

## Chapter 5: Changing Ocean, Marine Ecosystems, and Dependent Communities Supplementary Material

**Coordinating Lead Authors:** Nathaniel L. Bindoff (Australia), William W. L. Cheung (Canada), James G. Kairo (Kenya)

**Lead Authors:** Javier Arístegui (Spain), Valeria A. Guinder (Argentina), Robert Hallberg (USA), Nathalie Hilmi (Monaco/France), Nianzhi Jiao (China), Md saiful Karim (Australia), Lisa Levin (USA), Sean O'Donoghue (South Africa), Sara R. Purca Cuicapusa (Peru), Baruch Rinkevich (Israel), Toshio Suga (Japan), Alessandro Tagliabue (United Kingdom), Phillip Williamson (United Kingdom)

**Contributing Authors:** Sevil Acar (Turkey), Juan Jose Alava (Ecuador/Canada), Eddie Allison (United Kingdom), Brian Arbic (USA), Tamatoa Bambridge (French Polynesia), Inka Bartsch (Germany), Laurent Bopp (France), Philip W. Boyd (Australia/ United Kingdom ), Thomas Browning (Germany/United Kingdom), Francisco P. Chávez (USA), Mine Cinar (USA), Daniel Costa (USA), Lijing Cheng (China), Omar Defeo (Uruguay), Salpie Djoundourian (Lebanon), Catia Domingues (Australia), Tyler Eddy (Canada), Sonja Endres (Germany), Alan Fox (UK), Christopher Free (USA), Thomas Frölicher (Switzerland), Jean-Pierre Gattuso (France), Gemma Gerber (South Africa), Charles Greene (USA), Nicolas Gruber (Switzerland), Gustaav Hallegraef (Australia), Matthew Harrison (USA), Sebastian Hennige (UK), Mark Hindell (Australia), Andrew Hogg (Australia), Taka Ito (USA), Tiff-Annie Kenny (Canada), Kristy Kroeker (USA), Lester Kwiatkowski (France/UK), Vicky Lam (China/Canada), Philippe LeBillon (Canada), Nadine Le Bris (France), Heike Lotze (Canada), Jennifer MacKinnon (USA), Annick de Marffy-Mantuano (Monaco), Patrick Martell (South Africa), Nadine Marshall (Australia), Kathleen McInnes (Australia), Jose Garcia Molinos (Japan/Spain), Serena Moseman-Valtierra (USA), Andries Motau (South Africa), Sandor Mulsow (Brazil), Kana Mutombo (South Africa), Andreas Oschlies (Germany), Muhammed Oyinlola (Nigeria), Elvira S. Poloczanska (Australia), Nicolas Pascal (France), Maxime Philip (France), Sarah Purkey (USA), Saurabh Rathore (India), Xavier Rebelo (South Africa), Gabriel Reygondeau (France), Jake Rice (Canada), Anthony Richardson (Australia), Ulf Riebesell (Germany), Christopher Roach (Australia), Joacim Rocklöv (Sweden), Murray Roberts (United Kingdom ), Alain Safa (France), Sunke Schmidt (Germany), Gerald Singh (Canada), Bernadette Sloyan (Australia), Karinna von Schuckmann (France), Manal Shehabi (England), Matthew Smith (USA), Amy Shurety (South Africa), Fernando Tuya (Spain), Cristian Vargas (Chile), Colette Wabnitz (France), Caitlin Whalen (USA)

**Review Editors:** Manuel Barange (South Africa), Brad Seibel (USA)

**Chapter Scientist:** Axel Durand (Australia)

**Date of Draft:** 14 June 2019

**Notes:** TSU Compiled Version

---

### Table of Contents

|                   |  |            |
|-------------------|--|------------|
| <b>SM5.1</b>      | <b>Ocean Heat Content .....</b>  | <b>2</b>   |
| <b>SM5.2</b>      | <b>Risk Assessment of Open Ocean Ecosystems in Support of Section 5.2.5 .....</b>        | <b>11</b>  |
| <b>SM5.3</b>      | <b>Risk Assessment of Coastal Ecosystems .....</b>                                       | <b>18</b>  |
| <b>SM5.4</b>      | <b>Additional Information Relating to ‘Ocean Solutions’ in Section 5.5.1.1 .....</b>     | <b>24</b>  |
| <b>SM5.5</b>      | <b>Supplementary Information Supporting Table 5.7.....</b>                               | <b>26</b>  |
| <b>SM5.6</b>      | <b>Supplementary Information Supporting Table 5.8.....</b>                               | <b>47</b>  |
| <b>SM5.7</b>      | <b>Observed Changes in the Ocean and Related Impacts in Support of Figure 5.24 .....</b> | <b>93</b>  |
| <b>References</b> | <b>.....</b>   | <b>100</b> |

## SM5.1 Ocean Heat Content

The assessed rate of increase in ocean heat content is given in Section 5.2.2 (Table 5.1). The table below (Table SM5.1) is the supplementary information to support the new observational assessment in the two depth layers 0-700 m and 700-2000 m and their *very likely* ranges. Fluxes in  $\text{W m}^{-2}$  are averaged over the Earth's entire surface area. The four periods cover earlier and more recent trends; the 2005-2017 period has the most complete interior ocean data coverage and the greatest consistency between estimates, while longer trends are better for distinguishing between forced changes and internal variability. These observationally-estimated rates come from an assessment of the recent research.

Section 5.2.2 (Table 5.1) also has estimates of the spread of the ocean heat content change for the same periods as the observational assessments and the background for that part of Table 5.1 is in the second table below (Table SM5.2). The CMIP5 ESM estimates are based on a combined 28-member ensemble of historical, RCP2.6 and RCP8.5 simulations.

**Table SM5.1:** NaN means missing value, in effect the depth layer is unavailable for this ocean heat content product. The data sets are drawn from range of websites or other sources and are estimates of ocean heat uptake that have been updated from published methods. The references are from (Palmer et al., 2007; Domingues et al., 2008; Roemmich and Gilson, 2009; Hosoda et al., 2010; Levitus et al., 2012; Lyman and Johnson, 2014; Von Schuckmann et al., 2014; Cheng et al., 2017; Ishii et al., 2017; Johnson et al., 2018).

| Ocean Heat Content Changes  |                                 |                                    |   |                               |  |                      |   |   |                               |  |                      |  |   |                               |  |                      |                    |   |                               |  |                      |
|---|---------------------------------|------------------------------------|---|-------------------------------|--|----------------------|---|---|-------------------------------|--|----------------------|--|---|-------------------------------|--|----------------------|--------------------|---|-------------------------------|--|----------------------|
| W m <sup>-2</sup> Earth surface (averaged over Earth's surface: 5.1*10 <sup>14</sup> m <sup>2</sup> ) |                                 |                                    |   |                               |  |                      |   |   |                               |  |                      |  |   |                               |  |                      |                    |   |                               |  |                      |
|   |                                 |                                    |   |                               |  |                      |   |   |                               |  |                      |  |   |                               |  |                      |                    |   |                               |  |                      |
|   |                                 | Long term trend period (1970-2017) | Ocean Heat Content estimate (0-700) m layer | 90% confidence level or range | Ocean Heat Content estimate (700-2000) m layer | 90% confidence level | Short or near term trend period (2005-2017) | Ocean Heat Content estimate (0-700) m layer | 90% confidence level or range | Ocean Heat Content estimate (700-2000) m layer | 90% confidence level | period (1993-2017)   | Ocean Heat Content estimate (0-700) m layer | 90% confidence level or range | Ocean Heat Content estimate (700-2000) m layer | 90% confidence level | period (1969-1993) | Ocean Heat Content estimate (0-700) m layer | 90% confidence level or range | Ocean Heat Content estimate (700-2000) m layer | 90% confidence level |
| Paper on Ocean Heat Content   | Units                           |                                    |   |                               |  |                      |   |   |                               |  |                      |  |   |                               |  |                      |                    |   |                               |  |                      |
| (Cheng et al., 2017) (from Cheng website, latest version)   | W m <sup>-2</sup> Earth surface | 1970-2017                          | 0.28  | 0.06                          | 0.14   | 0.03                 | 2005-2017                                   | 0.32  | 0.05                          | 0.2  | 0.02                 | 1993-2017  | 0.39  | 0.04                          | 0.18   | 0.01                 | 1969-1993          | 0.15  | 0.05                          | 0.05   | 0.03                 |
| (Ishii et al., 2017) (from Ishii website, latest version)   | W m <sup>-2</sup> Earth surface | 1970-2017                          | 0.26  | 0.03                          | 0.16   | 0.04                 | 2005-2017                                   | 0.35  | 0.05                          | 0.28   | 0.05                 | 1993-2017  | 0.36  | 0.04                          | 0.25   | 0.04                 | 1969-1993          | 0.19  | 0.04                          | 0.09   | 0.02                 |
| (Domingues et al., 2008) (updated to presente and udated after 2018)                                  | W m <sup>-2</sup> Earth surface | 1970-2017                          | 0.3   | 0.05                          | NaN  | NaN                  | 2005-2017                                   | 0.35  | 0.05                          | 0.28   | 0.05                 | 1993-2017  | 0.41  | 0.05                          | NaN  | NaN                  | 1970-1993          | 0.29  | 0.08                          | NaN  | NaN                  |
| (Ishii et al., 2017; Johnson et al., 2018) (BAMS SoC) MRI/JMA   | W m <sup>-2</sup> Earth surface |                                    |   |                               |  |                      |   |   |                               |  |                      | 1993-2017(use the values above, Ishii et al. most updated version) | 0.36  | 0.06                          | 0.22   | 0.06                 |                    |   |                               |  |                      |

|  |                                 |  |      |      |      |      |  |      |      |      |      |   |      |      |      |      |   |      |      |      |      |
|--|---------------------------------|--|------|------|------|------|--|------|------|------|------|---|------|------|------|------|---|------|------|------|------|
| (Domingues et al., 2008; Johnson et al., 2018) (BAMS SoC) CSIRO/UTAS   | W m <sup>-2</sup> Earth surface |  |      |      |      |      |  |      |      |      |      | 1993-2017 (use the values above, Domingues et al.)                  | 0.4  | 0.07 | NaN  | NaN  |   |      |      |      |      |
| (Lyman and Johnson, 2014; Johnson et al., 2018) (BAMS SoC) PMEL/JPL/JMAR   | W m <sup>-2</sup> Earth surface |  |      |      |      |      |  |      |      |      |      | 1993-2017   | 0.4  | 0.07 | 0.35 | 0.03 |   |      |      |      |      |
| (Levitus et al., 2012; Johnson et al., 2018) (BAMS SoC) NCEI   | W m <sup>-2</sup> Earth surface | 1970-2016 (Pentadal time series used, end at 2016) | 0.23 | 0.05 | 0.11 | 0.04 | 2005-2016 (Pentadal time series used, end at 2016) | 0.33 | 0.05 | 0.26 | 0.02 | 1993-2017   | 0.38 | 0.07 | 0.19 | 0.07 | 1969-1993 (from NCEI website, Pentadal time series) | 0.18 | 0.09 | 0.05 | 0.04 |
| (Johnson et al., 2018) (BAMS SoC) Hadley Centre. (Palmer et al., 2007)   | W m <sup>-2</sup> Earth surface |  |      |      |      |      |  |      |      |      |      | 1993-2017   | 0.4  | 0.18 | NaN  | NaN  |   |      |      |      |      |
| (Cheng et al., 2017; Johnson et al., 2018) (BAMS SoC) ICES   | W m <sup>-2</sup> Earth surface |  |      |      |      |      |  |      |      |      |      | 1993-2017 (use the values above, Cheng et al. most updated version) | 0.4  | 0.06 | 0.19 | 0.01 |   |      |      |      |      |
| Argo product: (Roemmich and Gilson, 2009)  |                                 |  |      |      |      |      | 2005-2017  | 0.3  | 0.06 | 0.2  | 0.03 |   |      |      |      |      |   |      |      |      |      |
| Argo product: JAMSTEC : (Hosoda et al., 2010)  |                                 |  |      |      |      |      | 2005-2017  | 0.32 | 0.03 | 0.27 | 0.02 |   |      |      |      |      |   |      |      |      |      |
| Argo product:(Schuckmann and Traon, 2011) (up-date)  |                                 |  |      |      |      |      | 2005-2017  | 0.35 | 0.1  | 0.28 | 0.1  | 1993-2017   |      |      |      |      |   |      |      |      |      |
| Copernicus Marine Service (von Schuckmann et al., 2018), <a href="http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/catalogue/">http://marine.copernicus.eu/science-learning/ocean-monitoring-indicators/catalogue/</a> |                                 |  |      |      |      |      |  |      |      |      |      | 1993-2017   | 0.6  | 0.2  |      |      |   |      |      |      |      |

**Table SM5.2:** The CMIP5 ESM estimates are based on a combined 28-member ensemble of historical, RCP2.6 and RCP8.5 simulations to make times series that cover all of the periods in Table 5.1. The mean value of the ensemble models with the half range of the 90% certainty spread was used in Table 5.1 because this presentation of the ensemble models spread is most similar to the presentation of the mean observed heat content change and their associated confidence intervals. The models are CESM, CMCC-CMS, CNRM-CM5, CSIRO-Mk3, CanESM2, FGOALS-S2.0, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-CC, HadGEM2-ES, INM-CM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC-ESM, MIROC5, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, and NorESM1-M. Up to 3

ensemble members or variants were included per model, and all changes are relative to a control run with an identical initial condition but with preindustrial forcing. A table with a description and citations for each of these models, along with more detailed discussion of the use of ESM output, can be found in (Flato et al., 2013)

|  |                 |                 |                  |   |             |                         |                  |                  |                  |             |                         |  |  |
|--|-----------------|-----------------|------------------|---|-------------|-------------------------|------------------|------------------|------------------|-------------|-------------------------|--|--|
| <b>Global Ocean Heat Content Change (ZJ/yr)</b>                      |                 |                 |                  | <i>From combined RCP2.6 and RCP8.5 ensemble</i> |             |                         |                  |                  |                  |             |                         |  |  |
|  |                 | <b>0-700m</b>   |                  |   |             |                         | <b>700-2000m</b> |                  |                  |             |                         |  |  |
| <b>Time Period</b>   | <b>Ens size</b> | <b>5th pct.</b> | <b>95th pct.</b> | <b>50th pct.</b>                                | <b>mean</b> | <b>5-95% half-range</b> | <b>5th pct.</b>  | <b>95th pct.</b> | <b>50th pct.</b> | <b>mean</b> | <b>5-95% half-range</b> |  |  |
| 1969-1993  | 28              | 1.71            | 5.54             | 3.78  | 3.6         | 1.915                   | -0.38            | 2.6              | 1.31             | 1.32        | 1.49                    |  |  |
| 1993-2017  | 28              | 5.39            | 9.57             | 7.34  | 7.37        | 2.09                    | 1.08             | 3.9              | 2.89             | 2.72        | 1.41                    |  |  |
| 1970-2017  | 30              | 3.74            | 7.54             | 5.66  | 5.64        | 1.9                     | 0.32             | 3.34             | 1.94             | 1.99        | 1.51                    |  |  |
| 2005-2017  | 27              | 4.97            | 10.38            | 8.04  | 7.85        | 2.705                   | 1.12             | 4.61             | 3.47             | 3.33        | 1.745                   |  |  |
|  |                 |                 |                  |   |             |                         |                  |                  |                  |             |                         |  |  |
|  |                 |                 |                  |   |             |                         |                  |                  |                  |             |                         |  |  |
| <b>Global Ocean Heat Uptake average over Earth's surface (W m-2)</b> |                 |                 |                  | <i>From combined RCP2.6 and RCP8.5 ensemble</i> |             |                         |                  |                  |                  |             |                         |  |  |
|  |                 | <b>0-700m</b>   |                  |   |             |                         | <b>700-2000m</b> |                  |                  |             |                         |  |  |
| <b>Time Period</b>   |                 | <b>5th pct.</b> | <b>95th pct.</b> | <b>50th pct.</b>                                | <b>mean</b> | <b>5-95% half-range</b> | <b>5th pct.</b>  | <b>95th pct.</b> | <b>50th pct.</b> | <b>mean</b> | <b>5-95% half-range</b> |  |  |
| 1969-1993  |                 | 0.106           | 0.344            | 0.235   | 0.224       | 0.119                   | -0.024           | 0.162            | 0.081            | 0.082       | 0.093                   |  |  |
| 1993-2017  |                 | 0.335           | 0.595            | 0.456   | 0.458       | 0.130                   | 0.067            | 0.242            | 0.180            | 0.169       | 0.088                   |  |  |
| 1970-2017  |                 | 0.232           | 0.468            | 0.352   | 0.350       | 0.118                   | 0.020            | 0.208            | 0.121            | 0.124       | 0.094                   |  |  |
| 2005-2017  |                 | 0.309           | 0.645            | 0.500   | 0.488       | 0.168                   | 0.070            | 0.286            | 0.216            | 0.207       | 0.108                   |  |  |
|  |                 |                 |                  |   |             |                         |                  |                  |                  |             |                         |  |  |

|   |          |                 |                         |         |                               |        |                  |                         |  |                               |       |               |       |
|---|----------|-----------------|-------------------------|---------|-------------------------------|--------|------------------|-------------------------|--|-------------------------------|-------|---------------|-------|
| Assessed Real-world Global Ocean Heat Uptake from Observational Estimates (ZJ/yr) |          |                 |                         |         |                               |        |                  |                         |  |                               |       |               |       |
|   |          | <b>0-700m</b>   |                         |         |                               |        | <b>700-2000m</b> |                         |  |                               |       | 8-Values RMS: | 1.194 |
| <b>Time Period</b>  |          | <b>Mean</b>     | <b>5-95% half-range</b> |         | <b>Squared CMIP-OBS diff.</b> |        | <b>Mean</b>      | <b>5-95% half-range</b> |  | <b>Squared CMIP-OBS diff.</b> |       |               |       |
| 1969-1993   |          | 3.22            | 1.61                    |         | 0.1444                        |        | 0.97             | 0.64                    |  | 0.1225                        |       |               |       |
| 1993-2017   |          | 6.28            | 0.48                    |         | 1.1881                        |        | 3.86             | 2.09                    |  | 1.2996                        |       |               |       |
| 1970-2017   |          | 4.35            | 0.8                     |         | 1.6641                        |        | 2.25             | 0.64                    |  | 0.0676                        |       |               |       |
| 2005-2017   |          | 5.31            | 0.48                    |         | 6.4516                        |        | 4.02             | 0.97                    |  | 0.4761                        |       |               |       |
|   |          |                 |                         |         | <b>RMS:</b>                   | 1.5369 |                  |                         |  | <b>RMS:</b>                   | 0.701 |               |       |
| Earths surface area   | 5.10E+14 | Second per year | <b>31557600</b>         | J to ZJ | 1E+21                         |        | 6.21E-02         |                         |  |                               |       |               |       |

**Table SM5.3:** Compiled information on the rate of pH change from various time series, ship reoccupations and Pacific Ocean moorings. Modified after Table in Williams et al. (2015) with additional datasets.

| Region                        | pH change<br>(pH units per decade) | uncertainty | Study                          | Study period | Study type              |
|-------------------------------|------------------------------------|-------------|--------------------------------|--------------|-------------------------|
| Irminger Sea                  | -0.026                             | 0.006       | (Bates et al., 2014)           | 1983–2012    | Time series             |
| N. Atlantic (BATS)            | -0.017                             | 0.001       | (Bates et al., 2014)           | 1983–2012    | Time series             |
| N. Atlantic (BATS)            | -0.018                             | 0.002       | (Takahashi et al., 2014)       | 1983–2010    | Time series             |
| Iceland Sea                   | -0.023                             | 0.003       | (Olafsson et al., 2009)        | 1985–2008    | Time series             |
| N. Pacific (ALOHA)            | -0.018                             | 0.001       | (Dore et al., 2009)            | 1988–2007    | Time series             |
| N. Pacific (HOT)              | -0.016                             | 0.001       | (Bates et al., 2014)           | 1988–2012    | Time series             |
| N. Pacific (HOT)              | -0.018                             | 0.001       | (Takahashi et al., 2014)       | 1988–2009    | Time series             |
| N.W. Pacific                  | -0.02                              | na          | (Ishii et al., 2017)           | 1994–2008    | Time series             |
| Mediterranean (Dyfamed)       | -0.03                              | 0.01        | (Yao et al., 2016)             | 1995–2011    | Time series             |
| Mediterranean (Gibraltar)     | -0.044                             | 0.0006      | (Flecha et al., 2015)          | 2012–2015    | Time-series             |
| N. Atlantic (ESTOC)           | -0.018                             | 0.002       | (Bates et al., 2014)           | 1995–2012    | Time series             |
| N. Atlantic (ESTOC)           | -0.017                             | 0.001       | (González-Dávila et al., 2010) | 1995–2004    | Time series             |
| Caribbean (CARIACO)           | -0.025                             | 0.004       | (Bates et al., 2014)           | 1995–2012    | Time series             |
| N. Atlantic (ESTOC)           | -0.02                              | 0.004       | (Takahashi et al., 2014)       | 1996–2010    | Time series             |
| S.W. Pacific (Munida)         | -0.013                             | 0.003       | (Bates et al., 2014)           | 1998–2012    | Time series             |
| Atlantic Ocean                | -0.013                             | 0.009       | (Kitidis et al., 2017)         | 1995–2013    | Merged ship occupations |
| E. Equatorial Indian          | -0.016                             | 0.001       | (Xue et al., 2014)             | 1962–2012    | Merged ship occupations |
| Polar Zone                    | -0.02                              | 0.003       | (Midorikawa et al., 2012)      | 1963–2003    | Merged ship occupations |
| Southern Ocean                | -0.015                             | 0.005       | (Midorikawa et al., 2010)      | 1983–2007    | Merged ship occupations |
| N.W. Pacific                  | -0.017                             | NA          | (Byrne et al., 2010)           | 1991–2006    | Merged ship occupations |
| N. Pacific                    | -0.017                             | NA          | (Williams et al., 2015)        | 1992–2011    | Merged ship occupations |
| Pacific Southern Ocean (S4P)  | -0.022                             | 0.004       | (Waters et al., 2011)          | 1994–2008    | Merged ship occupations |
| S. Pacific                    | -0.016                             | NA          | (Williams et al., 2015)        | 1995–2011    | Merged ship occupations |
| Pacific Southern Ocean (P16S) | -0.024                             | 0.009       | (Pardo et al., 2017)           | 1995–2011    | Merged ship occupations |
| Southern Ocean (SR03)         | -0.031                             | 0.004       | (Takahashi et al., 2014)       | 2002–2012    | Merged ship occupations |
| Drake (PZ)                    | -0.015                             | 0.008       | (Takahashi et al., 2014)       | 2002–2012    | Merged ship occupations |
| Drake (SAZ)                   | -0.023                             | 0.007       | (Takahashi et al., 2014)       | 2002–2012    | Merged ship occupations |
| WHOTS (23N, 158W)             | -0.02                              | 0.003       | (Sutton et al., 2017)          | 2004–2013    | Mooring                 |
| Stratus (20S, 86W)            | -0.02                              | 0.003       | (Sutton et al., 2017)          | 2006–2015    | Mooring                 |

|                     |       |       |                          |           |         |
|---------------------|-------|-------|--------------------------|-----------|---------|
| KEO (32N,<br>144E)  | -0.01 | 0.005 | (Sutton et al.,<br>2017) | 2007-2014 | Mooring |
| Papa (50N,<br>145W) | -0.01 | 0.005 | (Sutton et al.,<br>2017) | 2007-2014 | Mooring |

