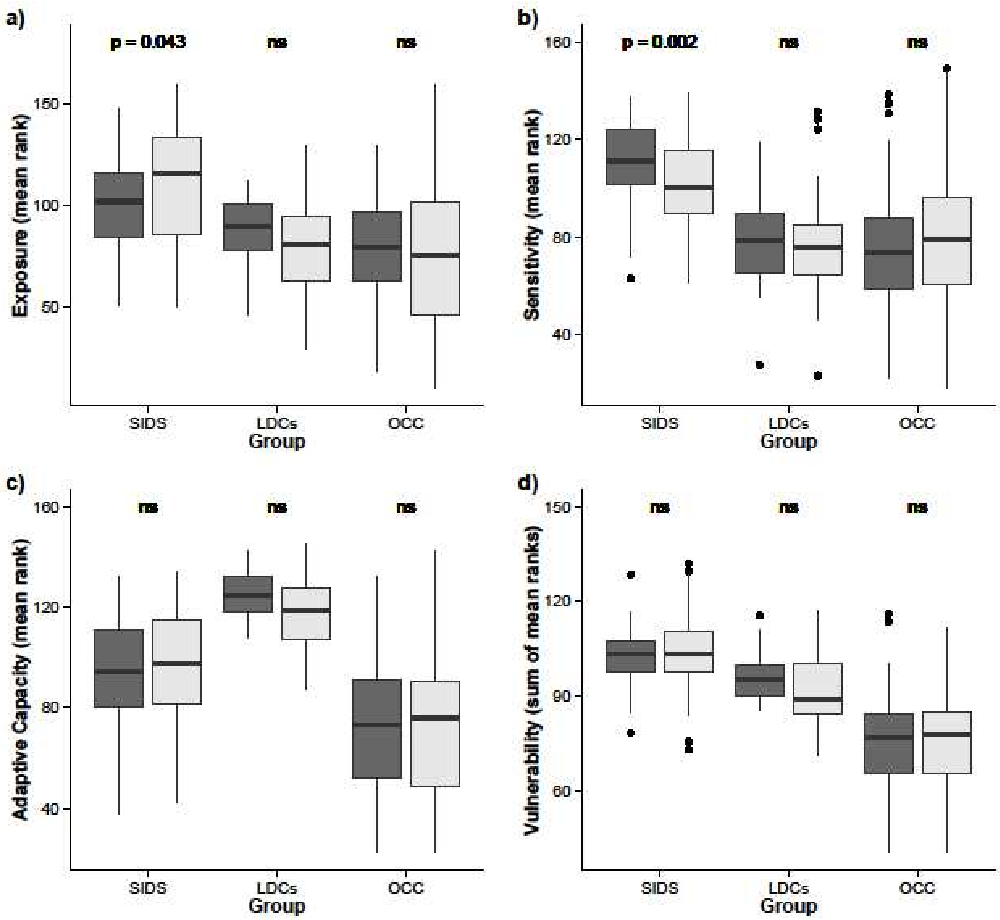

a)
p = 0.043
ns
ns
Exposure (mean rank)
150
100
50
SIDS
LDCs
OCC
Group
b)
p = 0.002
ns
ns
Sensitivity (mean rank)
160
120
80
40
SIDS
LDCs
OCC
Group
c)
ns
ns
ns
Adaptive Capacity (mean rank)
160
120
80
40
SIDS
LDCs
OCC
Group
d)
ns
ns
ns
Vulnerability (sum of mean ranks)
150
120
90
60
SIDS
LDCs
OCC
Group