**Table SM5.4:** Models and variables used. Black crosses indicate data over the period 1861 to 2100 following the RCP8.5 scenario, black circles indicate data following the RCP2.6 scenario, and numbers indicate the length of the control simulation. The models are also used in Frolicher et al. (2016).

| Model        | Surface pH | SST      | O <sub>2</sub> (100-600) | NPP (0-100m) | NO <sub>3</sub> (0-100m) | References               |
|--------------|------------|----------|--------------------------|--------------|--------------------------|--------------------------|
| CanESM2      | xo996      | xo996    |                          |              |                          | (Arora et al., 2013)     |
| CNRM-CM5     |            | xo850    |                          |              |                          | (Voldoire et al., 2013)  |
| IPSL-CM5A-LR | xo1000     | xo1000   | xo1000                   | xo1000       | xo1000                   | (Dufresne et al., 2013)  |
| IPSL-CM5A-MR | xo300      | xo300    | xo300                    | xo300        | xo300                    | (Dufresne et al., 2013)  |
| IPSL-CM5B-LR | x300       |          | x300                     | x300         | x300                     | (Dufresne et al., 2013)  |
| MIROC-ESM    |            |          |                          |              | xo630                    | (Watanabe et al., 2011)  |
| MPI-ESM-LR   | xo1000     |          | xo1000                   | xo1000       | xo1000                   | (Giorgetta et al., 2013) |
| MPI-ESM-MR   | xo560      | xo1000   | xo650                    | xo1000       | xo1000                   | (Giorgetta et al., 2013) |
| CCSM4        |            | xo1051   |                          |              |                          | (Gent et al., 2011)      |
| NorESM1-ME   |            | xo252    |                          |              |                          | (Bentsen et al., 2013)   |
| GFDL-ESM2G   | xo500      | xo500    | xo500                    | xo500        |                          | (Dunne et al., 2012)     |
| GFDL-ESM2M   | xo500      | xo500    |                          | xo500        |                          | (Dunne et al., 2012)     |
| GISS-E2-H    |            | xo281    |                          |              |                          | (Shindell et al., 2013)  |
| GISS-E2-R    |            | xo531    |                          |              |                          | (Shindell et al., 2013)  |
| CESM1-CAM5   |            | xo319    |                          |              |                          | (Meehl et al., 2011)     |
| BCC_CSM1-1   |            | xo500    |                          |              |                          | (Wu et al., 2014)        |
| BCC-CSM1-1-m |            | x400     |                          |              |                          | (Wu et al., 2014)        |
| Total        | 8/7/8      | 14/13/14 | 6/5/6                    | 7/6/7        | 6/5/6                    |                          |

**Table SM5.5:** Table of evidence of observed effects and projected impacts of climate hazards on cold water corals (in support of Box 5.2 Cold-water Corals and Sponges)

| Species   | Locations          | Evidence type | Key findings   | Reference              |
|---|--------------------|---------------|--|------------------------|
| <i>Lophelia pertusa</i> *<br><i>Note recently<br/>renamed to<br/>Demophyllum<br/>pertusum</i> | Northeast Atlantic | Experiment    | Acidification exposure over 12 months will cause the biomineralized aragonite skeleton of <i>L. pertusa</i> to exhibit less organization, a longer and thinner growth form, and reduced structural integrity of the exposed skeletal | (Hennige et al., 2015) |

|  |                              |                           |  |                                    |
|--|------------------------------|---------------------------|--|------------------------------------|
|  |                              |                           | framework which forms the base of cold-water coral reefs and a significant proportion of the habitat   |                                    |
| <i>Desmophyllum dianthus</i>   | Fjords of Northern Patagonia | Observations              | Thrives under natural low pH conditions (down to 7.4)  | (Fillinger and Richter, 2013)      |
| <i>Desmophyllum dianthus</i>   | Mediterranean Sea            | Experiment                | Elevated pCO <sub>2</sub> (750 ppm CO <sub>2</sub> ) when combined with elevated temperatures (from 13°C to 15°C) reduces calcification and respiration rates and shifts metabolic substrates from a mixture of protein and carbohydrate/lipids to a less efficient protein-dominated catabolism | (Gori et al., 2016)                |
| <i>Desmophyllum</i> spp.,<br><i>Lophelia pertusa</i> ,<br><i>Madrepora oculata</i> ,<br><i>Acanella arbuscula</i> ,<br>and <i>Paragorgia arborea</i> | Northwest Atlantic           | Habitat suitability model | Habitat suitability analyses suggest that food supply (POC flux) is a critical variable  | (Morato et al., 2006; Levin, 2018) |
| <i>Desmophyllum</i> spp.,<br><i>Lophelia pertusa</i> ,<br><i>Madrepora oculata</i>   | Northwest Atlantic           | Habitat suitability model | Dissolved oxygen is critical in defining habitat suitability   | (Morato et al., 2006; Levin, 2018) |
| <i>Lophelia pertusa</i> ,<br><i>Madrepora oculata</i>  | Mediterranean Sea            | Experiment                | Net calcification and respiration of both species was unaffected by the levels of pCO <sub>2</sub> of 350 to 1000 µatm during both short and long-term (9 mo) exposure   | (Maier et al., 2013)               |
| <i>Madrepora oculata</i>   | Mediterranean Sea            | Experiment                | Energy demand to maintain calcification at 800 µatm is 2 times that required for calcification at ambient pCO <sub>2</sub> , but only 1% of that of respiratory metabolism.  | (Maier et al., 2016)               |



|  |  |              |   |                            |
|--|--|--------------|---|----------------------------|
| <i>Lophelia pertusa</i>                              | Northeast Atlantic   | Experiment   | Capable of calcifying under elevated CO <sub>2</sub> (800µatm) and temperature (12oC), its condition (fitness) is more strongly influenced by food availability rather than changes in seawater chemistry               | (Büscher et al., 2017)     |
| <i>Lophelia pertusa</i>                              | Gulf of Mexico   | Experiment   | Some genotypes were able to calcify at pH 7.6 and aragonite undersaturation for 2 mo but all exhibited reduced calcification after 6 mo exposure  | (Kurman et al., 2017)      |
| <i>Desmophyllum dianthus</i>                         | Global ocean   | Paleo record | Populations waxed and waned over the last 40,000 years as the global ocean was influenced by glacial advances and retreats and changing concentrations of CO <sub>3</sub> -2, O <sub>2</sub> , and surface productivity | (Thiagarajan et al., 2013) |
| <i>Desmophyllum dianthus</i>                         | Seamounts in the North Atlantic and Southwest Pacific Oceans | Paleo record | Populations on altered their depth distribution in response to changes in the aragonite saturation depth,   | (Thiagarajan et al., 2013) |
| <i>Lophelia pertusa</i> and <i>Madrepora oculata</i> | Mediterranean Sea  | Experiment   | No effect of pH 7.81 on skeletal growth rate, microdensity and porosity after 6 mo exposure   | (Movilla et al., 2014)     |
| Probably <i>Solenosmilia</i> and <i>Enalopsammia</i> | North Pacific  | Observation  | Live scleractinian reefs persist on six seamounts at depths of 535–732 m and aragonite saturation state (Ω <sub>arag</sub> ) values of 0.71–1.33, suggesting little influence of the aragonite saturation horizon       | (Baco et al., 2017)        |

|                                     |                                     |   |  |  |
|-------------------------------------|-------------------------------------|---|--|--|
| Antipathes fiordensis (black coral) | New Zealand fjords                  | Observation                               | Shallow occurrence in a low salinity fjord.  | (Jiang et al., 2015)                     |
| Lophelia pertusa                    | Northwest Atlantic                  | Experiment                                | Upper lethal limit is 15°C   | (Brooke et al., 2013)                    |
| Lophelia pertusa, Madrepora oculata | Gulf of Mexico<br>Mediterranean Sea | In situ observation<br>Experiment         | Species-specific thermal adaptations may regulate tolerance to future conditions. L. pertusa shows thermal acclimation in respiration and calcification but M. oculata does not  | (Naumann et al., 2014)                   |
| Lophelia pertusa                    | North Atlantic                      | Experiment, Model                         | The long planktonic duration (8-9 wk) and upward swimming of larvae make connectivity of cold water coral populations likely to be sensitive to future changes in the state of North Atlantic Oscillation (NAO) in the NE Atlantic | (Larsson et al., 2014; Fox et al., 2016) |
| Geodia barrette                     | North Atlantic                      | Experiment                                | Sponge and its microbiome tolerate a 5°C increase in temperature, accompanied by rise in respiration, nitrogen efflux and cellular stress  | (Strand et al., 2017)                    |
| Radiella sp., Polymastia sp         | Northwest Atlantic                  | Experiment                                | Ocean acidification (pH 7.5) reduces the feeding of demosponge taxa  | (Robertson et al., 2017)                 |
| Solenosmilia variabilis             | Southern Australia, Seamounts       | Observation, Habitat Suitability Modeling | Limited to $\Omega_{arag}$ of > 2.5 and temperature > 7°C. By the end of the century low carbonate saturation levels and upper temp. limit eliminates all areas with a habitat suitability >40%; at RCP8.5,                        | (Thresher et al., 2015)                  |

**SM5.2 Risk Assessment of Open Ocean Ecosystems in Support of Section 5.2.5**

The deep seafloor and pelagic embers are generated based on earth system model projection of climate variables to the seafloor under RCP 2.6 and RCP 8.5 scenarios, and then translated to RCP- associated change in SST. The assessed confidence in assigning the levels of risk at present day and future scenarios are *low, medium, high, and very high* levels of confidence. A detailed account of the procedures involved in the ember for each type of ecosystem, such as their exposure to climate hazards, sensitivity of key biotic and abiotic components, natural adaptive capacity, observed impacts and projected risks, and regional hotspots of vulnerability is provided in Table SM5.6 (below) and Table 5.5.

**Table SM5.6:** Shows the main factors in the assessment of the deep seafloor and pelagic embers.

| Deep Sea Floor Ecosystem                     | Water Depth (m)            | Ecosystem Component | Main Climate Hazard  | Sensitivity  | Adaptive Capacity   | Vulnerability (Risk)   | Other Hazards  | Impacts and Risks   | Hotspots   |
|--|----------------------------|---------------------|--|--|---|--|--|---|--|
| Cold-water corals                            | 200-1600 m (forming reefs) | BI, F, CWC, sponges | <b>warming, acidification (especially aragonite undersaturation), deoxygenation, particulate organic carbon (POC) flux</b> | <b>SST</b> > CWC- moderate (obs., exp, HSM, proj)                                      | Moderate: Corals can survive for 1000s years and appear tolerant of elevated CO <sub>2</sub> , but not significant warming or loss of oxygen. Genetic variability underpins adaptation to current conditions. | Moderate/High under rcp85 : Tolerance to declining pH and omega. Drastic reduction in fitness under combined T, DO and pH/omega stress. Aragonite undersaturation weakens CWC skeletons and increases vulnerability to bioerosion by sponges, annelids, fungi. | Physical disturbance from fishing (bottom trawling and longlining ), oil spills, potential for minerals mining disturbance   | Loss of CWC habitat through dissolution of non-living components of reefs under aragonite undersaturation, loss of fish habitat. Loss of resilience through changes in food supply (as POC flux decline) or mediated by migrating plankton.   | Greatest vulnerability to aragonite undersaturation and loss of habitat suitability in the north Atlantic, and on south Australia seamounts  |
|  |                            |                     |  | <b>pH/CO<sub>2</sub>/omega(arag)</b> > CWC - medium (obs, exp, proj)                   |   |  |  |   |  |
|  |                            |                     |  | <b>POC flux</b> > CWC (proj)   |   |  |  |   |  |
|  |                            |                     |  | <b>DO</b> > CWC, BI - high (obs, exp, proj)  |   |  |  |   |  |
|  |                            |                     |  |  |   |  |  |   |  |
| Bathyal features: Seamounts, canyons, slopes | 200-3000 m                 | BI, F, Protozoa,    | <b>deoxygenation, acidification, warming, POC flux</b>   | <b>DO</b> > BI, F, Protozoa - moderate/high (obs.paleo, exp, proj)                     | Moderate: Mostly unknown. Adults are exposed to wide range of conditions naturally. Fish and BI can migrate upslope or downslope to reach suitable conditions   | Moderate under rep8.5, low under rcp2.6. Tolerance to declining DO and omega on upwelling margins but not everywhere. Lack of studies on sublethal responses   | Coincident human activities on seamounts, canyons and slopes such as cable laying, bottom fishing, oil and gas extraction/spills, waste disposal/debris accumulation can create cumulative stress. Altered precipitation and winds on land can | Loss of biodiversity, changes in trophic pathways and carbon cycling, reduction in biomass and habitat compression of Fish and BI under decliningDO. Effects of acidification are poorly known for deep water species, but some hypoxia and acidification-tolerant taxa will expand | Largest declines in pH and POC flux in the Northeast Atlantic may lead to alteration of canyon and seamount ecosystems ; expanding OMZs will create biodiversity loss and habitat compression at |
|  |                            |                     |  | <b>pH/CO<sub>2</sub>, omega (arag)</b> . BI, F - low/moderate (obs., paleo, exp. Proj) |   |  |  |   |  |
|  |                            |                     |  | <b>SST</b> > BI, F - low (obs., proj)  |   |  |  |   |  |
|  |                            |                     |  | <b>POC flux</b> > BI low (proj)  |   |  |  |   |  |
|  |                            |                     |  |  |   |  |  |   |  |

|                           |       |                     |   |  |   |  |  |  |   |
|---------------------------|-------|---------------------|---|--|---|--|--|--|---|
|                           |       |                     |   |  |   |  | alter benthopelagic coupling.  | distributions. Protozoan and metazoan meiofauna show different responses in different regions, but more tolerant than macro- or megafauna.   | suboxic thresholds on EBU slopes (Northeast Pacific) .  |
| Epipelagic (low-latitude) | 0-200 | P, Z, F, MM, NPP,EF | warming, stratification, acidification, deoxygenation, nutrient concentration | <b>SST</b> > P, Z, F (high),MM (moderate) <i>high confidence</i> (obs., proj.)               | Moderate: Plankton, F and MM can migrate poleward, following thermal and productivity gradients to reach suitable conditions. Poleward shifts of Z may be limited by the seasonality of light cycle at high latitudes that drives the P cycle. Geographic barriers such as land boundaries, or barriers related climate driven processes (e.g. low oxygen waters), may limit the range shift and migration patterns of F and MM. P may genetically adapt to | High under rcp8.5, moderate under 2.6. Uncertain effects and tolerance of planktonic organisms (calcified vs non-calcified) and fishes on declining oxygen and pH, with temperature exacerbating acidification and deoxygenation. Major risk on declining productivity and fish biomass in low latitudes (tropical waters), as well as lower export flux in subtropical and tropical waters. | Enhanced decline of fish biomass due to overfishing with extended impact on large-bodied animals | Poleward shifts of plankton and fish organisms, following expanding thermal gradients, with changes in community structure towards small-size organisms in low latitudes. Earlier timing of spring phenology in Z and F, with cascading effects on the ecosystem. Enhanced stratification due to surface warming leads to reduced nutrient availability and lower NPP, with moderate to high Z and F biomass declines, and lower carbon export production to | Greatest impact on decline of NPP in equatorial regions. Projections from multiple fish species distribution models show hotspots of decrease in species richness in the Indo-Pacific region, and semi-enclosed seas such as the Red Sea and Arabian Gulf |
|                           |       |                     |   | <b>pH/CO<sub>2</sub></b> - P, Z, F, (low/moderate) <i>medium confidence</i> (obs, exp, proj) |   |  |  |  |   |
|                           |       |                     |   | <b>EF</b> > (low) <i>low confidence</i> (proj)   |   |  |  |  |   |
|                           |       |                     |   | <b>DO</b> > Z, F, (moderate) <i>medium confidence</i> (obs, exp, proj)                       |   |  |  |  |   |
|                           |       |                     |   | <b>NPP</b> > (low) <i>low confidence</i> (proj)  |   |  |  |  |   |
|                           |       |                     |   | <b>Nut</b> > P, Z, F (high), MM (moderate) <i>medium confidence</i> (obs., proj.)            |   |  |  |  |   |

|                                   |       |              |   |   |   |   |  |   |   |
|-----------------------------------|-------|--------------|---|---|---|---|--|---|---|
|                                   |       |              |   |   | changing climate conditions. Marine ectotherms have some capacity for physiological adjustment and evolutionary adaptation that lowers their sensitivity to warming and decrease in oxygen, but adaptation not always suffices to mitigate projected impacts.   |   |  | the deep ocean. The combined effects of warming, ocean deoxygenation and acidification in the 21st century are projected to exacerbate the impacts on the growth, reproduction and mortality of fishes, and consequently increases their risk of population decline   |   |
| Eastern boundary upwelling system | 0-200 | P, Z, F, NPP | warming, upwelling intensification, acidification (especially aragonite undersaturation), deoxygenation, nutrient concentration | SST> P, Z,- (low/moderate) <i>medium confidence</i> (obs., proj.) | Moderate: Plankton and F are exposed to large natural variability, so would be able to adapt to changing climate conditions. Calcified plankton species (e.g. pteropods, forams) unable to adapt to undersaturated carbonate (calcite and aragonite) thresholds, will be under serious risk of disappearance. | Moderate under rcp8.5, low under rcp2.6. High resilience of EBUS to changing climate conditions. Uneven effects on the four EBUS. Major risk on deoxygenation (expansion of OMZ) and acidification (carbonate undersaturations) in the two Pacific EBUS | Non climatic stressors like overfishing and coastal pollution alter ecosystems' resilience. Changes in wind intensification and coastal precipitation alter upwelling intensity and local oceanographic conditions | EBUS are rather close to a number of important thresholds in terms of increasing deoxygenation and ocean acidification, enhanced by ocean warming. Regional fisheries highly sensitive to local upwelling projected to increase due to wind intensification in three of the four EBUS (except the Canary Current EBUS). The direction | Model projections for the end of the century suggest strong effects of deoxygenation and reduced pH in the Humboldt Current and the California Current EBUS under RCP8.5, the Humboldt Current transitioning toward |
|                                   |       |              |   | pH/CO2/omega (arag) BI none/low (obs)                             |   |   |  |   |   |
|                                   |       |              |   | POC flux> BI - low (obs)  |   |   |  |   |   |
|                                   |       |              |   | DO> BI - moderate (obs, proj)                                     |   |   |  |   |   |
|                                   |       |              |   |   |   |   |  |   |   |

|                   |                            |                     |   |   |  |  |  |  |  |
|-------------------|----------------------------|---------------------|---|---|--|--|--|--|--|
|                   |                            |                     |   |   |  |  |  | and magnitude of observed changes vary between and within EBUS with mechanisms explaining these variabilities not fully understood yet. Given the high sensitivity of the coupled human-natural EBUS to oceanographic changes, the future sustainable delivery of key ecosystem services (fisheries, aquaculture, coastal tourism and climate regulations) is at risk under climate change | widespread undersaturated conditions with regard to aragonite within a few decades. Observed and projected warming in the Canary Current EBUS, with a strong dependence on EBUS services and low adaptive capacity |
| Cold-water corals | 200-1600 m (forming reefs) | BI, F, CWC, sponges | warming, acidification (especially aragonite undersaturation), deoxygenation, particulate organic carbon (POC) flux | <p>SST&gt; CWC-moderate (obs., exp, HSM, proj)</p> <p>pH/CO2/omega(arag)&gt; CWC - medium (obs, exp, proj)</p> <p>POC flux&gt; CWC (proj)</p> <p>DO&gt; CWC, BI - high (obs, exp, proj)</p> | Moderate: Corals can survive for 1000s years and appear tolerant of elevated CO2, but not significant warming or loss of oxygen. Genetic variability underpins adaptation to | Moderate/High under rcp85 : Tolerance to declining pH and omega. Drastic reduction in fitness under combined T, DO and pH/omega stress. Aragonite undersaturation weakens CWC skeletons and increases vulnerability to | Physical disturbance from fishing (bottom trawling and longlining ), oil spills, potential for minerals mining disturbance | Loss of CWC habitat through dissolution of non-living components of reefs under aragonite undersaturation, loss of fish habitat. Loss of resilience through changes in food supply (as POC flux decline) or  | Greatest vulnerability to aragonite undersaturation and loss of habitat suitability in the north Atlantic, and on south  |

|   |            |                  |  |   | current conditions.   | bioerosion by sponges, annelids, fungi.  |  | mediated by migrating plankton.   | Australia seamounts   |
|---|------------|------------------|--|---|---|--|--|---|---|
| Bathyal features:<br>Seamounts, canyons, slopes | 200-3000 m | BI, F, Protozoa, | <b>deoxygenation, acidification, warming, POC flux</b> | DO > BI, F, Protozoa - moderate/high (obs.paleo, exp, proj) | Moderate: Mostly unknown. Adults are exposed to wide range of conditions naturally. Fish and BI can migrate upslope or downslope to reach suitable conditions | Moderate under rcp8.5, low under rcp2.6. Tolerance to declining DO and omega on upwelling margins but not everywhere. Lack of studies on sublethal responses | Coincident human activities on seamounts, canyons and slopes such as cable laying, bottom fishing, oil and gas extraction/spills, waste disposal/debris accumulation can create cumulative stress. Altered precipitation and winds on land can alter benthopelagic coupling. | Loss of biodiversity, changes in trophic pathways and carbon cycling, reduction in biomass and habitat compression of Fish and BI under declining DO. Effects of acidification are poorly known for deep water species, but some hypoxia and acidification-tolerant taxa will expand distributions. Protozoan and metazoan meiofauna show different responses in different regions, but more tolerant than macro- or megafauna. | Largest declines in pH and POC flux in the Northeast Atlantic may lead to alteration of canyon and seamount ecosystems ; expanding OMZs will create biodiversity loss and habitat compression at suboxic thresholds on EBU slopes (Northeast Pacific) . |