Figure 9a-d

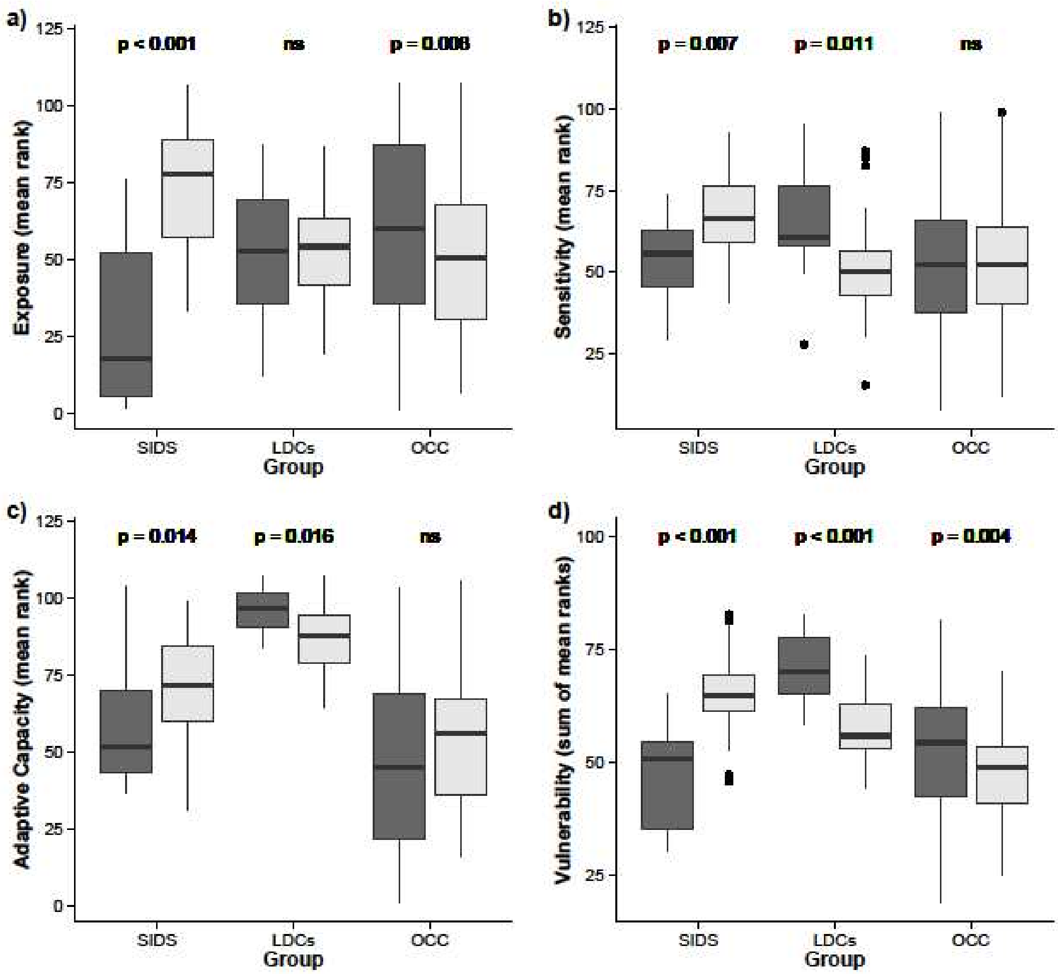
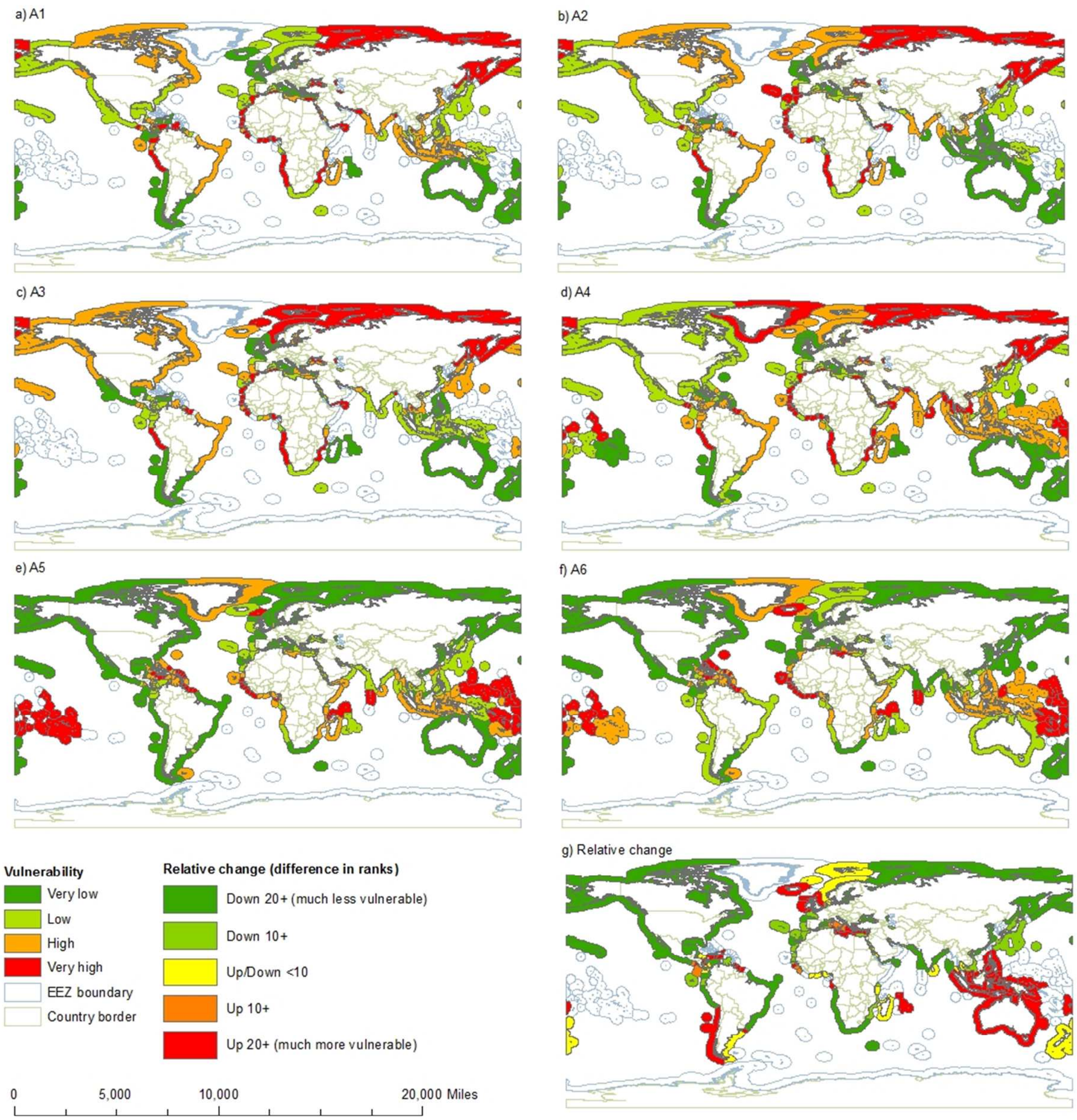

a)
p < 0.001
ns
p = 0.008
Exposure (mean rank)
125
100
75
50
25
0
SIDS
LDCs
OCC
Group
b)
p = 0.007
p = 0.011
ns
Sensitivity (mean rank)
125
100
75
50
25
SIDS
LDCs
OCC
Group
c)
p = 0.014
p = 0.016
ns
Adaptive Capacity (mean rank)
125
100
75
50
25
0
SIDS
LDCs
OCC
Group
d)
p < 0.001
p < 0.001
p = 0.004
Vulnerability (sum of mean ranks)
100
75
50
25
SIDS
LDCs
OCC
Group

Fig. 10a-g


a) A1
b) A2
c) A3
d) A4
e) A5
f) A6
g) Relative change
Vulnerability
Very low
Low
High
Very high
EEZ boundary
Country border
Relative change (difference in ranks)
Down 20+ (much less vulnerable)
Down 10+
Up/Down <10
Up 10+
Up 20+ (much more vulnerable)
0
5,000
10,000
20,000 Miles

Supplementary information: Vulnerability assessment methodology Monnereau et al.

Table 1: Countries per country group included for assessments A1-A3 and A4-A6 respectively

Countries	SIDS	LDCs	Other coastal countries	Other coastal countries
A1-A3	Belize Dominican Rep Fiji Guinea-Bissau Guyana Haiti Jamaica Mauritius Papua New Guinea Suriname Trinidad and Tobago	Angola Bangladesh Cambodia Congo, Dem Rep Gambia Guinea Madagascar Mauritania Mozambique Senegal Sierra Leone Sudan Tanzania, United Rep Togo Yemen	Albania Algeria Argentina Australia Belgium Bosnia and herzegovina Brazil Bulgaria Cameroon Canada Chile China Colombia Congo Costa Rica Croatia Cyprus Côte d'Ivoire Denmark Ecuador Egypt El Salvador Estonia Finland France Gabon Georgia Germany Ghana Greece Guatemala Honduras Iceland India Indonesia Iran, Islamic Rep Ireland Israel Italy	Jordan Kenya Kuwait Latvia Lebanon Libya Lithuania Malaysia Malta Mexico Morocco Namibia Netherlands New Zealand Nicaragua Nigeria Norway Pakistan Panama Peru Philippines Poland Portugal Romania Russian Federation Saudi Arabia Slovenia South Africa Spain Sri Lanka Sweden Syrian Arab Rep Thailand Tunisia Turkey Ukraine United Kingdom United States Uruguay Venezuela