**Table SM5.7:** A summary of available evidence to document the potential effects of climate change in Western and Eastern American sandy beach macrobenthic communities. Based on the theoretical framework detailed in Parmesan et al. (2013). Adapted from McLachlan and Defeo (2017). The numbers indicate the source references.

| Lines of evidence  | Attribution process  | References  |
|--|--|---|
| Long-term observations and resurveys                                 | Mass mortality events of <i>Mesodesma</i> clams in South America consistently follow warm sea surface temperature events (e.g., El Niño) <sup>1</sup> in the Pacific ( <i>M. donacium</i> in Perú and Northern Chile) and occurred sequentially in a north-south direction in the Atlantic ( <i>M. mactroides</i> in Brazil, Uruguay and Argentina), following oceanographic shifts, increasing SST and isotherms moving poleward <sup>2</sup> .   | 1. (Riascos et al., 2009)<br>2. (Ortega et al., 2013; Ortega et al., 2016)<br>3. (Herrmann et al., 2009; Adams et al., 2011; Herrmann et al., 2011)   |
| Fingerprints   | 30 years of systematic sampling in Uruguay <sup>2</sup> and resurveys in Brazil and Argentina <sup>3</sup> across the distribution range of the clam <i>M. mactroides</i> document declines and local extirpations related to increasing SST and associated factors.<br>Population extirpations along the northern (trailing) range edge and lowest levels of impact along southern (leading) range boundaries <sup>1, 2, 4</sup> , uniquely consistent with regional warming in the Pacific and Atlantic oceans and not with local human-caused stresses. Drastic long-term demographic changes in the population of <i>M. mactroides</i> in sandy beaches from Uruguay are associated with changes in primary production driven by a climatic shift from a cold to a warm phase and increasing offshore winds, where reduced harvesting allow the population recovery. <sup>11</sup>   | 4. (Riascos et al., 2011)<br>5. (Fiori et al., 2004; Vázquez et al., 2016)  |
| Meta-analyses: global coherence of responses across taxa and regions | Mass mortalities of the yellow clam <i>Amarilladesma mactroides</i> occurred during warmer seasons throughout its entire distribution range <sup>5</sup> , concurrently with accelerating SST warming.<br>Mass mortalities observed across Pacific and Atlantic sandy beaches of South America, particularly during El Niño events and recorded oceanographic shifts <sup>1, 2</sup> .<br>Drastic changes in the composition of the suspension-feeder assemblages, with coherent responses across taxa and regions. <i>Mesodesma</i> clams were virtually extirpated at their northern range edges, being partially replaced by <i>Donax</i> clams and <i>Emerita</i> mole crabs (tropical affinities) in both Pacific <sup>6, 7</sup> and Atlantic <sup>8, 9, 10</sup> sandy beaches. Impoverished macrofaunal communities and <i>Mesodesma</i> species never reached biomasses at pre-mortality levels <sup>6, 9, 15</sup> . | 6. (Riascos et al., 2011)<br>7. (Arntz et al., 1987; Arntz et al., 2006)<br>8. (Celentano and Defeo, 2016)<br>9. (Dadon, 2005)<br>10. (Herrmann et al., 2009)<br>11. (Lercari et al., 2018) |
|  | Species introduction from adjacent areas in benthic macrofauna communities of surf zones driven by storm surges. <sup>12</sup>   | 12. (Carcedo et al., 2015; Carcedo et al., 2017)  |
|  | Changes in spatial zonation of benthic macrofauna along the profile of mesotidal sandy beaches due to sediment movement in response to winds and storm surges. <sup>13</sup>   |   |
|  | Parasites were found in clams, and also necrosis in gills and stomachs, during mortality events in the Atlantic (Argentina <sup>4</sup> and Uruguay <sup>2</sup> ) and in the Pacific during strong El Niño events <sup>6</sup> .<br>Mass mortality events of the yellow clam <i>Amarilladesma mactroides</i> (considered a vulnerable   |   |

|             |   |   |
|-------------|---|---|
|             | species since the mid-1990s) likely in response to high population densities and pathogenic infections by <i>Vibrio</i> sp. <sup>5</sup> .  |   |
|             | Body downsizing towards warmer latitudes was consistently observed for the guilds of intertidal suspension feeders and benthic crustaceans including isopods, crab and amphipod species in sandy beaches from the SW Atlantic <sup>2, 8</sup> and the NE and SE Pacific (USA and Chile) <sup>1, 4, 14</sup> . |   |
| Experiments | Controlled in-vitro experiments showed that <i>D. obesus</i> (tropical affinities) was tolerant to El Niño temperatures, whereas <i>M. donacium</i> (temperate) was sensitive to both El Niño and La Niña extreme conditions, with sublethal and lethal effects <sup>15</sup>                                 | 14. (Jaramillo et al., 2017)<br>15. (Carstensen et al., 2010) |

### SM5.3 Risk Assessment of Coastal Ecosystems

The level of vulnerability to climate hazards of each type of coastal ecosystem assessed in Sections 5.3.1 to 5.3.6 depends on their sensitivity and adaptive capacity. The ecosystem sensitivity is assessed by discriminating the distinct responses to climate hazards of the main biotic and abiotic components that define each ecosystem, such as vegetation, benthic fauna, plankton, biogeochemical gradients (e.g. salinity, nutrients) and geomorphology. The level of exposure of each type of coastal ecosystem to climate hazards depends on the ecosystem (1) geographical distribution and (2) topographic characteristics i.e., intertidal or submerged, and (3) the level of local human impacts, e.g. eutrophication, aquaculture and coastal infrastructure. For example, estuaries (Section 5.3.1) and sandy beaches (Section 5.3.3) are distributed all across the global coastlines that are experiencing diverse range of changes in climate hazards, while mangroves (Section 5.3.2) are restricted to temperate and tropical/subtropical regions (Figure 5.14) where their exposure to climate hazards is generally similar in nature. Likewise, kelp forests (Section 5.3.6) and most seagrass meadows (Section 5.3.2) are submerged ecosystems, while all the other ecosystems defined here are intertidal, except rocky reefs (Section 5.3.5) and coral reefs (Section 5.3.4) that can be both, intertidal and submerged. Intertidal ecosystems are more threatened by flooding and erosive processes due to SLR and storm surges than submerged ecosystems; which are more affected by ocean warming, acidification and marine heat waves. Furthermore, the pervasive anthropogenic habitat degradation exacerbates climate vulnerabilities of coastal systems. Common examples of these compounding effects are the expansion of hypoxic zones enhanced by eutrophication in estuaries, and the reduction of the adaptive capacity of wetlands to flooding and salinization by coastal squeezing, which constrains the landward migration of vegetated forms.

The common ecosystem responses to global warming (Sections 5.3.1 to 5.3.6) are habitat contraction, migration and loss of functionality and biodiversity. At the species level, the main biological responses are similar to those in pelagic ecosystems (Section 5.2.3), including shifts in species distribution towards the poles or specific physicochemical gradients (e.g. salinity and type of substrate) that result in species range expansions and local extinctions. Unique biological responses in coastal areas include the potential for inland migration of benthic fauna and littoral vegetation in response to increased sea water intrusion. Consequently, the restructuring of coastal ecosystems will negatively affect their functioning and services such as carbon storage, sediment stability, storm protection and provisioning of foraging and nursery sites (Section 5.4.1).

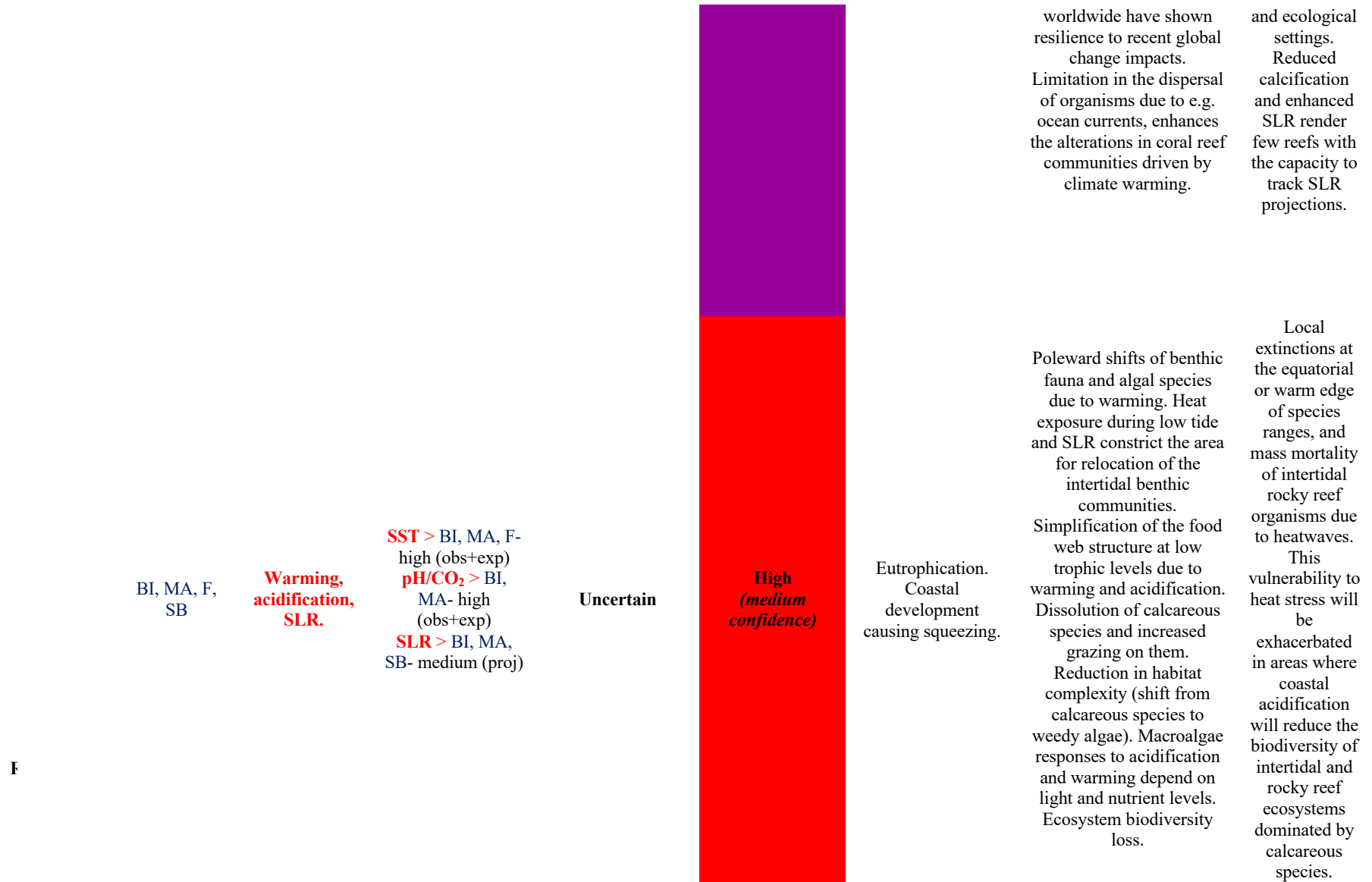
**Table SM5.8:** Tidal exposure: IT: intertidal; S: submerged. Ecosystem component: R-S: river-sea transition. GM: geomorphology. BGQ: biogeochemistry. BI: Benthic invertebrates. P: Plankton. V: Vegetation. F: Fishes. MM: Marine mammals. SB: Sea birds. SE: Soil elevation. T: turtles. MA: Macroalgae.

| Coastal Ecosystem | Tidal exposure | Ecosystem component       | Main climate hazard          | Sensitivity   | Adaptive capacity   | Vulnerability (Risk)         | Other hazards   | Impacts and risks  | Hotspots   |
|-------------------|----------------|---------------------------|------------------------------|---|---|------------------------------|---|--|--|
| Estuaries         |                | R-S, BGQ, BI, P, V, F, MM | SLR, warming, deoxygenation. | <p><b>SST</b> &gt; BGQ, BI, P, V, F, MM-medium (obs+proj)</p> <p><b>pH/CO<sub>2</sub></b> &gt; BI, F-low (proj)</p> <p><b>SLR</b> &gt; BGQ, GM, V- high (obs+proj)</p> <p><b>DO</b> &gt; BGQ, P, F -medium (obs+proj)</p> <p><b>Precipitation/river runoff (droughts/floods)</b> &gt; BGQ, BI, V (obs+proj).</p>  | <p><b>Moderate/High</b> (High resilience, especially deep, macrotidal estuaries with high exchange with the open ocean).</p>  | Moderate (medium confidence) | <p>Habitat degradation due to human activities: aquaculture, agriculture, urbanization. Eutrophication. Pollution. Overfishing. Shipping/Dredging. Sedimentation/mouth closure.</p> | <p>Salinization, increase in nutrient and sediment loads. Changes in circulation patterns. Upstream redistribution of brackish and marine benthic and pelagic species, depending on their tolerance range to salinity and substrate type. Organic matter accumulation. Increased bacterial respiration. Hypoxia and anoxia. Occurrence of harmful algal blooms (HABs) and pathogenic outbreaks. Increased mortality of invertebrates and fishes. Polward migration of low latitude flora and fauna species between estuaries. Reduction in above- and belowground plant biomass, carbon storage and soil elevation. Tolerance to inundation and salinization depends on plant species and organic accretion. Shifts in plant species, local extinctions. Habitat restructuring from saltmarshes to mudflats, biodiversity loss. Reduction in sediment stability. Reduction in foraging and nursery services. The projected loss in global coastal wetlands (20-60 %) is in</p> | <p>Microtidal, shallow and eutrophic estuaries in mid and high latitudes are more vulnerable to SLR, warming, deoxygenation and acidification. Salinization due to SLR and warming will intensify in estuaries in drought regions.</p> <p>Saltmarshes in microtidal estuaries in dry areas, with low sediment supply and low soil accretion capacity, are exposed to high salinization due to SLR and warming. Saltmarshes in sub-tropical areas are threatened by expansion of mangrove</p> |
|                   |                |                           |                              | <p><b>SST</b> &gt; V, F-medium (obs+exp+proj) but positive/negative effects.</p> <p><b>pH/CO<sub>2</sub></b> &gt; V- low (obs+proj+exp) but positive/negative effects</p> <p><b>SLR</b> &gt; V, SE, SB-high (obs+proj).</p> <p><b>Increased storm disturbance</b> (but positive/negative effects depending on sediment supply) &gt; V, SE (obs+proj).</p> | <p><b>Moderate</b> (Saltmarshes are initially resilient to SLR due to soil accretion (biomass accumulation and sediment deposition) but system won't be able to withstand SLR after 60 years under RCP 8.5.</p> | High (medium confidence)     |   |  |  |

---

Total pages: 110

|               |                 |                                      |  |   |                                  |  |   |  |
|---------------|-----------------|--------------------------------------|--|---|----------------------------------|--|---|--|
|               |                 |                                      |  |   |                                  |  | reduction of Cymodosea nodosa meadows (46 %) in the Mediterranean, and expansion into the Atlantic. Increased herbivory by tropical consumers on temperate seagrasses, ecosystem biodiversity loss.   | invasion of tropical herbivorous species.  |
| Sandy beaches | GM, BI, V, P, T | SLR, warming, storms.                | <p>SST &gt; BI, P, T-high (obs+proj)</p> <p>pH/CO<sub>2</sub> &gt; BI, P-low (obs+proj)</p> <p>SLR &gt; GM, BI, V, T-high (obs+proj)</p> <p>Increased storm disturbance, runoff &gt; GM, BI, V (obs+prj).</p>        | Moderate  | Moderate (medium confidence)     | Infrastructure development causing squeezing, habitat degradation. | <p>Increasing erosion/sediment loss related to storms, waves and SLR. Changes in beach morphology, dune scarping, vegetation loss, reduction in beach area and turtle nesting sites. Poleward shifts in macrobenthic communities, reduction in body size with warming, mass mortality of clams. Limitation in the landward migration of the beach profile due to human development.</p> <p>Species-specific responses to multiple-climate drivers. Coral bleaching, mass mortality. Drastic reduction in coral fitness (growth, reproduction) due to combined effects of warming, acidification and SLR. Spread of invasive species. Reef dissolution and bioerosion. Shift in habitat structure from calcified corals towards algal or soft, slow growing coral dominated reefs. Ecosystem biodiversity loss. Only a few reefs</p> | <p>Sandy beaches in the SW Atlantic and SE Pacific (Chile, South Brasil, Uruguay and Argentina) are exposed to compound effects of SLR, storm surges, warm phases of El Niño and changes in tidal amplitudes. The highest probability of coral bleaching occurs at tropical mid-latitude sites (15-20 degrees north and south of the Equator). However, coral bleaching is less common in localities with a high variance in SST anomalies</p> |
| Coral reefs   | BGQ, BI, P, F   | Warming, acidification, SLR, storms. | <p>SST &gt; BGQ, BI, P, F-high (obs+exp+proj)</p> <p>pH/CO<sub>2</sub> &gt; BGQ, BI, P-high (obs+exp+proj)</p> <p>SLR &gt; GM, BI-high (obs+exp+proj)</p> <p>Increased storm disturbance &gt; GM, BI (obs+proj).</p> | Low/Moderate (some populations seem adapted to climate changes) | Very high (very high confidence) | Habitat degradation, eutrophication, overfishing, pollution.       |   |  |



|              |           |                     |   |  |                                  |  |   |   |
|--------------|-----------|---------------------|---|--|----------------------------------|--|---|---|
| Kelp forests | MA, MM, F | Warming, heatwaves. | SST > MA, MM, F- high (obs+exp+proj)<br>pH/CO2 > MA-low (exp+proj)<br>SLR (nd)<br>Increased heatwaves and storm disturbances > MA- high (obs+exp+proj). | Low (kelps are highly sensible to warming and have low dispersal capacity) | Very High (very high confidence) | Habitat degradation by human activities. Overgrazing by sea urchins. | Mass mortality of kelps due to hetwaves combined with high irradiance; eutophication delays the re-establishment. Global range contractions of kelps at the warm end of distributional margins and expansions at the poleward end, spread of invasive species. Reduction in habitat complexity (from kelps to turfs). Macroalgae responses to acidification and warming depend on light and nutrient levels. Ecosystem biodiversity loss. In polar fjords, kelp fitness is reduced by warming and increased turbidity due to ice-melting. | Kelp forests in the higher rage of temperature distribution will experience the larger reduction due to warming, and those exposed to increased heatweaves events, such as kelp forests in Australia. |
|--------------|-----------|---------------------|---|--|----------------------------------|--|---|---|

**SM5.4 Additional Information Relating to ‘Ocean Solutions’ in Section 5.5.1.1**

Details are given in Tables SM5.9a and SM5.9b below on the ten potential ocean-based actions that provide the rows of Figure 5.23, and on the associated five benefits and four constraints that provide the columns of that figure. Additional information, including more than 500 supporting references, is given in Gattuso et al. (2018).