Countries	SIDS	LDCs	Other coastal countries	Other coastal countries
			Japan	Vietnam
A4-A6	Anguilla Antigua and Barbuda Aruba Bahamas Bahrain Barbados Belize Bermuda British Virgin Islands Cape Verde Cayman Islands Comoros Cook Islands Cuba Dominica Dominican Republic Fiji French Guiana French Polynesia Grenada Guadeloupe Guam Guinea-Bissau Guyana Haiti Jamaica Kiribati Maldives Marshall Islands Martinique Mauritius Micronesia, Fed.States of Montserrat Nauru Netherlands Antilles New Caledonia Niue Palau Papua New Guinea Puerto Rico Réunion Saint Kitts and Nevis	Angola Bangladesh Benin Cambodia Congo, Dem Rep Djibouti Equatorial Guinea Eritrea Gambia Guinea Liberia Madagascar Mauritania Mozambique Myanmar Senegal Sierra Leone Somalia Sudan Tanzania, United Rep Togo Yemen	Albania Algeria Argentina Australia Belgium Bosnia and Herzegovina Brazil Brunei Darussalam Bulgaria Cameroon Canada Chile China China, Hong Kong Colombia Congo Costa Rica Côte d'Ivoire Croatia Cyprus Denmark Ecuador Egypt El Salvador Estonia Faeroe Islands Falkland Is.(Malvinas) Finland France Gabon Georgia Germany Ghana Greece Greenland Guatemala Honduras Iceland India Indonesia Iran, Islamic Rep	Japan Jordan Kenya Korea, Dem People's Rep Korea, Rep Kuwait Latvia Lebanon Libya Lithuania Malaysia Malta Mexico Morocco Namibia Netherlands, The New Zealand Nicaragua Nigeria Norway Oman Pakistan Panama Peru Philippines Poland Portugal Qatar Romania Russian Federation Saudi Arabia Slovenia South Africa Spain Sri Lanka Sweden Syrian Arab Rep Taiwan Thailand Tunisia Turkey

Countries	SIDS	LDCs	Other coastal countries	Other coastal countries
	Saint Lucia Saint Vincent/Grenadines Samoa Sao Tome and Principe Seychelles Singapore Solomon Islands Suriname Timor-Leste Tokelau Tonga Trinidad and Tobago Turks and Caicos Islands Tuvalu US Virgin Islands Vanuatu		Iraq Ireland Israel Italy	Ukraine United Arab Emirates United Kingdom United States Uruguay Venezuela Vietnam

Table 2: Indicators characteristics for indicators used in the global assessment A5 and A6
*Indicators are reversed so that highest score indicates highest vulnerability

Component	**Indicator**	**Source of data and year**	**Relevance**
Exposure	Sea Surface Temperature observed 1985-2005	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Poleward shifts in plankton and fished species; changes in timing of phytoplankton blooms; changing zooplankton composition; changes in fish distribution
Exposure	Sea level Rise projections (SLR) 2050 (RCP 4.5)	Data supplied by Hinkel et al. (2014)	Sea level rise results in coastal inundation and habitat loss. Storm surges and coastal flooding can lead to death, injury, ill-health or disrupted livelihoods in low-lying coastal zones. Increased storm frequency and intensity may also imply more days at sea lost to unfavourable weather and increased risk of accidents and decrease of safety at sea for fishers (Daw Adger and Brown 2009; Mahon 2002). High flood risks affect the fishing infrastructure, e.g. landing and market sites, boats, processing plants in these areas. SLR will also alter fisheries habitats, such as seagrasses, mangroves and salt marshes (Morris et al. 2002).
Exposure	Ocean acidification 1870-2000	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Ocean acidification results in reduced growth and survival of commercially valuable shellfish and other calcifiers, e.g. reef building corals and calcareous red algae (Burkett et al. 2014).
Exposure	UV radiation observed 1996-2004	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Recent results continue to support the general consensus that ozone-related increases in UV-B radiation can negatively influence many aquatic species and aquatic ecosystems (Häder et al. 2007). Solar UV radiation penetrates to ecologically significant depths in aquatic systems and can affect both marine and freshwater systems from major biomass producers (phytoplankton) to consumers (e.g., zooplankton, fish, etc.) higher in the food web (Häder et al. 2007).