**Table SM5.9a:** Descriptions of ocean-based actions assessed in Figure 5.23. Global scale assumes worldwide implementation (at maximum theoretical level); local scale is based on implementation at less than ~100 km<sup>2</sup>. Three global-scale actions considered by Gattuso et al. (2018) are excluded here: land-ocean hybrid methods, marine cloud brightening, and increased surface ocean albedo.

| Action                                       | Description   | Scale            |
|--|---|------------------|
| Marine renewable energy (physical processes) | The production of energy using offshore wind turbines and harvesting of energy from tides, waves, ocean currents, and thermal stratification. This action is included for comparison of its benefits and constraint to those of others.   | Global           |
| Ocean fertilisation (open ocean)             | The artificial increase in the ocean’s primary production and carbon uptake by phytoplankton, achieved primarily by adding soluble iron to surface waters where it is currently lacking.  | Global           |
| Enhanced weathering (alkalinisation)         | The addition of a variety of minerals or other alkaline substances that consume CO <sub>2</sub> and/or neutralize acidity, usually involving raising the concentration of carbonate or hydroxide ions.  | Global and local |
| Restoring and conserving coastal vegetation  | Management of coastal ‘blue carbon’ ecosystems, primarily saltmarshes, mangroves and seagrasses, to enhance their carbon sink capacity and avoid emissions from the degradation or loss of their existing carbon stocks.  | Global and local |
| Marine protected areas                       | The conservation of habitats and ecosystems, in order to increase the abundance of marine species and thereby help protect natural populations against climate impacts.   | Local            |
| Reducing pollution (including nutrients)     | The decreased release of harmful substances that increase the sensitivity of marine organisms and ecosystems to climate-related drivers, or those that can directly exacerbate ocean acidification and hypoxia.   | Local            |
| Restoring hydrological regimes               | The maintenance and restoration of marine hydrological conditions, including the tidal and riverine delivery of water and sediments, to alleviate local changes in climate-related drivers.   | Local            |
| Eliminating over-exploitation                | Management action to ensure that living resources are sustainably harvested (within biologically safe limits and maintaining ecosystem function) and that the extraction of non-living resources (e.g., sand and minerals) is at levels that avoid irreversible ecological impacts. | Local            |
| Assisted evolution                           | The large-scale genetic modification, captive breeding and release of organisms with enhanced stress tolerance.   | Local            |
| Relocation and restoration (reef systems)    | The restoration and/or active relocation of degraded coral and oyster reefs, with the potential creation of new habitats and use of more resilient species or strains.  | Local            |

**Table SM5.9b:** The scoring schemes for the benefits and constraints relating to ocean-based actions described in Table SM5.9a above and summarised in Figure 5.23, assuming worldwide implementation for global scale actions, and implementation at less than ~100 km<sup>2</sup> for local scale. The 1 to 5 (very low to very high) scoring scale is based on combined assessments of the positive or negative consequences relating to four marine ecosystems and habitats (coral reefs, mangroves and saltmarshes, seagrass habitats and Arctic biota) and four marine ecosystem services (fin fisheries, finfish aquaculture, bivalve fisheries and aquaculture and coastal protection) arising from deployment of each action at its maximum physical capacity, with quantification based on a comprehensive literature review combined with expert judgement. Scores for benefits indicate the potential for reducing the difference in climatic impacts on between emissions scenarios RCP 8.5 and RCP 2.6 by 2100. Scores for constraints indicate the potential for adverse consequences or other issues that would need to be addressed for full-scale implementation. These scoring schemes follow those used in Gattuso et al. (2018), although the scores for constraints are reversed in scale.

| Benefits | Scoring scheme | Scale |
|----------|----------------|-------|
|----------|----------------|-------|



|  |  |        |
|--|--|--------|
| Impact reduction: warming  | Scoring scale: 1, cumulative carbon mitigation (reduction or removal) potential of 0 to 250 GtC to 2100; 2, mitigation potential of 250 to 500 GtC; 3, mitigation potential of 500 to 750 GtC; 4, mitigation potential of 750 to 1000 GtC; 5, mitigation potential of >1,000 GtC. Scale based on cumulative emission difference of 1400 GtC between RCP 2.6 and RCP 8.5, over the period 2012-2100.  | Global |
|  | Scores from assessment of effectiveness of local impact reduction, based on comparing projected warming impacts to 2100 of RCP 8.5 and RCP 2.6.  | Local  |
| Impact reduction: ocean acidification                                      | Scores based on carbon mitigation, allowing for specificities of actions with regard to their effects on seawater carbonate chemistry, and assuming a difference of 0.25pH units between RCP2.6 and RCP 8.5 for mean global surface seawater.  | Global |
|  | Scores from assessment of effectiveness of local impact reduction, based on comparing projected ocean acidification impacts of RCP 8.5 and RCP 2.6 to 2100   | Local  |
| Impact reduction: sea level rise   | Scores as for global warming mitigation less 1, to allow for inherent inertia of sea level response  | Global |
|  | Scores from assessment of effectiveness of local impact reduction, based on comparing projected sea level rise impacts of RCP 8.5 and RCP 2.6 to 2100  | Local  |
| Impact reduction: warming, ocean acidification and sea level rise combined | Mean score of mitigation for all three drivers of climate change.  | Global |
|  | Scores from assessment of effectiveness of local impact reduction, based on comparing projected warming, ocean acidification and sea level rise impacts f RCP 8.5 and RCP 2.6 to 2100  | Local  |
| Co-benefits  | Scores for literature-based expert judgement of potential non-climatic benefits at global scale, including improvement of ecosystem status and the generation of ecosystem services.   | Global |
|  | Scores for literature-based expert judgement of potential non-climatic benefits at local scale, including improvement of ecosystem status and the generation of ecosystem services.  | Local  |
| Constraints  | Scoring scheme   | Scale  |
| Trade-offs   | Scores for literature-based expert judgement of potential adverse impacts for ecosystems and ecosystem services arising as a result of the action. Societal effects (e.g. inequity) that depend on socio-economic scenarios are excluded. [Note that trade-offs are considered as 'dis-benefits' in Gattuso et al. (2018)]   | Global |
|  | As above, considered at local scale  | Local  |
| Technical issues to overcome   | A combined score for technological readiness (with range between fully ready for deployment and conceptual-only); lead time for full potential effectiveness (days/months to decades), and (im)permanence of effect (duration of effect once implemented), each assessed on 1-5 scale with higher scores indicating greater technological barriers.  | Global |
|  | As above, considered at local scale  | Local  |
| Cost (for warming mitigation)  | Mean values for carbon removal or emission reduction determined from the range of literature costs for implementation of actions. Scoring scale: 1, <10 US\$ per tonne CO <sub>2</sub> removed; 2, 10-60; 3, 60-110; 4, 110-160; 5, >160.  | Global |
|  | Mean values on a per unit area basis determined from the range of literature costs for implementation of actions. Scoring scale: 1, <100 US\$ per ha; 2, 100-200; 3, 200-300; 4, 300-400; 5, >400.   | Local  |
| Governability challenges   | Assessment of the capability of the global community of nation states and other international actors to implement actions through cooperation and coordination, based on semi-quantified biophysical factors (e.g., distribution of benefits and dis-benefits) and occurrence of formal and informal institutional arrangements. Sub-national governance challenges were also recognised as important by Gattuso et al. (2018), but were not scored. | Global |
|  | As above. For actions considered at both global and local scales, the same score was applied.  | Local  |

**SM5.5      Supplementary Information Supporting Table 5.7**

Summary of reported Adaptation responses (A), the Impacts (I) they aimed to address, and the expected Benefits (B) in coastal ecosystems within Physical, Ecological, Social, Governance, Economic and Knowledge categories. The Summary is presented in Table 5.7 and the papers used to support that assessment is found below.

Ecosystems: Coral Reefs

Climate drivers

Sea level rise

Increased storm wave energy and frequency

Ocean acidification

Anthropogenic co-drivers

*Physical:*

Dense urban development (Osorio-Cano et al., 2017; Beck et al., 2018; Gattuso et al., 2018) with coastal built infrastructure (Perkins et al., 2015) to accommodate population growth (Beck et al., 2018)

Physical damage from shipping (van Oppen et al., 2017), mining (Beck et al., 2018), dredging (Wynveen and Sutton, 2015), sedimentation (Wynveen and Sutton, 2015; Elliff and Silva, 2017) and destructive fishing techniques (van Oppen et al., 2017; Gattuso et al., 2018)

Pollution (Gallagher et al., 2015; Elliff and Silva, 2017; van Oppen et al., 2017; Gattuso et al., 2018)

*Ecological:*

Overharvesting (Wynveen and Sutton, 2015; van Oppen et al., 2017; Gattuso et al., 2018)

*Social:*

Marine tourism (Wynveen and Sutton, 2015)

Impact

*Physical:*

*Coastal physical processes disrupted*

Loss of coastal protection services (Lirman and Schopmeyer, 2016) resulting in coastal flooding (Perkins et al., 2015; Beetham et al., 2017; Elliff and Silva, 2017; Beck et al., 2018; Comte and Pendleton, 2018)

Habitat loss (Perkins et al., 2015; Gattuso et al., 2018 ) via increased wave energy (Beetham et al., 2017)

*Ecological:*

*Ecosystem degradation and loss*

Decreasing hydrodynamic roughness (Osorio-Cano et al., 2017)

Deteriorating quality of reef habitat (Lirman and Schopmeyer, 2016; van Oppen et al., 2017) including coral bleaching (Wynveen and Sutton, 2015; Elliff and Silva, 2017; Osorio-Cano et al., 2017; van Oppen et al., 2017; Beck et al., 2018; Comte and Pendleton, 2018; Gattuso et al., 2018)

*Biodiversity and genetic diversity loss*

Loss of reef-building taxa (Lirman and Schopmeyer, 2016) and biodiversity impacts (Lirman and Schopmeyer, 2016)

*Habitat range shifts*

Habitat range shifts (Gallagher et al., 2015; Miller et al., 2017)

*Sub-lethal species impacts*

Species level impacts (growth and reproduction) (Gallagher et al., 2015)

*Invasive alien species*

*Social:*

*Local decline in agriculture and fisheries*

Declining fisheries (Lirman and Schopmeyer, 2016)

Adaptation responses

*Physical:*

*Supporting physical processes*

Pollution reduction (Gattuso et al., 2018)

Restoring hydrology (Gattuso et al., 2018)

*Hard engineering responses*

Watershed management (Lirman and Schopmeyer, 2016)

*Ecological:*

*Ecosystem restoration and protection*

Protection and maintenance of coral reefs (Elliff and Silva, 2017; Comte and Pendleton, 2018; Gattuso et al., 2018)

Coral gardening and reef restoration (Lirman and Schopmeyer, 2016)

*Bioengineering*

Bioengineering by increasing habitat complexity on coastal structures (Perkins et al., 2015)

*Assisted evolution and relocation*

Assisted colonization (Gallagher et al., 2015; Lirman and Schopmeyer, 2016) and evolution (van Oppen et al., 2017; Gattuso et al., 2018)

Relocation (Gattuso et al., 2018)

*Social:*

*Switching livelihoods*

Fisheries engaging in alternative livelihoods (Miller et al., 2017)

Stakeholder involvement, including access to information, technology and funding (Miller et al., 2017)

*Community participatory programmes*

Building trust through community participation to increase buy-in for adaptation response (Wynveen and Sutton, 2015)

*Sustainable resource use*

Eliminating overexploitation (Gattuso et al., 2018)

Sustainable fishing practices (Lirman and Schopmeyer, 2016)

*Governance:*

Horizontal/ vertical integration of governance

Horizontal and vertical integration of organisations and policies (Miller et al., 2017)

*Developing partnerships and building capacity*

Engaging in tourism partnerships with other industries (Miller et al., 2017)

*Improving implementation and coordination of policies*

Interdisciplinary and cross-jurisdictional approaches (Miller et al., 2017)

*Improving ICM/ MPAs*

MPA establishment (Lirman and Schopmeyer, 2016)

*Multiple adaptation responses used*

Synergistic application of multiple responses supported (van Oppen et al., 2017)

Coral gardening and reef restoration need to be used with other tools such as watershed management, sustainable fishing practices, MPA establishment (Lirman and Schopmeyer, 2016)

*Benefits**Physical:**Physical processes supported*

Coastal protection (Perkins et al., 2015; Elliff and Silva, 2017; Comte and Pendleton, 2018) from flooding (Beetham et al., 2017; Beck et al., 2018)

*Ecological:**Ecosystem/ ecological resilience supported*

Improved ecosystem functioning (Perkins et al., 2015; Miller et al., 2017; Comte and Pendleton, 2018)

Restoration of coral reefs (Lirman and Schopmeyer, 2016; van Oppen et al., 2017) with increased reef resilience (Gattuso et al., 2018)

*Increased biodiversity*

Increased biodiversity (Gallagher et al., 2015; Perkins et al., 2015)

*Improved organismal fitness*

Increased reef resilience (Gattuso et al., 2018) including inter-habitat connectivity (Perkins et al., 2015; Lirman and Schopmeyer, 2016), vertical reef accretion (Beetham et al., 2017), stress tolerance (van Oppen et al., 2017) a

*Social:**Access to sustainable ecosystem services*

Reduced social vulnerability (through provisioning services) (Beck et al., 2018)

Improved ecosystem service provision (Perkins et al., 2015; Miller et al., 2017; Comte and Pendleton, 2018)

*Improved employment and livelihoods*

Improved livelihoods (Lirman and Schopmeyer, 2016)

*Increased adaptive capacity*

Reduced social vulnerability (through provisioning services) (Beck et al., 2018)

Improved coping and adaptive capacity (Beck et al., 2018)

*Governance:**Developing partnerships and building capacity*

Stakeholder-management trust encourages adoption of pro-environmental behaviour (Wynveen and Sutton, 2015)

*Economic:**Increased revenue/ income*

Revenue from tourism (Lirman and Schopmeyer, 2016; Comte and Pendleton, 2018)

*Knowledge:**Improved education and outreach*

Provide scientific information, education and outreach opportunities (Lirman and Schopmeyer, 2016)

## Co-benefits

### Constraints and limitations

#### *Physical:*

Site availability (Gallagher et al., 2015)

Reefs with low resilience from anthropogenic drivers are less likely to adapt to climate change impacts. (Elliff and Silva, 2017)

Tools not developed yet for large-scale implementation (van Oppen et al., 2017)

Ocean acidification as a limiting factor in warm water adaptation (Lirman and Schopmeyer, 2016; Miller et al., 2017)

#### *Ecological:*

Failure of some species to colonize restored reef (Gallagher et al., 2015)

Sea level rise may outpace reef vertical accretion (Beetham et al., 2017; Elliff and Silva, 2017)

Restoration efforts may not support intertidal communities (Perkins et al., 2015)

Natural systems with organismal thermal tolerance and limits with biochemical characteristics (Miller et al., 2017)

Coral predator abundances, disease impacts on out planted populations and nurseries and genetic impacts on extant nurseries (Lirman and Schopmeyer, 2016)

#### *Social:*

Social and cultural norms with conflicting and competing values (Miller et al., 2017), including loss of local support (Lirman and Schopmeyer, 2016) and vandalism and physical damage to nursery resources (Lirman and Schopmeyer, 2016)

Public lack of knowledge on climate change and distrust of information sources (Wynveen and Sutton, 2015)

#### *Governance:*

Effective implementation challenges (Comte and Pendleton, 2018)

Cross border coordination challenges (Gallagher et al., 2015)

Inadequate governance and institutional structures (Miller et al., 2017)

Turnover on personnel (Lirman and Schopmeyer, 2016)

#### *Economic:*

Economic undervaluation of ecosystems and the services they provide (Perkins et al., 2015)

Financial costs of design (Gallagher et al., 2015)

Lack of finances (Miller et al., 2017), including sustained funding beyond nursery stage (Lirman and Schopmeyer, 2016)

#### *Knowledge:*

Absence of baseline data may undermine coastline management (Perkins et al., 2015)

Knowledge gap on restoration of coral reef systems as an adaptation tool (Comte and Pendleton, 2018)

Public knowledge gaps and distrust of information sources (Wynveen and Sutton, 2015)

### Costs

#### *Physical:*

Site availability (Gallagher et al., 2015)

Reefs with low resilience from anthropogenic drivers are less likely to adapt to climate change impacts. (Elliff and Silva, 2017)

Tools not developed yet for large-scale implementation (van Oppen et al., 2017)

Ocean acidification as a limiting factor in warm water adaptation (Miller et al., 2017)

Coastal protection from flooding reducing annual expected costs by \$4 billion (Beck et al., 2018)

*Social:*

social and cultural norms with conflicting and competing values (Miller et al., 2017)

*Ecological:*

Failure of some species to colonize restored reef (Gallagher et al., 2015)

Sea level rise may outpace reef vertical accretion (Beetham et al., 2017; Elliff and Silva, 2017)

Restoration efforts may not support intertidal communities (Perkins et al., 2015)

Natural systems with organismal thermal tolerance and limits with biochemical characteristics (Miller et al., 2017)

*Economic:*

Economic undervaluation of ecosystems and the services they provide (Perkins et al., 2015)

Financial costs of design (Gallagher et al., 2015)

Lack of finances (Miller et al., 2017)

*Governance:*

Effective implementation challenges (Comte and Pendleton, 2018)

Cross border coordination challenges (Gallagher et al., 2015)

Inadequate governance and institutional structures (Miller et al., 2017)

*Knowledge:*

Absence of baseline data may undermine coastline management (Perkins et al., 2015)

Knowledge gap on restoration of coral reef systems as an adaptation tool (Comte and Pendleton, 2018)

Ecosystem: Mangroves

Climate drivers

Sea level rise

Increased storm wave energy and frequency

Extreme high tide events

Changed ocean circulation patterns

Drought and changes in rainfall patterns and intensity

Rising global temperatures in oceans and air

Anthropogenic co-drivers

*Physical:*

Dense urban development due to human population growth (Sierra-Correa and Cantera Kintz, 2015; Feller et al., 2017; Romañach et al., 2018)

Habitat transformation through coastal reclamation (Triyanti et al., 2017), mangrove in-filling (Gilman et al., 2008), conversion for agriculture, such as rice farming (Romañach et al., 2018) and aquaculture (Gilman et al., 2008; Feller et al., 2017; Nguyen et al., 2017; Romañach et al., 2018)

Over-exploitation of resources (Sierra-Correa and Cantera Kintz, 2015) such as timber (Nanlohy et al., 2015; Romañach et al., 2018) causing deforestation (Alongi, 2015), groundwater extraction (Triyanti et al., 2017), salt harvesting (Romañach et al., 2018)

Pollution (Gilman et al., 2008; Romañach et al., 2018)

*Ecological:*

Invasive species (Romañach et al., 2018)

*Governance:*

Poorly planned development (Sierra-Correa and Cantera Kintz, 2015)

Weak governance controls (Sierra-Correa and Cantera Kintz, 2015)

*Impact**Physical:**Coastal physical processes disrupted*

Coastal flooding (Alongi, 2015; Sierra-Correa and Cantera Kintz, 2015; Triyanti et al., 2017) causing increased erosion (Gilman et al., 2008)

Saline intrusion (Ward et al., 2016)

Loss of mangroves with releases of Greenhouse gases (Gilman et al., 2008), decreased accretion rates of inorganic sediments (Gilman et al., 2008), peat collapse and soil compression (Gilman et al., 2008) and reduced estuarine and coastal water quality (Gilman et al., 2008)

Increased sulphide soil toxicity (Gilman et al., 2008)

*Ecological:**Ecosystem degradation and loss*

Mangrove migration constrained by coastal squeeze (Feller et al., 2017)

Loss of mangroves (Nitto et al., 2014; Nanlohy et al., 2015; Sierra-Correa and Cantera Kintz, 2015; Feller et al., 2017)

Decreased habitat quality (Sierra-Correa and Cantera Kintz, 2015) including nursery habitats (Gilman et al., 2008), with changes in community composition (Gilman et al., 2008) including local extinctions (Gilman et al., 2008) due to salinity (Ward et al., 2016)

*Biodiversity and genetic diversity loss*

Biodiversity (Gilman et al., 2008; Alongi, 2015) and mangrove species genetic structure (Gilman et al., 2008) impacts

*Habitat range shifts*

Mangrove migration across a latitudinal gradient (Gilman et al., 2008; Alongi, 2015; Miller et al., 2017; Romañach et al., 2018) and landwards (Gilman et al., 2008; Nitto et al., 2014; Alongi, 2015; Nanlohy et al., 2015; Romañach et al., 2018)

*Sub-lethal species impacts*

Changes in reproduction and dispersion (Miller et al., 2017; Romañach et al., 2018), seedling survival (Gilman et al., 2008) and changes to propagule dispersal

Higher temperatures are likely to increase growth, reproduction, phenology (Gilman et al., 2008; Miller et al., 2017), photosynthesis and respiration rates (Alongi, 2015) with potential species richness and inter-specific interactions increasing (Miller et al., 2017)

Increased salinity causing decreasing net primary productivity and growth (Nanlohy et al., 2015)

Mangrove species specific differences in resilience to climate change due to morphology and anatomy (Alongi, 2015) including leaf anatomy, vascular vessel densities, diameter, grouping and length and fibre wall thickness (Alongi, 2015)

*Invasive alien species**Social:**Loss of ecosystem services*

Impacts on coastal protection (Ataur Rahman and Rahman, 2015; Ahmed and Glaser, 2016)

*Local decline in agriculture and fisheries*

Agricultural (Nanlohy et al., 2015) and fisheries production impacts through declines in catch and size of catch (Nanlohy et al., 2015)

*Increased community vulnerability*

Increased community vulnerability (Sierra-Correa and Cantera Kintz, 2015)

*Adaptation responses*

*Physical:*

*Supporting physical processes*

Ensure sediment supply to mangroves to support elevation (Sierra-Correa and Cantera Kintz, 2015)

Managing catchment activities that affect mangrove sediment elevation (Gilman et al., 2008)

Support mangrove sediment deposition and erosion processes to adjust to sea level change (Ward et al., 2016; Romañach et al., 2018)

*Hard engineering responses*

Hard engineering infrastructure to halt erosion (Gilman et al., 2008) including backlines to reduce flooding from sea (Sierra-Correa and Cantera Kintz, 2015)

Improving drainage systems (Sierra-Correa and Cantera Kintz, 2015)

*Managed retreat and coastal realignment*

Managed retreat allowing mangroves to migrate and retain their natural functional processes (Gilman et al., 2008)

*Ecological:*

*Ecosystem restoration and protection*

Eliminate conversion and support reclamation of wetlands. (Romañach et al., 2018)

Protection and maintenance of mangroves (Sierra-Correa and Cantera Kintz, 2015; Romañach et al., 2018) and mangrove restoration (Feller et al., 2017)

Ecosystem management interventions supporting positive surface elevation gains compared to sea level rise and salinity (Ward et al., 2016; Romañach et al., 2018)

*Social:*

*Sustainable resource use*

Sustainable resource use through harvesting only mature trees (Nguyen et al., 2017)

*Community participatory programmes*

Improved community participation in mangrove management programmes (Nanlohy et al., 2015)

Mangrove planting programmes (Triyanti et al., 2017) using contracts with local community members (Nguyen et al., 2017)

*Governance:*

*Adopting/ mainstreaming sustainability policies*

Increased political will to conserve (Gilman et al., 2008)

*Improving implementation and coordination of policies*

Interactive governance (Triyanti et al., 2017)

Better synergism between monitoring and implementation programmes (Gilman et al., 2008)

*Finance:*



*Improving financial resources availability*

Improve mangrove bonding social capital (Triyanti et al., 2017)

*Knowledge:**Better monitoring and modelling*

Regional monitoring networks (Gilman et al., 2008), improving data collection. (Romañach et al., 2018) and use of technologies and innovation (Nanlohy et al., 2015)

*Improving planning processes*

Improving site and land use planning (Gilman et al., 2008) using buffer areas (Sierra-Correa and Cantera Kintz, 2015) for managed retreat

*Improving decision support frameworks*

Establishing baselines (Gilman et al., 2008)

*Improving scientific communication*

Improving communication between scientists (Romañach et al., 2018) in multi-disciplinary teams (Nanlohy et al., 2015)

*Stakeholder identification, outreach and education*

Outreach and education to empower decisions makers and communities to make informed decisions (Gilman et al., 2008; Nanlohy et al., 2015; Romañach et al., 2018)

*Multiple adaptation responses used*

Addressing climate change impacts by reducing anthropogenic co-drivers (Gilman et al., 2008; Sierra-Correa and Cantera Kintz, 2015; Romañach et al., 2018)

*Benefits**Physical:**Physical processes supported*

Mangrove restoration may delay or buffer climate impacts (Romañach et al., 2018) by providing shoreline protection (Gilman et al., 2008; Alongi, 2015; Sierra-Correa and Cantera Kintz, 2015; Doughty et al., 2017; Nguyen et al., 2017; Sheng and Zou, 2017; Romañach et al., 2018), erosion protection (Triyanti et al., 2017) through shoreline stabilization (Nanlohy et al., 2015), raising sediments heights (Hayden and Granek, 2015) and inundation protection (Triyanti et al., 2017; Romañach et al., 2018) from storm surge and tsunamis through wave attenuation (Romañach et al., 2018)

Improved water quality (Gilman et al., 2008)

Vertical sediment accumulation may allow mangroves to outpace sea level rise (in areas of higher elevation and relatively low tidal range) (Romañach et al., 2018)

Sediment trapping (Kamal et al., 2017) including sequestration of nutrients and contaminants (Alongi, 2015) and carbon storage (Alongi, 2015; Nanlohy et al., 2015; Kelleway et al., 2016; Yando et al., 2016; Romañach et al., 2018)

*Ecological:**Ecosystem/ ecological resilience supported*

Increased structural heterogeneity (Romañach et al., 2018)

Improved biodiversity and ecological functioning (Triyanti et al., 2017) of nursery grounds (Sierra-Correa and Cantera Kintz, 2015; Miller et al., 2017; Romañach et al., 2018) and breeding sites (Alongi, 2015) supporting improved fisheries (Benzeev et al., 2017; Goecke and Carstenn, 2017)

Increased mangrove resilience and recovery (Romañach et al., 2018)

*Improved organismal fitness*

Increased primary production (Triyanti et al., 2017)

*Social:**Access to sustainable ecosystem services*

Improved fisheries (Benzeev et al., 2017; Goecke and Carstenn, 2017)

Sustained ecosystem services, including timber and fuelwood (Alongi, 2015; Nanlohy et al., 2015; Palacios and Cantera, 2017)

Improved cultural services (Triyanti et al., 2017; Romañach et al., 2018) including recreation and aesthetic experience (Triyanti et al., 2017)

*Human systems supported*

Supporting aquaculture (Huxham et al., 2015; Ahmed and Glaser, 2016)

*Improved employment and livelihoods*

Supporting coastal livelihoods (Triyanti et al., 2017) providing a source of income for communities (Nanlohy et al., 2015; Nguyen et al., 2017)

*Increased adaptive capacity*

Reduced vulnerability in communities (Gilman et al., 2008; Sierra-Correa and Cantera Kintz, 2015)

*Co-benefits**Social:*

Supporting coastal livelihoods (Triyanti et al., 2017) providing a source of income for communities (Nanlohy et al., 2015; Nguyen et al., 2017)

*Constraints and limitations**Physical:*

Insufficient mitigation of Greenhouse Gases will make adaptation more difficult. (Sierra-Correa and Cantera Kintz, 2015)

Mangroves occupy a range of tidal settings making it difficult to offer simple solutions (Alongi, 2015)

*Social:*

People are increasingly distanced from nature and may be less concerned about nature conservation (Romañach et al., 2018)

*Governance:*

Ineffective mangrove protection due to poor implementation of maintenance programmes (Nguyen et al., 2017)

Poor law enforcement and technical guidance (Nguyen et al., 2017)

Administrative and settlement boundaries do not always align with natural boundaries. (Triyanti et al., 2017)

Human adaptation response has not been keeping pace with sea level rise. (Gilman et al., 2008)

Inadequate governance and institutional structures, lack of finances, lack of information access, social and cultural norms, conflicting and competing values (Miller et al., 2017)

*Economic:*

Replanting and restoration communities may be more motivated by financial reward than ecological interest (Romañach et al., 2018)

*Knowledge:*

Perception of exclusion from resource harvesting due to poor understanding of mangrove protection services (Romañach et al., 2018)

Translating good science and strong community engagement into effective policy can be difficult due to disconnect between scientific, community and decision-making processes (Waite et al., 2015; Romañach et al., 2018)

Lack of data, funding and institutional trust (Torres and Hanley, 2017; Romañach et al., 2018)

Knowledge gaps in mangrove ecological and human management response to climate change (Ward et al., 2016)

Costs

Ecosystem: Salt marshes and wetlands

Climate drivers

Sea level rise

Ocean warming and changes in wave regimes

Changes in precipitation and storm patterns

Increased frequency and intensity of extreme events

Anthropogenic co-drivers

*Physical:*

Increase in human populations, development and infrastructure (Schuerch et al., 2018) and anthropogenic threats (Ondiviela et al., 2014)

Eutrophication (Watson et al., 2017; Wigand et al., 2017)

Mechanical damage of wetland meadows (e.g., dredging) (Ondiviela et al., 2014)

Impact

*Physical:*

*Coastal physical processes disrupted*

Increased coastal flooding (Wigand et al., 2017), changing sediment dynamics (Schaeffer-Novelli et al., 2016) with decreased sediment inputs (Watson et al., 2017), shoreline erosion (Ondiviela et al., 2014; Wigand et al., 2017) and salt water intrusion (Ondiviela et al., 2014; Miloshis and Fairfield, 2015; Schaeffer-Novelli et al., 2016)

Deterioration of water quality (nutrient loading, pollution and suspended material) (Ondiviela et al., 2014)

*Ecological:*

*Ecosystem degradation and loss*

Loss of wetlands (Schuerch et al., 2018), wetland degradation (Miloshis and Fairfield, 2015) and destruction of vegetation cover (Schaeffer-Novelli et al., 2016; Watson et al., 2017) including loss of root biomass (Schaeffer-Novelli et al., 2016)

*Biodiversity and genetic diversity loss*

Loss of biodiversity (Schuerch et al., 2018) including IUCN extinction list of 4 species (Ondiviela et al., 2014)

Increased rates of edge erosion (Watson et al., 2017)

*Sub-lethal species impacts*

Seasonal and geographic changes in abundance and distribution (Ondiviela et al., 2014; Schaeffer-Novelli et al., 2016), declines in macrophyte productivity (Watson et al., 2017), impacts on sea grass metabolism (Schaeffer-Novelli et al., 2016) and decreased crab herbivory (Watson et al., 2017) resulting in increased marsh vulnerability (Wigand et al., 2017)

Increased dissolved CO<sub>2</sub> concentrations promote growth (Ondiviela et al., 2014)

Increase in water velocity may contribute to plant productivity in some areas (Ondiviela et al., 2014)

*Invasive alien species*

Invasive species (Ondiviela et al., 2014)

*Social:**Decreased access to ecosystem services*

Loss of ecosystem services (Schuerch et al., 2018), including shoreline protection (Ondiviela et al., 2014)

*Adaptation responses**Physical:**Supporting physical processes*

Shoreline protection by raising the elevation of the marsh (Ondiviela et al., 2014) and increasing marsh drainage (Watson et al., 2017)

Dam removal (Wigand et al., 2017) allowing hydrologic remediation with restoration of sediment supplies (Watson et al., 2017)

Sediment diversion to reduce land conversions on flood plains and deltas (Miloshis and Fairfield, 2015)

*Integrated hard and soft engineering*

Artificial measures (construction of structures, beach nourishment or coastal realignment, hard structures), vegetation fields (mangroves or willow forests) and restoration of bay areas (Ondiviela et al., 2014)

*Managed retreat and coastal realignment*

Facilitating marsh upland migration (Schaeffer-Novelli et al., 2016; Wigand et al., 2017)

*Ecological:**Ecosystem restoration and protection**Bioengineering*

Eco-engineering using organisms (Ondiviela et al., 2014; Miloshis and Fairfield, 2015)

Reductions in edge losses using biomaterials (Watson et al., 2017)

*Economic:**Improving financial resources availability*

Interventions such as sediment subsidies (Watson et al., 2017)

*Knowledge:**Improving planning processes*

Spatial planning for wetland protection and management (Schuerch et al., 2018)

*Multiple adaptation responses used**Benefits**Physical:**Physical processes supported*

Vertical sediment accretion, which may outpace sea level rise (Schuerch et al., 2018)

Coastal flood protection (Miloshis and Fairfield, 2015; Wigand et al., 2017) through wave attenuation (Ondiviela et al., 2014; Schaeffer-Novelli et al., 2016)

Water quality improvement (Schaeffer-Novelli et al., 2016; Wigand et al., 2017; Schuerch et al., 2018) including improved water transparency, increased light availability and quality through trapping and sorting solid particles and dissolved nutrients (Ondiviela et al., 2014)

Sequestering carbon dioxide through burial or exporting offshore (Schaeffer-Novelli et al., 2016)

*Ecological:**Ecosystem/ ecological resilience supported*

Ecosystem engineers facilitating trophic transfer to adjacent habitats (Ondiviela et al., 2014)

Habitat sustainability providing support for species of concern (Wigand et al., 2017)

Improved primary productivity (Ondiviela et al., 2014) and a source of carbon to the detrital pool (Ondiviela et al., 2014)

*Increased biodiversity*

Increased biodiversity (Ondiviela et al., 2014; Miloshis and Fairfield, 2015)

*Habitat range shifts accommodated*

Facilitated marsh-upland migration. (Watson et al., 2017)

*Social:*

*Access to sustainable ecosystem services*

Support for fisheries (Ondiviela et al., 2014; Miloshis and Fairfield, 2015; Schaeffer-Novelli et al., 2016; Schuerch et al., 2018)

Improved ecosystem services like carbon sequestration (Schuerch et al., 2018) and climate regulation (Miloshis and Fairfield, 2015), nutrient sequestration (Wigand et al., 2017) and cycling (Miloshis and Fairfield, 2015), sediment and biomatter accumulation and the provision of a vegetative buffer to reduce flow velocities during tidal and storm surges (Miloshis and Fairfield, 2015)

*Co-benefits*

*Constraints and limitations*

*Physical:*

Constraints on the inland migration of coastal wetlands due to adverse human-modified soil conditions, unsuitable geomorphological characteristics or elevation constraints (Schuerch et al., 2018)

Areas with high sediment input from riverine sources are likely to accommodate a 1m rise in sea level (Miloshis and Fairfield, 2015)

*Ecological:*

Genetic diversity could help the plants adapt to higher temperatures through individual thermal tolerances if changes occur at a slow enough rate (Ondiviela et al., 2014)

*Governance:*

Balancing adaptation expenses against pervasive marsh loss (Watson et al., 2017)

*Knowledge:*

Inherent uncertainties in models (Schaeffer-Novelli et al., 2016)

*Costs*

Ecosystem: Estuaries

Climate drivers

Sea level rise

Increased ocean temperature

Changes in wave action and storm surge

Increased storm frequency and severity

Changes in rainfall and evapotranspiration patterns

Ocean acidification

Anthropogenic co-drivers

*Physical:*

Increasing coastal populations (Runting et al., 2017) combined with inappropriate development and infrastructure (Barbier, 2015b; Peirson et al., 2015; Wigand et al., 2017), resulting in habitat loss and alteration (Peirson et al., 2015)

Dam emplacement (Wigand et al., 2017), freshwater diversions (Peirson et al., 2015), catchment agriculture (Robins et al., 2016; Sheaves et al., 2016), deforestation (Wigand et al., 2017) and dredging (Peirson et al., 2015)

Poorly planned and managed aquaculture and shellfish fisheries (Robins et al., 2016), fisheries over-exploitation (Peirson et al., 2015)

Organic carbon loading (Peirson et al., 2015), nutrient enrichment (Peirson et al., 2015) and eutrophication (Thorne et al., 2017; Wigand et al., 2017)

#### *Ecological:*

Alien invasive species (Peirson et al., 2015)

#### *Impact*

#### *Physical:*

##### *Coastal physical processes disrupted*

Increased coastal flood risk (Monbaliu et al., 2014; Robins et al., 2016; Wigand et al., 2017) with extreme water levels and changes in flood current velocity (Seiffert and Hesser, 2014), increased tidal range (Monbaliu et al., 2014; Peirson et al., 2015) and tidal dynamics (Seiffert and Hesser, 2014)

Shoreline erosion (Robins et al., 2016; Wigand et al., 2017) increased due to wetland loss

Decreased freshwater flow (Peirson et al., 2015), salinity intrusion (Robins et al., 2016; Seiffert, 2014 #107), nutrient enrichment and eutrophication (Robins et al., 2016) resulting in deteriorating water quality (Robins et al., 2016)

Increased hypoxia (Robins et al., 2016)

##### *Coastal infrastructure damage*

Damage to coastal infrastructure (Thorne et al., 2017) and property with increased vulnerability (Barbier, 2015b; Robins et al., 2016)

#### *Ecological:*

##### *Ecosystem degradation and loss*

Wetlands lost through inundation (Runting et al., 2017; Wigand et al., 2017)

Habitat modification (Robins et al., 2016) including vegetation type changes and soil moisture reductions (Robins et al., 2016) resulting changes in coastal wetland distribution (Runting et al., 2017) and marsh vulnerability (Wigand et al., 2017)

##### *Biodiversity and genetic diversity loss*

##### *Habitat range shifts*

Habitat modification (Robins et al., 2016) including vegetation type changes and soil moisture reductions (Robins et al., 2016) resulting changes in coastal wetland distribution (Runting et al., 2017) and marsh vulnerability (Wigand et al., 2017) causing changes in breeding grounds (Peirson et al., 2015) and species composition (Peirson et al., 2015; Thorne et al., 2017)

##### *Sub-lethal species impacts*

Changes in breeding grounds (Peirson et al., 2015) and species composition (Peirson et al., 2015; Thorne et al., 2017)

##### *Invasive alien species*

Increased invasive species (Robins et al., 2016)

#### *Social:*

*Public health risks*

Harmful algae blooms (Robins et al., 2016)

*Adaptation responses**Physical:**Supporting physical processes*

Adaptive sediment management (Seiffert and Hesser, 2014)

Catchment dam removal (Wigand et al., 2017) supported by appropriate built infrastructure (Barbier, 2015b)

*Hard engineering responses*

Hydraulic engineering structures, including barriers narrowing the estuaries mouth to dampen storm surge (Seiffert and Hesser, 2014)

Catchment dam removal (Wigand et al., 2017) supported by appropriate built infrastructure (Barbier, 2015b)

*Managed retreat and coastal realignment*

Facilitate landward migration (Runting et al., 2017; Wigand et al., 2017)

*Ecological:**Ecosystem restoration and protection*

Restoration (Barbier, 2015b; Wigand et al., 2017)

Expanding the coastal reserve network to accommodate wetlands response (Runting et al., 2017)

*Governance:**Adopting/ mainstreaming sustainability policies*

Local planning authorities pre-emptively limit development in dry land areas that are likely to transition to wetlands under climate change (Runting et al., 2017)

*Development controls*

Local planning authorities pre-emptively limit development in dry land areas that are likely to transition to wetlands under climate change (Runting et al., 2017)

*Knowledge:**Better monitoring and modelling*

Improve estuarine modelling (Monbaliu et al., 2014) and long term monitoring effort (Robins et al., 2016)

Improve monitoring of estuary hydrology and dynamics (Wigand et al., 2017)

*Stakeholder identification, outreach and education*

Improve stakeholder identification and engagement to improve systems knowledge (Peirson et al., 2015)

*Multiple adaptation responses used**Physical:*

Catchment dam removal (Wigand et al., 2017) supported by appropriate built infrastructure (Barbier, 2015b)

*Benefits**Physical:**Physical processes supported*

Protection (Wigand et al., 2017) against storms and coastal floods (Robins et al., 2016), mainly through wave attenuation (Barbier, 2015b; Runting et al., 2017)

Nutrient retention (Runting et al., 2017; Wigand et al., 2017) and cycling of organic (Robins et al., 2016; Runting et al., 2017) and suspended particulate matter (Robins et al., 2016)

Water quality maintenance (Peirson et al., 2015)

*Ecological:*

*Ecosystem/ ecological resilience supported*

Water quality improvement (Peirson et al., 2015) supporting habitat for wildlife (Wigand et al., 2017), including improving nursery areas (Sheaves et al., 2016; Runting et al., 2017) for commercial fisheries (Peirson et al., 2015) or breeding areas for terrestrial animals like birds (Robins et al., 2016)

*Increased biodiversity*

Support optimal biodiversity (Sheaves et al., 2016)

*Social:*

*Access to sustainable ecosystem services*

Improved water supply for agriculture (Peirson et al., 2015) and aquaculture (Peirson et al., 2015)

*Human systems supported*

Improved water supply for tourism, heritage and recreational water uses (Peirson et al., 2015; Robins et al., 2016)

*Improved health*

Healthy human living environments (Sheaves et al., 2016)

*Knowledge:*

*Improved education and outreach*

Social learning during vulnerability assessments can play a key role in climate change adaptation planning through stakeholder engagement, learning and sharing of best practices (Thorne et al., 2017)

*Co-benefits*

*Constraints and limitations*

*Physical:*

Landward estuarine migration constraints (Robins et al., 2016)

Inherent complexity of coastal systems and climate change make it difficult to predict specific shoreline changes (Wigand et al., 2017) and requires an adaptive management strategy (Wigand et al., 2017)

*Ecological:*

Physical and ecological constraints on restoration actions (Wigand et al., 2017)

Biodiversity and community composition changes and the emergence of novel ecosystems will make protecting some species and ecosystems difficult (Wigand et al., 2017)

*Governance:*

Opportunity costs associated with retreat are borne immediately whereas the benefits take much longer to materialize (Runting et al., 2017)

Time, money and staff resources (Thorne et al., 2017)

Complex governance landscape (Sheaves et al., 2016)

Barriers include lack of funding, policy and institutional constraints and precise information on climate change projections (Wigand et al., 2017)

*Knowledge:*

Scale-relevant information for local decision making (Thorne et al., 2017)

Continuously evolving and large body of scientific publications about climate change (Thorne et al., 2017)

Rural areas require local adaptation strategies that rely on soft engineering and improved community awareness (Robins et al., 2016)



## Costs

Additional resources are required to expand the wetlands reserve network to allow for wetland migration depending on future climate scenario (Runting et al., 2017). Despite these higher costs, payments for ecosystem services have the potential to substantially reduce the net cost of expanding. (Runting et al., 2017)

## Ecosystem: Multiple Ecosystems

### Climate drivers

#### Sea level rise

#### Ocean warming

#### Storm frequency and intensity

### Anthropogenic co-drivers

#### *Physical:*

Habitat loss (Williams et al., 2016) or fragmentation (Hernández-González et al.) due to urbanisation (Hernández-González et al.; Williams et al., 2016) and development, including conversion of estuarine land to agriculture, compounded by poor agricultural practices (Hernández-González et al.) or aquaculture (Hernández-González et al.)

Agricultural, industrial and tourist activities impact aquaculture species composition (Williams et al., 2016)

Unsustainable exploitation of resources (Jiao et al., 2015; Williams et al., 2016) including mangrove harvest (Hernández-González et al.), overfishing and destructive fishing (Hernández-González et al.)

Intensive irrigation and dams (Hernández-González et al.)

Pollution (Jiao et al., 2015) including eutrophication (Williams et al., 2016), effluent from aquaculture (Williams et al., 2016)

### Impact

#### *Physical:*

##### *Coastal physical processes disrupted*

Coastal erosion (Hernández-González et al.) causing increased flooding of low-lying lands and salinization of groundwater (Hernández-González et al.)

##### *Coastal infrastructure damage*

Impacts on shoreline developments (Williams et al., 2016) compounded by coastal squeeze (Hernández-González et al.)

#### *Ecological:*

##### *Ecosystem degradation and loss*

Degradation of marine and coastal ecosystems (Jiao et al., 2015), causing impaired ecosystem functioning (Williams et al., 2016), shifts in ecological communities (Williams et al., 2016) and loss of biodiversity (Williams et al., 2016)

#### *Social:*

##### *Increased food insecurity*

Food security impacts (Williams et al., 2016)

### Adaptation responses

#### *Physical:*

##### *Integrated hard and soft engineering*

Ecosystem-based coastal defence structures, green: coastal defences selecting more tolerant species or strains and protecting key habitats under expanding aquaculture (Williams et al., 2016)

Incorporate proven management interventions (such as hybrid engineering structures) (Hernández-González et al., 2016)

*Managed retreat and coastal realignment*

Incorporate proven management interventions (such as managed realignment) (Hernández-González et al., 2016)

*Ecological:*

*Ecosystem restoration and protection*

Marine EBA: maintaining the balance and health of ecosystems (Jiao et al., 2015)

Incorporate proven management interventions (such as habitat restoration) (Hernández-González et al., 2016)

*Social:*

*Sustainable resource use*

Building resilience of socio-economic and ecological systems through sustainable management of natural resources (Hernández-González et al., 2016)

*Building socio-ecological resilience*

Building resilience of socio-economic and ecological systems through sustainable management of natural resources (Hernández-González et al., 2016)

*Governance:*

*Adopting/ mainstreaming sustainability policies*

Implement policies to support environmental integrity (Hernández-González et al., 2016)

Bring ecosystems into mainstream decision-making processes (Hernández-González et al., 2016)

Incorporate proven management interventions (such as MPAs, habitat restoration, managed realignment and hybrid engineering structures) (Hernández-González et al., 2016)

*Improving ICM/ MPAs*

Incorporate proven management interventions (such as MPAs) (Hernández-González et al., 2016)

*Developing partnerships and building capacity*

Build capacity for implementation (Hernández-González et al., 2016)

*Economic:*

*Economic diversification*

Building resilience of socio-economic and ecological systems through economic diversification (Hernández-González et al., 2016)

*Knowledge:*

*Better monitoring and modelling*

Develop regional, fine scale databases to identify possible winners or losers species for use in green coastal defences (Williams et al., 2016)

Developing evidence of climate related declines in foundational species and their associated marine ecosystems. (Williams et al., 2016)

*Improving decision support frameworks*

Consider ecosystems in vulnerability assessments of coastal communities (Hernández-González et al., 2016)

*Improving participatory processes*

Engage stakeholders (Hernández-González et al., 2016)

*Integrating knowledge systems*

Evidence for improving application of EBA responses through integrating traditional infrastructure (Perkins et al., 2015; Sutton-Grier et al., 2015; Sánchez-Arcilla et al., 2016; van der Nat et al., 2016)

*Multiple adaptation responses used*

EBA and CBA (Hernández-González et al., 2016)

Benefits

*Physical:*

*Physical processes supported*

Protection from storms surge (Williams et al., 2016) and coastal erosion prevention (Williams et al., 2016) by reducing wave energy (Hernández-González et al., 2016)

Increasing sedimentation and movement of sediment (Hernández-González et al., 2016) and contaminant filtration (Williams et al., 2016)

*Ecological:*

*Ecosystem/ ecological resilience supported*

Improved nursery grounds (Williams et al., 2016)

*Social:*

*Increasing resilience in human systems*

Aquaculture benefits providing food security (Williams et al., 2016)

Co-benefits

The co-benefits of ‘soft’ engineering options common for the ecosystems assessed include increasing ecological complexity, with multiple services provided, many economic benefits, and resilience to climate change (Perkins et al., 2015; Perry, 2015; Moosavi, 2017; Scarano, 2017)

The application of synergistic combinations of ecosystems can provide a range of co-benefits, and this approach is strengthened when combined with socio-institutional approaches (Kochnower et al., 2015; MacDonald et al., 2017)

Constraints and limitations

*Ecological:*

Multiple simultaneous stressors induce highly variable species responses impacting upon effectiveness of EBA response (Williams et al., 2016)

Coastal habitats such as salt marshes and mangroves may have an advantage over engineered coastal defences if they increase in elevation and grow with SLR

*Knowledge:*

There is a need to advance coastal protection science by quantifying ecosystem services (Hernández-González et al., 2016)