Component	Indicator	Source of data and year	Relevance
Sensitivity	Percentage of population living on land below 5 m above sea level	CIESIN 2010 http://sedac.ciesin.columbia.edu/data/collection/gpw-v3	Threats from sea level rise, floods and storms are higher if large cities (or the majority of all cities), ports and airports are located in coastal zone, and where coastal population pressure is high. Increased risk of flooding of houses and infrastructure will impact the lives of fishers, fishing communities and related industries when the majority of people live only a few meters above sea level. These high flood risks also affect the fishing infrastructure in these areas such as e.g. landing sites, boats, processing plants.
Sensitivity	Percentage of population 10 km from the coast	CIESIN 2010	Countries that do not have a large area of land or population in 5 meters above sealevel but have a large population and land within first 10 km of the coastline are also extremely vulnerable in their coastal zone in case of flooding, damages due to extreme evens etc. These high flood risks also affect the fishing infrastructure in these areas such as e.g. landing sites, boats, processing plants.
Sensitivity	Coastal land below 5m as percentage of total landarea	CIESIN 2010	Threats from sea level rise, floods and storms are higher if large part of the land are located in land area within 5 meters above sea level. If a country is small and a large percentage of their land is within 5 meters below sea level this will make it extremely vulnerable.
Sensitivity	Percentage of land 10 km from coastline as percentage of total landarea	CIESIN 2010	Threats from sea level rise, floods and storms are higher if large part of the land are located in land area within 10 km from the coast. If a country is small and a large percentage of their land is within 10 km from the coast this will make it extremely vulnerable.

Component	Indicator	Source of data and year	Relevance
Sensitivity	Cities in low lying coastal zone	McGranahan, Balk and Anderson (2007)	Countries are seeing increasing rates of urbanization. Cities are crucial for housing, employment and public and private services. Cities located in the low lying coastal zone are more prone to threats from sea level rise, floods and storms.
Sensitivity	Population largest city (%)	World Bank. World Development Indicators (2009) World Bank, World Development Indicators http://data.worldbank.org/products/data-books/WDI-2009	Countries where a large part of the population, infrastructure, governing and financial institutions are located in one city are more vulnerable than countries where this is more spread out.
Sensitivity	Biodiversity*	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Healthy biodiversity is crucial in ecosystem health
Sensitivity	Habitat*	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Habitats evaluates the condition of key habitats that support high number of species
Sensitivity	Species*	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Species evaluates the conservation status of marine species
Sensitivity	Exploitation stat us of fished stoc k*	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Climate change impacts on a fishery will be less severe if a fishery is sustainably harvested. A healthy fishery will be less vulnerable and more resilient to climate change impacts
Sensitivity	Fisheries employment	Monnereau et al. (2013)	Countries with higher contributions of fisheries to employment are more likely to be impacted (positively or negatively) by warming-related changes in the whole fishery productions systems of that nation (Allison et al. 2009)

Component	**Indicator**	**Source of data and year**	**Relevance**
Sensitivity	Fisheries exports	FAO (2009) http://www.fao.org/fishery/statistics/collections/en	Countries with higher contributions of fisheries to export income, and thus deliver foreign exchange to a nation, are more likely to be impacted (positively or negatively) by warming-related changes in the whole fishery productions systems of that nation.
Sensitivity	Fish catch	FAO (2010) http://www.fao.org/fishery/statistics/collections/en	Fish catches contribute to employment and food security. Countries with higher fish catches are more likely to be impacted (positively or negatively) by warming-related changes in the whole fishery productions systems of that nation.
Sensitivity	Fish nutrition	FAO (2005-2009) http://www.fao.org/fishery/statistics/collections/en	Nutritional dependency identifies countries reliant on fish as a primary source of animal protein. This is expressed by fish protein as the percentage of all animal protein per capita per day in grams. This assumes that countries with higher dietary protein of fish are more likely to be impacted (positively or negatively) by warming-related changes.
Sensitivity	Coastal Livelihoods and Economies	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	People rely on the ocean to provide livelihoods and stable economies for coastal communities. The jobs and revenue produced from marine-related industries directly benefit those who are employed, but also have substantial indirect value for community identity, tax revenue, and other related economic and social aspects of a stable coastal economy.

Component	Indicator	Source of data and year	Relevance
Ad. capacity	Healthy life expectancy*	United Nations Healthy Life Expectancy (2007) http://data.un.org/	Life expectancy provides a useful indicator of the overall health effects of environmental and other risk factors in a given population according to the World Health Organization. The link between health and climate protection is one of opportunity cost. Countries with significant public health problems are likely to find it socially and politically difficult to allocate resources to climate protection.
Ad. capacity	Health: access to sanitation*	Worldbank (2009-2011) http://data.worldbank.org/indicator/SH.STA.ACSN	Access to basic sanitation includes safety and privacy in the use of these services. Coverage is the proportion of people using improved sanitation facilities. Countries with significant public health problems are likely to find it socially and politically difficult to allocate resources to climate protection.
Ad. capacity	Health: infant mortality*	World Health Organisation (2010-2015) http://www.who.int/gho/child_health/mortality/neonatal_infant_text/en/	Infant mortality rate (IMR) is the number of deaths of children less than one year of age per 1000 live births. Countries with significant public health problems are likely to find it socially and politically difficult to allocate resources to climate protection.
Ad. capacity	Education*	CIA factbook (2000-2010) https://www.cia.gov/library/publications/the-world-factbook/	Countries with higher levels of education are likely to have higher adaptive capacity. Low levels of literacy, and education in general, can impede the economic development of a country in the current rapidly changing technology-driven world. Higher education signifies more skilled staff to undertake important functions related to climate protection, including skills for implementing adaptation programs, information management systems, and an array of other activities.

Component	Indicator	Source of data and year	Relevance
Ad. capacity	Woldwide Governance*	Worldbank (2011) http://data.worldbank.org/data-catalog/worldwide-governance-indicators	The level of governance is relevant to the adaptive capacity of a country. Countries with a higher level of governance are likely to have a higher level of adaptive capacity. Lower levels can impede the effectiveness of dealing with climate change.
Ad. capacity	Fisheries management capacity	Mora et al. (2009)	Marine governance (fisheries management capacity), marine protected areas (MPAs) and marine resilience are important as successful fisheries management and MPAs have the potential to increase ecosystem resilience. Countries with a higher level of fisheries management capacity are likely to have higher adaptive capacity. Lower levels can impede the effectiveness of dealing with climate change.
Ad. capacity	Fisheries management capacity: Marine Protected Areas*	Environment Performance Index (2012) http://epi.yale.edu/	MPAs are considered a tool for fisheries management and increase fisheries productivity. Higher levels of MPAs (area % of EEZ) can be considered to make fisheries less vulnerable to climate change
Ad. capacity	EEZ by coastline	Coastline Hinrichsen (2011) EEZ data from www.seaaroundus.org	A larger EEZ to coastline implies a larger area a country needs to manage which can impede effectiveness of management. A smaller EEZ/coast ration implies a smaller area to manage which could result in more effective management. More effective fisheries management (high levels of Monitoring, Control and Surveillance, lower levels of Illegal Unreported and Unregulated fishing) will enhance resilience of the fishery.
Ad. capacity (170)	Resilience Marine livelihood*	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Resilience of a fishery is important in adaptive capacity as a more resilient fishery is expected to be less vulnerable to climate change impacts.

Component	**Indicator**	**Source of data and year**	**Relevance**
Ad. capacity (170)	Resilience Wildfish caught*	Halpern et al. (2012) original 2012 global data; updated in Halpern et al. 2015	Climate change impacts on a fishery will be less severe if a fishery is sustainably harvested. A healthy fishery will be less vulnerable and more resilient to climate change impacts
Ad. capacity (173)	Gross Domestic Product per capita*	Worldbank (2011) http://data.worldbank.org/indicator/NY.GDP.PCAP.CD	Higher levels of economic power by residents and the country as a whole will enforce the adaptive capacity of the nation in the face of impacts of climate change. GDP per capita (ppp) is not a specific indicator of coastal protection or exposure. However, in the absence of more specific information it has been used as a proxy for coastal protection levels in other global studies of coastal vulnerability to sea-level rise (Hinkel 2008).
Ad. capacity (168)	Nigh Light Development Index (NLDI)*	Elvidge et al. (2012)	Economic vulnerability is important as countries with lower economic vulnerability can be expected to have a higher adaptive capacity. NLDI is considered a measure of economic development.
Ad. capacity (161)	Terms of trade*	UNCTAD (2010-2011) http://unctad.org/en/Pages/Statistics.aspx	Economic vulnerability is important as countries with lower economic vulnerability can be expected to have a higher adaptive capacity.
Ad. capacity (166)	Concentration of exports	UNCTAD (2013) http://unctadstat.unctad.org/wds/TableViewer/tableView.aspx?ReportId=120	Economic vulnerability is important as countries with lower economic vulnerability can be expected to have a higher adaptive capacity. The concentration index shows how exports and imports of individual countries or group of countries are concentrated on several products or otherwise distributed in a more homogeneous manner among a series of products.