Developing scenarios and tools to model complex combined risks to build decision-support systems for communities (Hernández-González et al., 2016)

Few syntheses of the context-specific application and cost-effectiveness of EBA approaches are to be found in the literature (Narayan et al., 2016)

Further research evaluating natural infrastructure is required (Roberts et al., 2017)

Costs

*Physical:*

Green coastal defence structures are expensive to maintain (Williams et al., 2016)

*Ecological:*

Coastal ecosystems can play an important and cost-effective role in reducing vulnerability (Hernández-González et al., 2016)

Ecosystem: Sandy beaches and dune systems

Climate drivers

Sea level rise

Increased storminess and storm surge

Extreme winds

Changes in rainfall

Anthropogenic co-drivers

*Physical:*

Increasing human coastal populations (Poumadère et al., 2015; Ranasinghe, 2016; Sánchez-Arcilla et al., 2016) leading to coastal development (Onaka et al., 2015; Ranasinghe, 2016; Ciccarelli et al., 2017; MacDonald et al., 2017; Pranzini, 2017; Salgado and Martinez, 2017; Vikolainen et al., 2017; Gracia et al., 2018) with vegetation clearing (Ciccarelli et al., 2017; Magnan and Duvat, 2018) and loss of sediment (Salgado and Martinez, 2017)

Unsustainable resource exploitation (Nehren et al., 2017)

*Social:*

Tourism (Onaka et al., 2015)

*Governance:*

Mismanagement practices (Carro, 2018)

Lack of integrated coastal management (Nehren et al., 2017)

Impact

*Physical:*

*Coastal physical processes disrupted*

Coastal squeeze (Villatoro et al., 2014) and erosion (Onaka et al., 2015; Poumadère et al., 2015; Ranasinghe, 2016; Sánchez-Arcilla et al., 2016; Goreau and Prong, 2017; Nehren et al., 2017; Pranzini, 2017; Salgado and Martinez, 2017; Vikolainen et al., 2017; Gracia et al., 2018) of sandy beaches, dunes, and bluffs (MacDonald et al., 2017; Shumack and Hesse, 2017; Carro, 2018; Magnan and Duvat, 2018)

Flooding (Villatoro et al., 2014; Poumadère et al., 2015; Sutton-Grier et al., 2015; Sánchez-Arcilla et al., 2016; Goreau and Prong, 2017; Nehren et al., 2017; Salgado and Martinez, 2017; Vikolainen et al., 2017)

*Ecological:*

*Ecosystem degradation and loss*

Fire and vegetation removal (Shumack and Hesse, 2017)

*Social:*

*Decreased access to ecosystem services*

Reduced ecosystem services (Nehren et al., 2017)

Adaptation responses

*Physical:*

*Supporting physical processes*

Recovery of natural buffer (100m unbuilt strip of vegetation) (Magnan and Duvat, 2018)

*Hard engineering responses*

Hard defences, including submerged breakwaters and groins (Sutton-Grier et al., 2015; Pranzini, 2017)

*Soft engineering responses and buffers*

Soft sand engineering (landscaping) (Sutton-Grier et al., 2015; Vikolainen et al., 2017)

Artificial dune/beach sand replenishment (Pranzini, 2017)

Vegetation planting (Magnan and Duvat, 2018)

*Integrated hard and soft engineering*

Hybrid hard and soft engineering solutions (Sutton-Grier et al., 2015; Martínez et al., 2017)

Sustainable drainage systems (Salgado and Martinez, 2017; Carro, 2018)

*Managed retreat and coastal realignment*

Shoreline natural readjustment and coastal managed realignment (MacDonald et al., 2017)

*Ecological:**Ecosystem restoration and protection*

Recovery of natural buffer (100m unbuilt strip of vegetation) (Magnan and Duvat, 2018)

Shoreline protection (Salgado and Martinez, 2017) through the creation and restoration of coastal ecosystems (e.g., dunes, sandy beaches and bluffs (Carro, 2018) and re-vegetation for dune regeneration (Salgado and Martinez, 2017; Carro, 2018)

Conserving, sustainably managing, and restoring (Nehren et al., 2017)

*Social:**Sustainable resource use*

Reduction of human use pressures (Salgado and Martinez, 2017; Carro, 2018)

Sustainable coastal management where old railways were transformed into walking and cycling routes and the railway embankment became a promenade (Pranzini, 2017)

*Governance:**Adopting/ mainstreaming sustainability policies*

Integrate management of ecology, recreation and land use with other aspects of coastal management (Vikolainen et al., 2017; Gracia et al., 2018)

*Developing partnerships and building capacity*

Capacity development in coastal protection and rehabilitation in Mauritius (Onaka et al., 2015)

*Knowledge:**Improving decision support frameworks*

Conceptual assessment design of the ecosystem (Gracia et al., 2018)

Integration of indicators and tools (Gracia et al., 2018)

Development of decision support systems (Gracia et al., 2018)

*Multiple adaptation responses used**Physical:*

Reduction of human use pressures (Salgado and Martinez, 2017; Carro, 2018)

*Benefits**Physical:**Physical processes supported*

Reduced coastal erosion (Sánchez-Arcilla et al., 2016; Goreau and Prong, 2017; Vikolainen et al., 2017; Carro, 2018; Gracia et al., 2018) through maintaining dunes (Pranzini, 2017) as natural buffers to wave

energy (Nehren et al., 2017), reducing flood risk (Onaka et al., 2015; MacDonald et al., 2017; Nehren et al., 2017) and increasing resilience to climate change impacts (Sutton-Grier et al., 2015; Gattuso et al., 2018)

Carbon sequestration (Gracia et al., 2018)

*Ecological:*

*Ecosystem/ ecological resilience supported*

Stimulate natural dune growth (Vikolainen et al., 2017)

Secure sustainable natural resources (Vikolainen et al., 2017; Gracia et al., 2018; Magnan and Duvat, 2018) like dunes (Onaka et al., 2015) to improve ecosystem capacity to cope with climate change impacts (Gracia et al., 2018)

*Increased biodiversity*

Stimulating biodiversity conservation (Gracia et al., 2018)

Natural infrastructure provides additional goods and services to humans, as opposed to built infrastructure which only provides coastal flood protection (Sutton-Grier et al., 2015)

*Strengthened socio-ecological system*

Strengthening resilience of both natural and human systems to coastal erosion effect (Gracia et al., 2018)

*Social:*

*Access to sustainable ecosystem services*

Secure ecosystem services (Nehren et al., 2017)

*Improved community participation*

Encouraging community participation (Gracia et al., 2018)

*Improved socio-economic services*

Socio-economic services maintained (MacDonald et al., 2017) with increase in nature-based recreation (MacDonald et al., 2017)

*Governance:*

*Political and institutional capacity developed*

Capacity building of municipal staff and stakeholders (Carro, 2018)

*Improved adaptive management*

Incorporation of EBA by subnational-level coastal governments (Carro, 2018)

*Improved implementation and policies*

Policy gaps addressed (Pranzini, 2017)

*Knowledge:*

*Improved co-production of knowledge*

Knowledge development and innovation (Pranzini, 2017; Vikolainen et al., 2017)

*Improved education and outreach*

Knowledge exchange with national decision makers and scientists (Carro, 2018)

Opportunity for ecological and conservation scientists to interact with social, economic and political scientists on ecosystem-based adaptation research (Scarano, 2017)

*Co-benefits*

*Ecological:*

Stimulating biodiversity conservation (Gracia et al., 2018)

Natural infrastructure provides additional goods and services to humans, as opposed to built infrastructure which only provides coastal flood protection (Sutton-Grier et al., 2015)

Constraints and limitations

*Physical:*

Space requirements (Sutton-Grier et al., 2015; Sánchez-Arcilla et al., 2016; Salgado and Martinez, 2017)

Natural vegetation cannot always protect shorelines in every location and/or situation (Salgado and Martinez, 2017)

Level of flood and erosion protection is limited by the condition of the dune system (Nehren et al., 2017)

Natural and hybrid infrastructure can take a lot longer to build than hard infrastructure (Sutton-Grier et al., 2015).

*Ecological:*

Slow recovery periods of natural systems (Gracia et al., 2018) and for ecological succession (Salgado and Martinez, 2017)

*Governance:*

Policy (Sánchez-Arcilla et al., 2016) and regulations can constrain this kind of restoration (Vikolainen et al., 2017)

Public and policy need to redefine dune protection in the context of sustainable development (Nehren et al., 2017)

Lack of expertise to implement hybrid solutions (Sutton-Grier et al., 2015)

*Economic:*

Economic constraints include cost of implementation and high cost of coastal land (Gracia et al., 2018)

Cheaper than man-made structures. (Nehren et al., 2017; Salgado and Martinez, 2017; Vikolainen et al., 2017; Gracia et al., 2018)

*Knowledge:*

Local conditions-compliant design requirement (Vikolainen et al., 2017)

Knowledge of which plant species to use (Salgado and Martinez, 2017)

Ecosystem-based adaptation research takes place within the socio-ecological systems framework, which is often carried out in isolation from socio-technical systems research. These should be integrated (Scarano, 2017)

Lack of data for cost-benefit analysis (Sutton-Grier et al., 2015).

Costs

Net annual provision of services is £262,935 (£1460.75/ha) at Hesketh Outmarsh West and £93,216 (£574.70/ha) at Inch of Ferryton (MacDonald et al., 2017)

Natural resilience larger for more energetic coasts, lower for littorals with milder drivers (Poumadère et al., 2015)

## **SM5.6      Supplementary Information Supporting Table 5.8**

Summary of reported Adaptation responses (A), the Impacts (I) they aimed to address, and the expected Benefits (B) in human systems within Physical, Ecological, Social, Governance, Economic and Knowledge categories. The Summary is presented in Table 5.8 and the papers used to support that assessment is found below.

Human System: Coastal Communities

Climate drivers

Sea level rise

Coastal Flooding

Saline intrusion

Drought

Extreme rainfall events and rainfall variability

Ocean warming

Increased frequency of climate change disasters

Increased monsoon intensity

Anthropogenic co-drivers

*Physical:*

Population growth (Marfai et al., 2015; Nursey-Bray et al., 2015; Wise et al., 2016) and rapid coastal urbanisation (Abedin et al., 2014; Lieske et al., 2014; Aatur Rahman and Rahman, 2015; Karlsson and Hovelsrud, 2015; Hobday et al., 2016; Betzold and Mohamed, 2017; Hagedoorn et al., 2019), including increases in daytime populations (Esteban et al., 2017), industrialization (Aatur Rahman and Rahman, 2015)

Landscape land use change, including hardened impermeable surfaces (with poor drainage and low infiltration) (Broto et al., 2015) and reclaimed agricultural land (Jones and Clark, 2014)

Settlement location in low lying areas (Linkon, 2018) , for example, the majority of people in SIDS live below the 4 meter contour, which is 2m above the present day high tide mark) (Hagedoorn et al., 2019)

Poorly planned (Aatur Rahman and Rahman, 2015) and inappropriately located (Abedin et al., 2014) construction and poorly maintained infrastructure (Abedin et al., 2014) including land reclamation (Betzold and Mohamed, 2017), land use change (Nagy et al., 2014; Marfai et al., 2015), embankments, polderization and unplanned afforestation (Aatur Rahman and Rahman, 2015), coastal squeeze (Betzold and Mohamed, 2017)

Pollution (DasGupta and Shaw, 2015; Marfai et al., 2015; Bennett et al., 2016; Hobday et al., 2016; Betzold and Mohamed, 2017; Hagedoorn et al., 2019), including solid waste (Broto et al., 2015; Marfai et al., 2015; Bennett et al., 2016; Betzold and Mohamed, 2017), contamination of ground and surface water (Aatur Rahman and Rahman, 2015) e.g. arsenic contamination (Abedin et al., 2014)

Increased waste (Dhar and Khirfan, 2016; Betzold and Mohamed, 2017) and pollution (Aatur Rahman and Rahman, 2015; Betzold and Mohamed, 2017)

Reduction of freshwater flow due to abstraction (Aatur Rahman and Rahman, 2015); Groundwater extraction (leading to land subsidence) (Marfai et al., 2015)

Fire damage (Bennett et al., 2016)

Informal settlements (located in areas with high flood risk; unregulated; lack infrastructural services; poor sanitation and drainage) (Broto et al., 2015; Marfai et al., 2015)

Geographic remoteness of islands (DasGupta and Shaw, 2015; Karlsson and Hovelsrud, 2015)

Impacts on sea ice and Artic ecology (Ford et al., 2016)

*Ecological:*

Unsustainable exploitation (Cinner et al., 2018) of mangroves (Aatur Rahman and Rahman, 2015) and dependence on natural resources (Cinner et al., 2018)

Habitat transformation (Hobday et al., 2016; Cinner et al., 2018) including forests and wetlands for rice agriculture (Aatur Rahman and Rahman, 2015; Marfai et al., 2015), mangrove forests (DasGupta and Shaw, 2015; Leon et al., 2015), reefs, sea grass and mangroves (Dhar and Khirfan, 2016), traditionally managed floodplains and coastal ecosystems (Aatur Rahman and Rahman, 2015) causing biodiversity loss (Nursey-Bray et al., 2015; Hagedoorn et al., 2019)



Low sand production (due to damaged ecosystems) impacting beach erosion (Dhar and Khirfan, 2016)

Illegal farming and deforestation in the Morass, which is slowly drying out (losing its basic functions, including flood alleviation, filtering nutrients and chemicals) (Dhar and Khirfan, 2016) causing increasing ecosystem vulnerability (Dhar and Khirfan, 2016)

Removal of coastal vegetation (Barbier, 2015a)

#### *Social:*

Socio-economic conditions (Smith and Rhiney, 2016; Jamero et al., 2018), including poverty (Jurjonas and Seekamp, 2018) food insecurity; housing shortage and poverty (Jamero et al., 2018), aging demographics (Jurjonas and Seekamp, 2018) and out-migration (Nurse-Bray et al., 2015; Jurjonas and Seekamp, 2018) in for example, Inuit communities (Ford et al., 2016)

Growing exposure of marginalised communities with limited power and agency (Wise et al., 2016)

Increased vulnerability on coastal floodplains from growing populations and industrialization (Ataur Rahman and Rahman, 2015), high levels of dependency on agriculture and fishing (Nagy et al., 2014; DasGupta and Shaw, 2015; Hobday et al., 2016; Smith and Rhiney, 2016) and over-fishing (Ataur Rahman and Rahman, 2015; Hobday et al., 2016)

Excessive use of resources (Dhar and Khirfan, 2016), including groundwater for irrigation (prime reason for arsenic contamination) (Abedin et al., 2014) and shrimp farming (Abedin et al., 2014), compounded by community reliance on groundwater for drinking, resulting in groundwater depletion (Abedin et al., 2014)

Unregulated sand mining (Ataur Rahman and Rahman, 2015; Karlsson and Hovelsrud, 2015; Betzold and Mohamed, 2017), including marine sand (Betzold and Mohamed, 2017) and weak enforcement measures (Betzold and Mohamed, 2017) compounded by a heavy dependency upon sand mining as an important source of income in Comoros (Betzold and Mohamed, 2017)

Social, political, economic, demographic and environmental changes occurring at local and national scales compound these changes. Some coastal communities are struggling to adapt to these changes with an increase in their vulnerability (Bennett et al., 2016)

Low access to health-sustaining resources (Ford et al., 2016)

Livelihoods in coastal communities have shifted away from subsistence fishing and agriculture towards dependence upon employment in the fisheries, agriculture, plantation and tourism sectors (Bennett et al., 2016)

Lack of loss of traditional practices and knowledge (Ataur Rahman and Rahman, 2015), for example in disaster and risk management (Audefroy and Sánchez, 2017)

Loss of ecosystem services means that these communities cannot respond to crises (DasGupta and Shaw, 2015)

Social fragmentation (Petzold and Ratter, 2015)

Modernization of villages (become reliant on capitalist activities) (Sakakibara, 2017)

Inability of different socio-economic groups to anticipate and respond to climate threats (Smith and Rhiney, 2016)

#### *Governance:*

Misuse of resources (Ataur Rahman and Rahman, 2015)

Coastal Zone Policy does not include ICZM (Ataur Rahman and Rahman, 2015) and is not informed by local knowledge (Ataur Rahman and Rahman, 2015) or local ecosystems (Ataur Rahman and Rahman, 2015) and is poorly implemented (Ataur Rahman and Rahman, 2015)

There is a disconnect between the national agencies and local level implementation in communities (Ataur Rahman and Rahman, 2015) with top-down decision making (Ataur Rahman and Rahman, 2015), political institutional barriers (Ataur Rahman and Rahman, 2015) and centralised risk and disaster policies (Audefroy and Sánchez, 2017), resulting in local communities, who are poorly adapted to climate change impacts

Poor enforcement (Marfai et al., 2015) of coastal setbacks, settlement planning and land use guidelines (Dhar and Khirfan, 2016)

Wide-ranging institutional challenges in community planning and health care provision (Ford et al., 2016)

Legacy of colonisation transforming traditional practices (Ford et al., 2016)

Poor government services provision (Jamero et al., 2018)

Gap between policy development and implementation (Karlsson and Hovelsrud, 2015)

Limited institutional support for local communities (Smith and Rhiney, 2016)

#### *Economic:*

Increasing reliance on erratic markets, facilitating foreign investment in national and local markets and liberalisation of national economic policies have led to the development of new technologies that change behaviour away from traditional harvest practices, affect market productivity and influence consumption demands (Bennett et al., 2016)

High levels of poverty (DasGupta and Shaw, 2015)

Economic disadvantages on the global market (Petzold and Ratter, 2015)

assets in flood prone areas (Marfai et al., 2015)

Possibilities of maladaptation (due to poor governmental coordination, lack of stakeholder awareness) (Wise et al., 2016)

Development planning is often captured by political elites and governmental officials (community needs are not met; lack of procedural justice; corruption) (Wise et al., 2016)

#### *Knowledge:*

Insufficient focus on the mapping of social and financial vulnerabilities at the local level (Audefroy and Sánchez, 2017)

Low levels of awareness of vulnerability (Esteban et al., 2017)

Lack of general awareness of adaptation efforts (Lieske et al., 2014; Smith and Rhiney, 2016)

Mismatches between top-down interventions and local cultural practices (Wise et al., 2016)

#### *Impacts*

##### *Physical:*

##### *Coastal physical processes disrupted*

Coastal erosion (Jones and Clark, 2014; Lieske et al., 2014; DasGupta and Shaw, 2015; Karlsson and Hovelsrud, 2015; Leon et al., 2015; Marfai et al., 2015; Nursey-Bray et al., 2015; Petzold and Ratter, 2015; Betzold and Mohamed, 2017; Hagedoorn et al., 2019) compounds saltwater intrusion (Abedin et al., 2014; Jurjonas and Seekamp, 2018) through soil loss (Ataur Rahman and Rahman, 2015) and buffering (Betzold and Mohamed, 2017)

Flooding (Jones and Clark, 2014; Nagy et al., 2014; DasGupta and Shaw, 2015; Marfai et al., 2015; Nursey-Bray et al., 2015; Dhar and Khirfan, 2016; Hobday et al., 2016; Jamero et al., 2018; Linkon, 2018; Hagedoorn et al., 2019) and breached embankments (with livelihood impacts) (Lieske et al., 2014; DasGupta and Shaw, 2015; Jamero et al., 2018)

Saline intrusion (Leon et al., 2015; Marfai et al., 2015; Petzold and Ratter, 2015; Jurjonas and Seekamp, 2018; Linkon, 2018) and variation (causing a reduction of mangrove diversity) (DasGupta and Shaw, 2015)

Sediment transportation processes affected (Karlsson and Hovelsrud, 2015)

##### *Catchment physical processes disrupted*

##### *Coastal infrastructure damage*

Loss of infrastructure and housing (Nursey-Bray et al., 2015; Hobday et al., 2016; Jurjonas and Seekamp, 2018; Linkon, 2018), including world heritage sites (Perry, 2015)

Communal toilets damaged (Jamero et al., 2018)

#### *Disruption of urban systems*

Disruption to roads (Leon et al., 2015) and transportation processes (Ataur Rahman and Rahman, 2015)

Interruptions to electricity supply (Jamero et al., 2018)

Rainwater supply depleted (Jamero et al., 2018)

Recreation or tourism opportunities supported by reef ecosystems or regional fisheries (Cooley et al., 2016)

#### *Land subsidence*

Land subsidence caused by groundwater extraction, loading of buildings and other constructions on compressible soils, natural consolidation of the alluvial soil or tectonic subsidence (Esteban et al., 2017)

#### *Ecological:*

##### *Ecosystem degradation and loss*

Loss of ecosystems (Ataur Rahman and Rahman, 2015; Petzold and Ratter, 2015; Dhar and Khirfan, 2016) including mangroves (Ataur Rahman and Rahman, 2015; DasGupta and Shaw, 2015; Leon et al., 2015) (e.g., the world heritage Sundarbans mangroves), wetlands (Leon et al., 2015; Marfai et al., 2015), beaches (Dhar and Khirfan, 2016; Betzold and Mohamed, 2017), and degradation of medicinal plants (Abedin et al., 2014), a reduction in soil fertility (Abedin et al., 2014) and coral bleaching (Petzold and Ratter, 2015; Hagedoorn et al., 2019) leading to a loss of reefs and beach erosion (Dhar and Khirfan, 2016)

Climate change impacts on Arctic residents includes transformed homelands (Sakakibara, 2017)

##### *Biodiversity and genetic diversity loss*

Loss of biodiversity (Abedin et al., 2014; Jones and Clark, 2014; Ataur Rahman and Rahman, 2015)

##### *Habitat range shifts*

Shifts in distribution, abundance and seasonal migrations of commercially valuable marine species (changes harvested fish abundance) (Hobday et al., 2016)

##### *Sub-lethal species impacts*

Shifts in reproductive patterns of commercially valuable marine species (changes harvested fish abundance) (Hobday et al., 2016)

Reduced growth and survival of species (Cooley et al., 2016) and loss of fish stocks (Hagedoorn et al., 2019)

Lack of predator avoidance of several finfish (Cooley et al., 2016)

Bivalve shellfish impacts caused by ocean acidification (Cooley et al., 2016)

Likely to enhance the biological effect of other simultaneous global changes (temperature increase, deoxygenation) (Cooley et al., 2016)

##### *Invasive alien species*

##### *Social:*

##### *Decreased access to ecosystem services*

Loss of marine ecosystem services (Cooley et al., 2016)

Reduced access to freshwater (Abedin et al., 2014; Dhar and Khirfan, 2016; Smith and Rhiney, 2016)