Component	Indicator	Source of data and year	Relevance
Ad. capacity (166)	Diversification of exports	UNCTAD (2013)	Economic vulnerability is important as countries with lower economic vulnerability can be expected to have a higher adaptive capacity. The diversification index signals whether the structure of exports or imports by product of a given country or group of countries differ from the structure of product of the world.
Ad. capacity	Agriculture as % of GDP	World Bank data (2010) http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS Missing data: CIA factbook https://www.cia.gov/index.html	Economic vulnerability is important as countries with lower economic vulnerability can be expected to have a higher adaptive capacity. Higher levels of agricultural production can be associated with lower levels of adaptive capacity.

References

Allison, E. H., Perry, A. L., Badjeck, M.-C., Adger, N. W., Brown, K., Conway, D., Dulvy, N. K. (2009) Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries 10* (2), 173–196.

Burkett, V.R., Suarez, A.G. Bindi, M., et al. (2014) Point of departure. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. C.B. Field, V.R. Barros, D.J. Dokken, et al. eds. Cambridge University Press, Cambridge, pp. 169-194.

Häder, D.-P., Kumar, H. D., Smith, R. C., and Worrest, R. C. (2007) Effects of solar UV radiation on aquatic ecosystems and interactions with climate change. *Photochemical & Photobiological Sciences : Official Journal of the European Photochemistry Association and the European Society for Photobiology* 6(3), 267–85.

Halpern, B., Longo, C., Hardy, D. et al. (2012) An index to assess the health and benefits of the global ocean. *Nature* 488, 615–620.

Halpern, B., Longo, C., Stewart Lowndes, J. et al. (2015) Patterns and Emerging Trends in Global Ocean Health. *Public Library of Science ONE* 10(3): e0117863. doi:10.1371/journal.pone.0117863

Hinkel, J., Linckea, D., Vafeidis, A. et al. (2014) Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences of the United States of America* 11 (9), 3292–3297.

Hinrichsen, D. (2011). The Atlas of Coasts and Oceans: Ecosystems, Threatened Resources, Marine Conservation. University of Chicago Press, Chicago, 124 pp.

Daw, T., Adger, W. N., and Brown, K. (2009) Climate change and capture fisheries: potential impacts, adaptation and mitigation. In: *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*. K. Cochrane, C. De Young, D. Soto, and T. Bahri eds. *FAO Fisheries and Aquaculture Technical paper* No. 530, Rome, pp. 107–153.

Elvidge, C.D, Baugh, K.E., Anderson, S.J. Sutton , P.C., and Ghosh, T. (2012) The Night Light Development Index (NLDI): a spatially explicit measure of human development from satellite data. *Social Geography (*7), 23–35.

Mahon, R. (2002) *Adaptation of Fisheries and Fishing Communities to the Impacts of Climate Change in the CARICOM Region.* Mainstreaming Adaptation to Climate Change (MACC) of the Caribbean Center for Climate Change (CCCC), Organization of American States, Washington, D. C., 33 pp.

McGranahan, G., Balk, D., and Anderson, B. (2007) The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization* 19(1), 17-37.

Mora, C., Myers, R., Coll, M., Libralato, S., Pitcher, T., Sumaila. R., Zeller, D., Watson, R., Gaston, K., Worm, B. (2009) Management Effectiveness of the World's Marine Fisheries. *PLoS Biology* 7(6): e1000131 doi:10.1371/journal.pbio.1000131

Monnereau, I., R. Mahon, P. McConney and L. Nurse. (2013) Vulnerability of the fisheries sector to climate change impacts in Small Island Developing States and the Wider Caribbean: early findings. Barbados. *CERMES Technical Report* No. 56*,* 45 pp.

Morris, J. T., Sundareshwar, P. V., Nietch, C. T., Kjerfve, B., & Cahoon, D. R. (2002). Responses of coastal wetlands to rising sea level. *Ecology 83*(10), 2869–2877.

Table 3: Significance

Table 3A: Results of Kruskal-Wallis tests exploring statistically significant differences in scores for vulnerability components within each country group [Small Island Developing States (SIDS), Least Developed Countries (LDCs), Other Coastal Countries(OCC)] between each pair of sequential assessments (e.g. A1-A2 shows differences in scores between assessments one and two for a given country group). Bold p values indicate a statistically significant difference at α=0.05. d.f. = degrees of freedom.

Comparison of assessments	Country group	Vulnerability component Kruskal-Wallis tests (d.f.=1)							
		Exposure		Sensitivity		Adaptive capacity		Vulnerability	
		χ^2	p	χ^2	p	χ^2	p	χ^2	p
A1-A2	SIDS	0.000	1.000	6.391	**0.011**	1.998	0.158	3.028	0.082
	LDC	0.000	1.000	0.314	0.575	2.170	0.141	0.000	0.983
	OCC	0.000	1.000	0.950	0.330	0.010	0.920	0.516	0.472
A2-A3	SIDS	0.000	1.000	0.389	0.533	0.010	0.921	0.674	0.412
	LDC	0.000	1.000	0.062	0.803	7.391	**0.006**	0.654	0.419
	OCC	0.000	1.000	0.034	0.853	0.433	0.510	0.104	0.746
A3-A4	SIDS	0.316	0.574	0.452	0.502	3.192	0.074	1.635	0.201
	LDC	2.800	0.094	4.425	**0.035**	0.310	0.577	0.009	0.926
	OCC	5.479	**0.019**	2.591	0.108	0.000	0.996	0.427	0.514
A4-A5	SIDS	63.284	**<0.001**	0.535	0.464	3.280	0.070	45.752	**<0.001**
	LDC	3.757	0.053	2.778	0.096	7.289	**0.007**	10.341	**0.001**
	OCC	35.080	**<0.001**	0.130	0.718	0.250	0.617	23.281	**<0.001**
A5-A6	SIDS	4.096	**0.043**	9.976	**0.002**	0.913	0.339	0.181	0.671
	LDC	1.406	0.236	0.020	0.888	2.548	0.110	3.796	0.051
	OCC	0.547	0.460	3.135	0.077	0.041	0.840	0.329	0.566

Table 3B: Results of Kruskal-Wallis tests exploring statistically significant differences in scores among country groups (Small Island Developing States (SIDS) vs Least Developed Countries (LDCs) vs Other Coastal Countries(OCC)) for each assessment (A1 to A6) and component (exposure, sensitivity, adaptive capacity, and vulnerability). Pairwise comparisons between country groups show results of Wilcoxon rank sum tests with Bonferroni correction applied. Bold p values indicate a statistically significant difference at α=0.05. d.f. = degrees of freedom.

Assessment	Vulnerability component	Kruskal-Wallis test d.f.=2		Pairwise comparison of country groups		
				LDC-Other	SIDS-LDC	SIDS-Other
		χ^2	p	p	p	p
A1	Exposure	9.040	**0.011**	1.000	0.071	**0.011**
	Sensitivity	5.030	0.081	-------	-------	-------
	Adapt. capacity	34.263	**<0.001**	**<0.001**	**0.005**	0.421
	Vulnerability	24.609	**<0.001**	**<0.001**	**<0.001**	0.759
A2	Exposure	9.040	**0.011**	1.000	0.071	**0.011**
	Sensitivity	21.193	**<0.001**	**0.002**	0.898	**0.002**
	Adapt. capacity	36.507	**<0.001**	**<0.001**	**0.021**	**0.040**
	Vulnerability	26.002	**<0.001**	**<0.001**	**0.024**	1.000
A3	Exposure	9.040	**0.011**	1.000	0.071	**0.011**
	Sensitivity	11.853	**0.003**	**0.008**	1.000	0.115
	Adapt. capacity	32.492	**<0.001**	**<0.001**	**0.005**	**0.050**
	Vulnerability	17.368	**<0.001**	**0.001**	**0.033**	1.000
A4	Exposure	76.844	**<0.001**	0.670	**<0.001**	**<0.001**
	Sensitivity	21.373	**<0.001**	0.110	0.520	**<0.001**
	Adapt. capacity	46.615	**<0.001**	**<0.001**	**<0.001**	0.270
	Vulnerability	34.979	**<0.001**	**<0.001**	**<0.001**	**0.009**
A5	Exposure	31.394	**<0.001**	0.371	**0.019**	**<0.001**
	Sensitivity	70.106	**<0.001**	1.000	**<0.001**	**<0.001**
	Adapt. capacity	64.583	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Vulnerability	100.337	**<0.001**	**<0.001**	**0.013**	**<0.001**
A6	Exposure	38.263	**<0.001**	1.000	**<0.001**	**<0.001**
	Sensitivity	28.431	**<0.001**	1.000	**<0.001**	**<0.001**
	Adapt. capacity	58.273	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Vulnerability	86.555	**<0.001**	**<0.001**	**0.001**	**<0.001**