Coastline protection by coral reefs (Cooley et al., 2016)

##### *Local decline in agriculture and fisheries*

Impaired food production (Abedin et al., 2014), with impacts on fisheries and agriculture (Abedin et al., 2014; Nagy et al., 2014; Ataur Rahman and Rahman, 2015; Jamero et al., 2018; Jurjonas and Seekamp, 2018)

Fishing days and jobs lost due to rough seas (Ataur Rahman and Rahman, 2015)

Movement of fishing vessels into other areas (Hobday et al., 2016)

Ocean acidification impacts marine harvests (Cooley et al., 2016)

Fisheries closures (Bennett et al., 2016)

MPAs may impact communities through Fisheries closures (Bennett et al., 2016)

#### *Increasing living costs*

Communities forced to buy food they normally produce (Smith and Rhiney, 2016) and increases in food prices (Smith and Rhiney, 2016)

Increases in price of imported water (Jamero et al., 2018)

#### *Livelihoods impacts*

Livelihood impacts (Abedin et al., 2014; Nagy et al., 2014; Leon et al., 2015; Dhar and Khirfan, 2016; Smith and Rhiney, 2016)

Livelihoods have shifted away from fishing and rice farming towards agriculture and tourism (Nagy et al., 2014; Bennett et al., 2016)

#### *Increased food insecurity*

Damage to crops and infrastructure (Cinner et al., 2018), food security (Smith and Rhiney, 2016; Hagedoorn et al., 2019)

#### *Public health risks increased*

Health problems (Abedin et al., 2014) e.g. diarrhoea and skin infections (Marfai et al., 2015), prevalence of diseases (Ataur Rahman and Rahman, 2015)

Mental health (Ford et al., 2016)

#### *Cultural and traditional knowledge impacts*

Increases in infrastructure and technology (communications, media, social services, disaster warning systems and transportation modes) have changed traditional communities (Bennett et al., 2016), with changing demographics in communities due to an influx of outside organisations and migrants and efflux of youth (Bennett et al., 2016)

#### *Gender-related impacts*

Gender bias due to water collection by females (Abedin et al., 2014), including harassment (Abedin et al., 2014)

#### *Increased social vulnerability*

Vulnerability (Broto et al., 2015; Bennett et al., 2016) to tropical cyclones and floods (Ataur Rahman and Rahman, 2015), especially within low lying (Ataur Rahman and Rahman, 2015; Broto et al., 2015; Leon et al., 2015) settlements (Marfai et al., 2015), resulting in loss of lives (Ataur Rahman and Rahman, 2015; Linkon, 2018)

Serious socio-economic and cultural impacts (weakening of social fabric, marginalization, unemployment and destruction of property by erosion) (Ataur Rahman and Rahman, 2015)

#### *Decreased access to local government services*

Impacts on education (Abedin et al., 2014) including closure of schools (Marfai et al., 2015)

#### *Socio-economic entrapment and decline*

Affecting mostly poor developing communities through poverty-environment trap (Barbier, 2015a)

Through an increase in government and outside organisation supporting communities, there is a perception that the collective have limited control over changes (locus of power is outside of individuals) (Bennett et al., 2016)

Habitat loss compounds damage to infrastructure and weakens the social fabric of coastal communities (Bennett et al., 2016)

*Global declines in food stocks*

*Public areas access restrictions*

*Decline in perceived value of human systems*

Decrease in sea ice impacting culture and economy of Inuit (Sakakibara, 2017)

*Conflict and migration*

Social conflict (Abedin et al., 2014)

Large-scale migration (Abedin et al., 2014)

Impacting mostly rural areas (Abedin et al., 2014)

Conflicts between coastal resource users (Ataur Rahman and Rahman, 2015)

*Governance:*

*Increased geopolitical tensions*

Increased economic and geopolitical tensions and instabilities (Abedin et al., 2014)

*Economic:*

*Increased business and living costs*

Financial costs for infrastructure repair and loss of archaeological sites (Sakakibara, 2017)

Rising prices of goods and declining incomes (Bennett et al., 2016)

*Business disruptions and losses*

Increasing financial losses (Audefroy and Sánchez, 2017)

Economic loss (Linkon, 2018) of tourism revenue from beach erosion (Dhar and Khirfan, 2016)

Increases in coastal flooding causing economic losses (Esteban et al., 2017)

Disruption of economic activities (price increases) (Marfai et al., 2015)

*Decreased value of assets/ products*

*Adaptation responses*

*Physical:*

*Hard engineering responses*

Includes seawalls, breakwaters and land reclamation (Jamero et al., 2018), coastal dykes (Esteban et al., 2017), artificial reefs (Bennett et al., 2016)

Coastal defence structures (Betzold and Mohamed, 2017) are often poorly designed and constructed increase erosion and reducing long term sustainability of beaches (Betzold and Mohamed, 2017)

(Location specific knowledge) including orientation of houses for sunlight (Ataur Rahman and Rahman, 2015), housing design (raising floors; natural windbreaks, bamboo in houses for wind protection) (Ataur Rahman and Rahman, 2015)

Building design, location, orientation, elevation, construction materials and reinforcement measures implemented (Linkon, 2018)

Adaptation responses included Raising the level of the house and building of houses with additional floors, building small dykes (using low quality building materials were cost was a factor, development of communal works systems to clear drainage around settlements and access to micro-finance (Marfai et al., 2015)

Paper focuses on perceptions of seawalls, which have been favoured, but implemented in an ad hoc manner. Communities favour these with little awareness of alternative approaches, despite problems caused by seawalls (Betzold and Mohamed, 2017)

*Soft engineering responses and buffers*

Beach nourishment, reef conservation or relocation (Betzold and Mohamed, 2017)

Planting design and selection of trees (raising of crops to prevent water-logging; seasonal planting for wet and dry season) (Ataur Rahman and Rahman, 2015)

Monitoring of beach profiles and coastal erosion along the Uruguayan coastal and incorporation of climate issues in the lagoon's management plan (Nagy et al., 2014)

*Integrated hard and soft engineering*

Traditional landscaping (building homesteads on a raised mound) (Ataur Rahman and Rahman, 2015), wooden platforms on excavated earth - with 2 or 3 ponds (conservation of floodplain) (Ataur Rahman and Rahman, 2015)

Hard engineered and soft ecological adaptation responses (Dhar and Khirfan, 2016)

*Ecological:**Ecosystem restoration and protection*

Habitat conservation (Petzold and Ratter, 2015) and restoration (Barbier, 2015a) in savannah (Bennett et al., 2016), mangroves (Bennett et al., 2016; Jamero et al., 2018), beach nourishment (Dhar and Khirfan, 2016) and coral reef management (Jamero et al., 2018)

Sundarbans mangrove forest provides protection from storms (Ataur Rahman and Rahman, 2015)

Community EbA measures identified include the establishment of marine and terrestrial protected areas (Hagedoorn et al., 2019)

Restoring coastal forests (Hagedoorn et al., 2019) through a participatory mangrove plantation programme (Ataur Rahman and Rahman, 2015)

Monitoring protected areas (Hagedoorn et al., 2019)

Ecosystem-based adaptation (favouring no or low regret adaptation options) (Dhar and Khirfan, 2016)

*Nature based solutions*

Invasive species management (Hagedoorn et al., 2019)

Implementing a riparian buffer (Hagedoorn et al., 2019)

Planting trees (Hagedoorn et al., 2019)

Compile a list of migratory birds and endangered species, use of soft coastal bio-physical protection measures such as beach and dune vegetation, and wind fencing (Nagy et al., 2014)

*Social:**Improving access to/ storage of natural resources*

Water conservation practices (Abedin et al., 2014), including rainwater harvesting and storage (Abedin et al., 2014; Ataur Rahman and Rahman, 2015; Bennett et al., 2016; Jamero et al., 2018), personal filtration devices (for arsenic) (Abedin et al., 2014), water boiling (Abedin et al., 2014), collection from distant, but safe sources (Abedin et al., 2014)

Stop groundwater extraction in Jakarta suggested to stop land subsidence (Esteban et al., 2017)

*Improving agricultural or fisheries practices*

Improving animal husbandry, increasing agricultural and seafood production and processing to improve livelihoods (Bennett et al., 2016)

Improving fishing community adaptation efforts by predicting future coastal-marine food resources, and co-developing adaptation options (Hobday et al., 2016)

Introduction of climate resistant crops (Hagedoorn et al., 2019)

Crop diversification (Hagedoorn et al., 2019) and changing harvesting techniques (Hagedoorn et al., 2019)

Screening of tube well water for contamination (Abedin et al., 2014)

*Sustainable resource use*

Waste management (Bennett et al., 2016)

Improved waste management to reduce pressure on ecosystems. (Hagedoorn et al., 2019)

Reducing resource extraction (Hagedoorn et al., 2019)

Sustainable technologies (Ataur Rahman and Rahman, 2015)

*Sustainable household management*

Cleaning community areas and the prevention of weeds/ pests (Hagedoorn et al., 2019)

Local foods, materials and structures were used to strengthen housing, provide alternative food sources, adopt adapting practices (like stilts), mangrove restoration for protection and observations of the environment for storm prediction (Hiwasaki et al., 2015)

Small-scale response strategies by communities to flooding included moving household possessions to higher levels; evacuation of children and elderly to mosques, but this was uncoordinated; receiving food parcel support (but lacked medicines) (Marfai et al., 2015)

*Maintaining or switching livelihoods*

Maintaining traditional fisheries livelihoods and supporting alternative livelihoods (Bennett et al., 2016) like nature based tourism (Bennett et al., 2016)

*Community participatory programmes*

Common currency or time banking systems where individuals are incentivised to volunteer (Cinner et al., 2018)

Empowering communities through participatory processes such as adaptive co-management (Cinner et al., 2018)

Use of adaptive, participatory, and transformative methods (Perry, 2015)

Participatory urban planning in Maputo incorporating highly technical knowledge from climate scenarios focussing on informal settlements (Broto et al., 2015)

Adaptation responses were based on top-down and bottom-up knowledge (Nagy et al., 2014)

Using participatory methods and community-based approaches so they are useful and implementable (Bennett et al., 2016)

Multi-stakeholder, participatory planning process prioritising rural livelihood adaptation strategies (Wise et al., 2016)

*Developing adaptive networks*

Formation of community water committees to address drought (Abedin et al., 2014)

Access to networks (Cinner et al., 2018)

*Improving access to community services*

National government: Providing construction materials for housing repair and acquisition of new water tanks, build new seawalls; Municipal: relocate island residents to mainland, provide funds for road maintenance; NGO: build temporary classrooms, donate stilted houses, elevate floors of classrooms, create rice cooperatives, establish microfinance; Barangay Council: elevate and extend roads, repair and elevate damaged infrastructure like seawalls, acquire large evacuation boats, increase electricity supply; Community: clean shared spaces after tidal flooding (Jamero et al., 2018)

*Empowering communities and addressing inequality*

Societal organisation to enable (or inhibit) cooperation, collective action and knowledge sharing (Cinner et al., 2018)

Empowering communities through removing barriers that may inhibit people's ability to exercise agency (Cinner et al., 2018)

*Building socio-ecological resilience*

Build capacity of tropical coastal communities to adapt to climate change (Cinner et al., 2018)

Factors contributing to higher vulnerability included a lack of coordination, poor environmental conditions, poor infrastructure maintenance and lack of public concern.

Building social capital (Cinner et al., 2018)

*Governance:*

*Adopting/ mainstreaming sustainability policies*

*Improving disaster response programmes*

Increased focus on vulnerability (looking at stressors, sensitivity to change, adaptive capacity (Bennett et al., 2016)

*Improving implementation and coordination of policies*

Switching between adaptation strategies through flexibility in policies and the removal of barriers (Cinner et al., 2018)

*Developing partnerships and building capacity*

Institutional support to legitimise and sustain adaptation through capacity building (Broto et al., 2015)

Social investments for sustaining livelihoods (Cinner et al., 2018)

Design of an agreed participatory multi-criteria model to manage a lagoon sand bar (Nagy et al., 2014)

*Improving access to community services*

Government programme to improve tap water (Bennett et al., 2016)

*Pursuing climate justice*

Adoption of a climate justice framework (Smith and Rhiney, 2016)

Factors driving vulnerability within communities are a function of centuries of economic neglect and political marginalization (Smith and Rhiney, 2016)

*Economic:*

*Improving financial resources availability*

Engaging with economic programmes e.g. the King of Thailand's sufficiency economy (Bennett et al., 2016)

*Improving access to insurance products*

Building assets could improve access affordable credit and insurance (Cinner et al., 2018)

*Knowledge:*

*Improving planning processes*

Increased focus on vulnerability (looking at stressors, sensitivity to change, adaptive capacity (Bennett et al., 2016)

Spectrum of adaptive capacity (from vulnerable to resilient) (Jurjonas and Seekamp, 2018)

*Improving forecasting and early warning systems*

Improved planning for disasters (Bennett et al., 2016)

*Improving decision support frameworks*

Consideration of 'futures' planning methodologies (visioning, backcasting and scenario planning) (Bennett et al., 2016)



Resilience assessment framework for coastal rural communities in low lying Asian mega-deltas (DasGupta and Shaw, 2015)

*Coordinating top down and bottom up approaches*

Combine top-down scientific models and bottom-up approaches involving community participatory action research using design charrettes.

Framework to foster resilience dialogue during community conversations; spark adaptive capacity from the bottom-up.

Integrating top down with bottom-up approaches (Hagedoorn et al., 2019)

Top-down and bottom-up approaches to identify adaptation options (Nagy et al., 2014)

*Integrating knowledge systems*

Observations using traditional knowledge to forecast extreme events may increase the resilience of coastal communities (Audefroy and Sánchez, 2017)

Integrating scientific and indigenous knowledge (Cinner et al., 2018)

Local and indigenous knowledge related to climate-related hazards, including folklore, rituals and ceremonies that reinforce religious, customary and traditional beliefs, which can strengthen community resilience (Hiwasaki et al., 2015)

Integration of local knowledge and traditional practices with scientific approaches in disaster risk reduction (Audefroy and Sánchez, 2017)

Humanistic research and community based projects in rural and indigenous communities often produce understandings of climate and climate change that are incompatible with statistical finds of climate science (Sakakibara, 2017)

Participatory model integrates traditional/local and scientific knowledge (Leon et al., 2015)

Increasing vulnerability assessments incorporating local and scientific knowledge (Bennett et al., 2016)

Vulnerable Arctic communities confront uncertainty through reinforcing traditional cultural practices and cultural response (Sakakibara, 2017)

Individual adaptation during building of dwelling units using indigenous knowledge (Linkon, 2018)

Building agency in communities by incorporating local or customary knowledge, skills, and management into both science and policy (Cinner et al., 2018)

Call for indigenous people to be primary actors in the monitoring of and adaptation to climate change (Smith and Rhiney, 2016)

*Improving location and context specific knowledge*

Need to understand structural inequalities (Broto et al., 2015)

Developing and understanding alternative community adaptation options (Hobday et al., 2016)

Improved use of local knowledge and traditional practices to strengthen the resilience of communities to climate change (Audefroy and Sánchez, 2017)

Perceptions of measures to increase resilience in Jakarta include build stronger and bigger dykes or a giant sea wall, plant mangroves, elevate districts adjacent to dykes and relocation of properties (Esteban et al., 2017)

*Improving scientific communication*

Access to information / knowledge (Cinner et al., 2018)

*Stakeholder identification, outreach and education*

Building regional skill-sets to understand, predict and communicate coastal vulnerability (Hobday et al., 2016)

Improving education (Bennett et al., 2016), in environment (Bennett et al., 2016), English language training (Bennett et al., 2016)

Ocean acidification responses include education/ outreach to inform policymakers, evidence-based action and policy (Cooley et al., 2016)

Multiple adaptation responses used

Synergistic adaptation responses:

Combines natural and traditional adaptation practices and defence mechanisms (Ataur Rahman and Rahman, 2015)

Complementary actions for managing the environment, community livelihoods and adapting to climate change (Bennett et al., 2016)

Synergize EbA with community-based adaptation (Scarano, 2017) to capitalise on the experiential knowledge of local communities in adapting to climate change (Dhar and Khirfan, 2016).

Fisheries management interventions and CBA (Hobday et al., 2016)

multiple adaption pathways (Wise et al., 2016)

Benefits

*Physical:*

*Physical processes supported*

Protection from wind, saltwater intrusion, landslides and erosion (Hiwasaki et al., 2015)

*Coastal infrastructure resilience increased*

Flood protection (Betzold and Mohamed, 2017)

*Ecological:*

*Physical processes supported*

Coastal forests attenuate wave and wind speed and bind soils for erosion protection) (Ataur Rahman and Rahman, 2015)

*Increased biodiversity*

Morass (wetland - biodiversity resource; protects species) (Dhar and Khirfan, 2016)

*Social:*

*Access to sustainable ecosystem services*

Traditional disaster reduction methods and location specific knowledge (Ataur Rahman and Rahman, 2015) helps secure protection against tidal surges and strong winds; landslides (Ataur Rahman and Rahman, 2015)

Improved water security (when in drought) (Hiwasaki et al., 2015)

Plants for medicinal purposes (Ataur Rahman and Rahman, 2015)

*Improved access to resources*

Provide alternative food sources (Hiwasaki et al., 2015)

*Human systems supported*

*Improved socio-economic services*

Building social capital (bonding, bridging and linking) (Cinner et al., 2018).

Creation of social capital (trust-building, creation of social norms) (Hagedoorn et al., 2019)

Strengthening of social capital to improve community resilience (Smith and Rhiney, 2016)

*Improved employment and livelihoods*

*Improved health*

*Improved community participation*

Promotes participatory discussion-making and agency (Jurjonas and Seekamp, 2018)

*Better informed communities*

CBA benefits include practical information and benefits; future focus; evaluation; accountability across scales (Ford et al., 2016)

Better prediction of natural hazard events (Hiwasaki et al., 2015)

Identified barriers to capacity building (Jurjonas and Seekamp, 2018)

*Improved integration of knowledge systems*

Traditional disaster reduction methods and location specific knowledge (Ataur Rahman and Rahman, 2015) helps secure protection against tidal surges and strong winds; landslides (Ataur Rahman and Rahman, 2015)

*Empowering women and children*

Empowerment of women and children in a male dominated society (Leon et al., 2015)

*Increased adaptive capacity*

Increased community perception of resilience (Jurjonas and Seekamp, 2018)

Social learning helps communities adapt to change (Nurse-Bray et al., 2015)

*Improved disaster preparedness*

Communities are better prepared for disasters and are improved in their risk management (Audefroy and Sánchez, 2017)

*Empowered communities**Improved community cohesion*

Strengthening networks, building trust, enhanced volunteerism, social cohesion (Cinner et al., 2018)

Strengthen social relations to build community resilience (Hiwasaki et al., 2015)

Community consensus on climate threats (Jurjonas and Seekamp, 2018)

*Reduced inequality*

Building socially just and robust coastal management strategies (Nurse-Bray et al., 2015)

*Governance:**Political and institutional capacity developed*

Build capacity (Ford et al., 2016; Hobday et al., 2016)

*Strengthened participatory governance*

Promotes citizenship and collective rights, empowerment and decentralising power (promotes the co-construction of knowledge) (Broto et al., 2015)

*Better planning processes supported*

Participation in development planning (Wise et al., 2016)

*Improved coordination and decision making*

Building political and institutional relationships (Broto et al., 2015)

*Improved implementation and policies*

Initiated discussions on other things like service provision (Broto et al., 2015)

*Better communication**Improved transparency and trust**Climate justice advanced*

Climate justice below the national scale (linked to developmental context) (Smith and Rhiney, 2016)

*Reduced conflict*

*Improved security*

*Improved adaptive management*

Can improve efforts in disaster risk reduction - as it can help develop coping mechanisms for inhabitants in flood-prone areas (Marfai et al., 2015)

*Development supported*

*Economic:*

*Increased revenue/ income*

Assets can improve market accessibility and catalyse other types of development (Cinner et al., 2018)

*Increased financial resources available*

*Reduced operational and capital costs*

*Investment strengthened*

*Knowledge:*

*Informed decision making tools*

Promotes adaptive co-management (Nagy et al., 2014)

*Improved co-production of knowledge*

Communities identified what is important to them (local knowledge). The process led to co-learning with potential to lead to more localised action (Bennett et al., 2016)

Co-production of knowledge to empower low income communities (Broto et al., 2015; Hobday et al., 2016)

Co-production of knowledge (Nagy et al., 2014)

Utilise indigenous/local knowledge (Ford et al., 2016)

Local knowledge included community engagement (Leon et al., 2015)

*Improved relevance of products*

*Improved education and outreach*

*Improved awareness*

Better understanding of structural inequalities in relation to climate change (Broto et al., 2015)

Better understanding of risk and acceptance of adaptation response (Lieske et al., 2014)

Empowers stakeholders (Nagy et al., 2014)

Addressing the climate knowledge gap (Smith and Rhiney, 2016)

*Co-benefits*

Co-benefits for human development and adaptive capacity (Wise et al., 2016)

*Constraints and limitations*

*Physical:*

Seawalls were typically poorly designed and constructed, and when compounded by sand winning, disrupted dynamic beach processes, and in so doing increased coastal erosion and the ability of the beach processes to respond to changing ocean conditions (Betzold and Mohamed, 2017)

Engineering solutions in SIDS are sometimes problematic, being characterised by poor design and construction, especially in rural areas, limited access to human, technical and financial capacity and a lack of data on site-specific conditions resulting in failure after short time periods (Betzold and Mohamed, 2017)

Seawalls negatively affect beach erosion within increased erosion at edges or bottom of seawalls leading to collapse and abandonment, while increasing or displacing beach erosion (Betzold and Mohamed, 2017)

Impacts are increasingly complex and unpredictable through direct and downstream effects of climate change (Bennett et al., 2016)

Dykes as hard defences in Jakarta are threatened by continual subsidence and possible but communities underestimate the level of vulnerability (Esteban et al., 2017)

#### *Ecological:*

Species selected (exotic) for mangrove plantations have not always been appropriate for location, and combined with poor planting methods have exacerbated damage (Ataur Rahman and Rahman, 2015)

Beach nourishment disturbed natural processes and adversely affected beach ecosystems (Betzold and Mohamed, 2017)

Undermining the long-term sustainability of coastal ecosystems trade-offs in adaptation strategies catalysing socio-ecological (Cinner et al., 2018) and poverty-environment (Barbier, 2015a) traps

Lack of synergy between EBA and CBA at regional scales (especially in practice) (Dhar and Khirfan, 2016)

#### *Social:*

Thick shelter beds protect the coastal zone but have shifted wind damage to interior regions (Ataur Rahman and Rahman, 2015)

Factors that impede individual or community response to coastal erosion and flooding include lack of resources, knowledge and capacity (Betzold and Mohamed, 2017)

Lack of capacity and resources impedes alternative measures that are adapted to local conditions, or the enforcement of rules and regulations such as a ban on sand mining (Betzold and Mohamed, 2017)

Considerable socioeconomic barriers to adaptation at various scales (Ford et al., 2016)

CBA is not a panacea: Not all communities want to have the level of engagement implied by CBA, there may be general participation problems with entrenchment of personal views and local power dynamics may shape the process causing tensions, resistance and withdrawal (Ford et al., 2016)

Maintaining a climate adaptation focus (communities have more other pressing issues that require attention (Ford et al., 2016)

Younger generation are abandoning rituals and practices (Hiwasaki et al., 2015)

Low levels of participation in planned measures, addressing symptoms and not causes and lack of local consultation (Jamero et al., 2018)

Existing communities' traditional coping mechanisms may be overwhelmed and not be able to respond (Smith and Rhiney, 2016)

Multi-level participatory approach limitations include: the structured social learning process failed to expose and address the systemic causes of vulnerability, stakeholders may have recognised systemic issues, but were unwilling to challenge them due to lack of confidence or capacity, or gave precedence to meeting immediate livelihood needs (Wise et al., 2016)

#### *Governance:*

Lack of enforcement of rules (Betzold and Mohamed, 2017)

New environmental management measures e.g. MPAs may impact communities through fisheries closures (Bennett et al., 2016)

Limitation like systemic issues, power relations and elite capture persisted despite participatory process (Broto et al., 2015)

Institutional support dwindled after the project finished (Broto et al., 2015), but participatory processes require support (Broto et al., 2015)

Lack of flexibility in governance processes (Jamero et al., 2018)

Planned measures were not enough (Jamero et al., 2018)

Maladaptation in autonomous measures include negative environmental consequences for elevating floors of classrooms using coral stones and using trash as foundation for new houses (Jamero et al., 2018)

The Belize national climate adaptation policy has not been implemented. With typically top-down hard and soft engineering measures such as sea-walls, land use planning, ecosystem conservation, building codes, insurance schemes and managed retreat of settlements, the strategies were ineffective; individual properties were submerged; the communal beach area reduced and tourism development area destroyed (Karlsson and Hovelsrud, 2015)

The implementation of pro-active, planned adaptation to reduce community vulnerability is strongly dependent upon people's perception of the threat posed to their communities at the local scale (Lieske et al., 2014)

Uncoordinated responses during flood events produces greater exposure to hazards, and notes that community responses remain below the ideal with a risk of maladaptation (Marfai et al., 2015)

Very few transformative strategies were identified to address deeper systemic issues (Wise et al., 2016)

#### *Economic:*

Limited local resources, therefore important role of donors (Betzold and Mohamed, 2017)

Access to a significant amount of financial resources and the transfer of technologies (Smith and Rhiney, 2016)

#### *Knowledge:*

A persisting perception exists that traditional knowledge is socially constructed and difficult to integrate with scientific and institutional information. It is reinforced by communication in a top-down manner (Audefroy and Sánchez, 2017)

Scenario planning capacity limitations related to local understanding of climate change and its local implications (Bennett et al., 2016)

Data availability (Broto et al., 2015)

People underestimate the severity of vulnerability due to their regular exposure (Esteban et al., 2017)

Conflict at the interface of Western and local/indigenous knowledge within a specific cultural context, which may compromise long-term sustainability (Ford et al., 2016)

The multifaceted role of the researcher to go beyond standard academic practice (Ford et al., 2016)

Potential for tokenistic engagement of communities, consultation fatigue, and imbalance between Western and indigenous knowledge in this work (Ford et al., 2016)

Developing comparative approaches across regions that differ in political institutions, socio-economic community demographics, resource dependency and research capacity is challenging (Hobday et al., 2016)

Social learning has not made the transition from theory to practice (Nurse-Bray et al., 2015)

#### *Costs*

Economic costs due to acute ocean acidification events in the Pacific Northwest, USA have jeopardized the \$270 million, 3200 jobs/year shellfish aquaculture industry in Washington State (Cooley et al., 2016)

Large projected economic costs associated with ocean acidification include \$75-187 million a year for shellfish harvests in USA; global shellfish harvests at \$6 billion a year; coral reef impacts at \$0-900 billion a year (Cooley et al., 2016)

Costs associated with management options for the coastline: accommodating sea level rise and flooding include tax burdens on citizens, high maintenance costs and possible biodiversity loss and with management retreat include loss of properties without compensation, flooding of agricultural land, loss of species and recreational activities (Jones and Clark, 2014)

Risk of maladaptation from substitution of materials to build additional floors by low income households, which were structurally weak (Marfai et al., 2015)

Human System: Built infrastructure

Anthropogenic co-drivers

*Physical:*

Growing coastal populations (Perkins et al., 2015; Moosavi, 2017; Carter, 2018), urbanization (Kabisch et al., 2017)

Hard engineering structures (Gracia et al., 2018)

Hardening of surfaces and run-off impacts (Kabisch et al., 2017)

Pollutants (Zikra et al., 2015; Peng et al., 2017) including Nitrogen & Sulphur (Kaja and Mellic, 2017)

Industrial activities (Martínez et al., 2018)

fires (Martínez et al., 2018)

*Ecological:*

Loss and degradation of natural areas (Kabisch et al., 2017)

*Social:*

Social vulnerabilities (Woodruff, 2018)

*Governance:*

Insufficient or inappropriate planning and policy (Becker et al., 2015)

poor governance (Vikolainen et al., 2017) and less public participation (Martínez et al., 2018)

Impacts

*Physical:*

*Coastal physical processes disrupted*

Coastal flooding (Villatoro et al., 2014; Shope et al., 2016; Kaja and Mellic, 2017; Brown et al., 2018; Elshorbagy et al., 2018)

Urban land use changes (Carter, 2018)

Coastal erosion (Moosavi, 2017; Martínez et al., 2018), including accelerated bottom erosion in front of the structure and down drift scouring (Gracia et al., 2018)

Large morphological changes to island coastlines (Shope et al., 2016)

Disturbance of sediments supply and beach reduction (Gracia et al., 2018) in communities down drift (Vikolainen et al., 2017)

Alteration of alongshore sediment transport (Gracia et al., 2018)

Ground water saline intrusion (Shope et al., 2016)

*Catchment physical processes disrupted*

*Coastal infrastructure damage*

Damage to infrastructure (Villatoro et al., 2014; Shope et al., 2016; Asadabadi and Miller-Hooks, 2017), including transport (Colin et al., 2016; Forzieri et al., 2018), freight, and equipment (Becker et al., 2015), energy (Brown et al., 2018), hydropower generation (Forzieri et al., 2018; Mikellidou et al., 2018) and water infrastructure (Friedrich and Kretzinger, 2012; Elshorbagy et al., 2018)

Salt mobilization and crystallization in buildings (Kaja and Mellic, 2017)

Wind damage (Kaja and Mellic, 2017)

Deterioration of marine steel (Peng et al., 2017)

*Disruption of urban systems*

Flooding can affect the quality of coal (Mikellidou et al., 2018)

Biological infestation in buildings(Kaja and Mellic, 2017)

Systemic disruptions (relate to system function, capability or capacity) (Rahimi et al., 2014)

*Land subsidence*

Landslide/debris (Jeong et al., 2014)

*Social:*

*Decreased access to ecosystem services*

hydropower generation impacts through reduced flow (Antwi-Agyeia et al., 2018)

*Local decline in agriculture and fisheries*

Shortened growing season with implications for the agricultural and fisheries sectors (Forzieri et al., 2018)

Extensive damage to crops and livestock leading to famine (Antwi-Agyeia et al., 2018)

*Increasing living costs*

*Livelihoods impacts*

*Increased food insecurity*

Food insecurity (Elshorbagy et al., 2018; Martínez et al., 2018)

Extensive damage to crops and livestock leading to famine (Antwi-Agyeia et al., 2018)

*Public health risks increased*

Potential risk to bathers (Gracia et al., 2018)

Health (Martínez et al., 2018)

Cultural and traditional knowledge impacts

*Gender-related impacts*

*Increased social vulnerability*

Increased social vulnerabilities (inequality) (Woodruff, 2018)

*Decreased access to local government services*

Restricted public access (Gracia et al., 2018)

*Socio-economic entrapment and decline*

*Global declines in food stocks*

*Public areas access restrictions*

*Decline in perceived value of human systems*

*Economic:*

*Increased business and living costs*

Clean up costs (Becker et al., 2015)

*Business disruptions and losses*

Loss of business and delays in commerce (Becker et al., 2015)

Reduced hydropower generation efficiency (Mikellidou et al., 2018)

Loss of economic activity due to damaged/ destructed infrastructure (Mikellidou et al., 2018)

*Decreased value of assets/ products*

Adaptation responses

*Physical:*

*Supporting physical processes*



Erosion control system/Framework (Jeong et al., 2014)

*Hard engineering responses*

Construction of groins, seawalls, revetments, gabions and breakwaters (Friedrich and Kretzinger, 2012; Moosavi, 2017; Vikolainen et al., 2017; Wadey et al., 2017)

Elevating infrastructure and improving drainage (Perkins et al., 2015; Becker et al., 2016; Colin et al., 2016; Asadabadi and Miller-Hooks, 2017; Brown et al., 2018)

Construction of an artificial island named Hulhumale (Wadey et al., 2017)

*Soft engineering responses and buffers*

*Integrated hard and soft engineering*

Ecologically enhanced hard engineered infrastructure (Perkins et al., 2015; van der Nat et al., 2016; Moosavi, 2017)

Hard engineering structures with EBA approaches (Jeong et al., 2014; Perkins et al., 2015; Gracia et al., 2018)

*Managed retreat and coastal realignment*

Relocation of infrastructure (Friedrich and Kretzinger, 2012; Colin, 2016 #27; Wadey et al., 2017)

*Ecological:*

*Ecosystem restoration and protection*

Land banking to secure spaces to implement green infrastructure (Carter, 2018)

*Bioengineering*

Sandscaping (Vikolainen et al., 2017) with EBA approaches (Jeong et al., 2014; Perkins et al., 2015; Gracia et al., 2018)

*Assisted evolution and relocation*

*Nature based solutions*

Nature-Based Solutions (urban green infrastructure and ecosystem-based adaptation (van der Nat et al., 2016; Kabisch et al., 2017; Gracia et al., 2018)

Landscape-based approach (Kaja and Mellic, 2017)

Developing approaches to empower local communities to adopt and manage green infrastructure sites (Carter, 2018)

*Social:*

*Community participatory programmes*

Stakeholder involvement (Becker et al., 2015)

*Developing adaptive networks*

Adaptation networks (Woodruff, 2018)

*Empowering communities and addressing inequality*

Developing approaches to empower local communities to adopt and manage green infrastructure sites (Carter, 2018)

*Governance:*

Adopting/ mainstreaming sustainability policies

Policy development (Becker et al., 2015), including zoning policies (Carter, 2018) and government adaptation policies (Woodruff, 2018)

Consolidate a system of environmental governance (Martínez et al., 2018)

ICM (Rosendo et al., 2018)

*Developing partnerships and building capacity*

Increase adaptive capacity (Martínez et al., 2018)

*Knowledge:*

*Better monitoring and modelling*

Assessing model and solution frameworks (Asadabadi and Miller-Hooks, 2017) and simulation models (Jeong et al., 2014), scenario development and land use modelling methods (Carter, 2018)

Data-model integration approach. The multi-hazard risk framework includes climate sensitivity of critical infrastructures, risk integration and adaptation scenarios (Forzieri et al., 2018)

Coupled Model Inter-comparison Project Phase 5 (CMIP5) and global climate models (GCMs) (Shope et al., 2016)

*Improving planning processes*

Infrastructure Planning Support System (Espinet et al., 2016)

Climatic design for critical infrastructure (Mikellidou et al., 2018)

Hindcasting and climate modelling (Villatoro et al., 2014)

Hydro-economic models. Intensity–duration–frequency (IDF) curves and design storms in various regions (Elshorbagy et al., 2018)

*Improving decision support frameworks*

Risk (Colin et al., 2016) and vulnerability assessment tools e.g. ARCoES DST (Brown et al., 2018)

Minimum assumption credible design (Becker et al., 2016)

A standard climate narrative is essential to assess port risk, vulnerability and resilience (Mutombo and Ölçer, 2016)

Sustainable engineered systems (SES) and early warning systems (Rahimi et al., 2014)

*Integrating knowledge systems*

Local communities understanding the local knowledge systems (Kaja and Mellic, 2017)

A consistent analysis framework, provided by the SPRC approach (Villatoro et al., 2014)

*Multiple adaptation responses used*

*Physical:*

Benefits

*Physical:*

*Physical processes supported*

Increase mitigation and coastal erosion co-benefits (Gracia et al., 2018)

*Coastal infrastructure resilience increased*

Protection of waste water infrastructure (Friedrich and Kretzinger, 2012)

Critical infrastructure is resilient to climate change impacts (Moosavi, 2017; Wadey et al., 2017; Mikellidou et al., 2018)

Engineered systems are built, maintained and eventually recycled within its larger embodied ecological systems(ecosystems) (Rahimi et al., 2014)

*Improved infrastructure functionality*

Improve the functionality of critical infrastructure (Mikellidou et al., 2018)

*Increased structural heterogeneity**Ecological:**Ecosystem/ ecological resilience supported*

Stimulate the resilience of natural systems (Gracia et al., 2018)

Improves ecosystem-based management (van der Nat et al., 2016)

*Physical processes supported*

Providing ecological defenses against coastal erosion (Gracia et al., 2018)

*Increased biodiversity*

Stimulate biodiversity conservation (Perkins et al., 2015; Gracia et al., 2018)

Creating habitat and protection of biodiversity (Vikolainen et al., 2017)

*Social:**Access to sustainable ecosystem services*

Important ecosystem services secured (Perkins et al., 2015)

*Improved health*

Improved health and social benefits (Kabisch et al., 2017)

*Empowered communities*

Cultural change and higher empowerment of society around urban problems related to ecosystems and nature (Martínez et al., 2018)

Inspiring and encouraging community participation in coastal erosion management processes

*Increased adaptive capacity*

Stimulate the resilience of human society to coastal erosion effects (Gracia et al., 2018)

*Improved community cohesion*

Develop common goals (Woodruff, 2018)

Improved community cohesion (Woodruff, 2018)

*Reduced inequality*

Reduction of health inequalities (Kabisch et al., 2017)

*Governance:**Political and institutional capacity developed*

Help governments with lack of technical expertise, staff time and funding (Woodruff, 2018)

*Better planning processes supported*

Greater emphasis on resilience planning (Becker et al., 2015)

*Economic:**Increased revenue/ income*

Increased tourism (Vikolainen et al., 2017)

*Increased financial resources available*

Attract investment (Woodruff, 2018)

*Reduced operational and capital costs*

Reduce damage costs from future extremes (Jeong et al., 2014)

Reduced costs of adaptation (Woodruff, 2018)

## Knowledge

### *Informed decision making tools*

Make resource forecast for adaptation projects more transparent, widely accessible, highlights shortfalls of current engineering (Becker et al., 2016)

Monitors future coastal vulnerabilities (sea-level rise & storms) (Brown et al., 2018)

Scenario planning can support decision makers in understanding and responding to the implications of divergent development pathway and contrasting future land use patterns on urban adaptive capacity (Carter, 2018)

Help managers and planners with tools to develop adaptation strategies (Colin et al., 2016)

Provides stakeholders with a roadmap for planned investments in building resilience to future change in sea level and extreme events (Brown et al., 2018)

Significant guidance for design engineers when factoring climate change in infrastructure design calculations (Mutombo and Ölçer, 2016)

improved coastal storm predictions such that the timing, intensity and other important storm variables can be forecast quite accurately up to approximately three days in advance (Villatoro et al., 2014)

The hydrometeorological research community has made significant strides in the direction of quantifying possible climate change impacts on precipitation, stream flow, temperature, reservoir operation, flood risks and droughts (Elshorbagy et al., 2018)

Hydro-economic models assess the economic impacts of climate change and water shortage on society (Elshorbagy et al., 2018)

### *Improved co-production of knowledge*

Shared learning (Woodruff, 2018)

### *Improved education and outreach*

increase awareness and facilitate information flow (Woodruff, 2018)

### *Co-benefits*

### *Constraints and limitations*

#### *Ecological:*

Ecosystems demand space to flourish, and sometimes require more space than conventional hard structures (Gracia et al., 2018)

Furthermore, development of the ecosystem and its functionality depends on the coastal setting, hydrodynamics, structure, and habitat dimensions, together with the severity of coastal erosion (Gracia et al., 2018)

Nature-based solutions still need to be developed, but they do have a strong action focus (problem rooted in climate change solving) (Kabisch et al., 2017)

The science of sustainability requires a deep understanding of ecological complexity. In addition, others believe ecological systems to be the prototypical complex adaptive systems (CAS) with emergent behaviours and feedback that influences subsequent interactions (Rahimi et al., 2014)

#### *Economic:*

Multiple benefits of Sandscaping are hard to calculate and link to funding paths, so the project partners focus on what would help to attract more money and make the project possible. (Vikolainen et al., 2017)

#### *Governance:*

This alone leaves municipalities with unanswered questions regarding the translation of the estimated change (e.g., 15% increase in extreme rainfall) to the urban storm water management infrastructure and its temporal storage capacity. Therefore, till such issues are addressed, it is difficult to convince decision-makers of the real impacts of climate change on water resource systems and infrastructure (Elshorbagy et al., 2018)

*Knowledge:*

Does not account for other social benefits derived from preventing flooding occurrences, such as property damage averted and reductions in lives lost on flooded roadways, lower risk to emergency personnel, avoided evacuations, reduced utility service losses and dampened local or regional, short- and long-term economic losses. (Asadabadi and Miller-Hooks, 2017)

The sample size looked at in the study was relatively small, making it difficult to compare how different sectors of stakeholders felt concern about different types of impacts or how different types of stakeholders perceived strategies differently (Becker et al., 2015)

Pathway that the design follows does not consider any other variables outside of optimization of materials. Thus, it is most likely not an optimal alignment to mitigate local wave dynamics and may cut through other important infrastructure, densely populated areas, critical habitat, or historic landmarks (Becker et al., 2016)

Detailed understanding of the local processes also allows the limitations of the ‘static’ morphology within the DST to be put in context thought the identification of how uncertainty within the mapped results could occur (Brown et al., 2018)

This study does not account for important climate change related factors including sea level rise, flooding, and other extreme events (Espinet et al., 2016)

The assumptions used in the case study are rather simple in approach due to data limitations (Jeong et al., 2014)

knowledge of coastal erosion management by means of ecosystems is, in part, little known and less applied and very few studies exist (Gracia et al., 2018)

Requires longer time frames to establish and needs research to understand dynamic processes (Moosavi, 2017)

While successful at increasing biodiversity, as neither baselines nor additional ecological parameters (e.g. ecosystem functions) were quantified for these systems, proportional and absolute ecological gains through mitigation remain unknown and mitigation effectiveness unquantified. For soft engineering options where mitigation outcomes have far greater potential, before-and-after quantifications are limited. (Perkins et al., 2015)

Ecological criteria used are rather general and based only on the literature on ecosystem-based management. Moreover, the method presented here evaluates flood protection systems based on ecological and engineering parameters alone. Lacking financial, political and social aspects, the method can only contribute to part of the total evaluation needed to choose a certain design concept. The method ignores the potential negative effects of the inherently large footprint of some design concepts. (van der Nat et al., 2016)

Adaptation networks may be limited in their ability to distribute knowledge and resources to cities that need the greatest support. (Woodruff, 2018)

Each port is unique and located in distinctive geographical locations therefore it is difficult to develop a climatic representation using GCMs that fit all port geographical and climatic conditions (Mutombo and Ölçer, 2016)

Understanding of long-term climate risks is limited by the lack of in-depth knowledge on the impacts of climate hazards, due to the absence of harmonized loss data recording. Also subject to bias (Forzieri et al., 2018)

Diffraction and wind interruption from the small islands within the model domain were not resolved due to the coarse spatial resolution of the WW3 domain. Additionally, the effects of ENSO were not considered (Shope et al., 2016)

This study lacks a detailed and up-to-date scientific assessment that considers sea levels, waves and coastal floods (Wadey et al., 2017)

Due to the short time scales covered by the majority of the available records, this often meant ignoring longer term trends, such as those resulting from climate variability and human induced sea level rise (Villatoro et al., 2014)

*Costs*

*Ecological:*

Construction based protection system in coastal erosion have proven to be more costly than ecosystem-based approaches (Moosavi, 2017; Gracia et al., 2018)

Economic loss of intertidal ecosystem functions and services can outweigh reclamation (Perkins et al., 2015)

Sandscaping is the most cost-effective compared to other adaptation measures (Vikolainen et al., 2017)

*Governance:*

Adaptation measures put in place can result in high costs in public services especially water and electricity (Martínez et al., 2018)

Cities participate in adaptation networks if transactional costs are outweighed by benefits

*Economic:*

Different approaches vary in costs but sea walls have proven to be much more costly (Asadabadi and Miller-Hooks, 2017)

The assessment of flooding and erosion risk on the coast is a complex problem, due to the large spatial variability of marine dynamics, geological, ecological and urban coastal environments, defences and protection measures, etc. (Villatoro et al., 2014)

**Human System: Fisheries and Aquaculture****Adaptation responses***Physical:**Supporting physical processes*

Prevent ocean mining (Jones et al., 2018)

Manage catchment vegetation to reduce sedimentation (Bell et al., 2018)

*Hard engineering responses*

Construction of earthen dams and coastal embankments to protect shrimp farms (Ahmed and Diana, 2015)

Netting, fencing, and higher dikes around shrimp farms (Ahmed and Diana, 2015)

*Soft engineering responses and buffers**Integrated hard and soft engineering**Managed retreat and coastal realignment**Ecological:**Ecosystem restoration and protection*

Retention of marine wilderness (Jones et al., 2018)

Ecosystem based adaption measures (Heenan et al., 2015; Hobday et al., 2015; Cheung et al., 2018), including restoration of essential habitats (Roberts et al., 2017; Cheung et al., 2018)

Mangrove plantation and conservation of the Sundarbans for breeding grounds of shrimp (Ahmed and Diana, 2015)

Precautionary ecosystem-based integration measures (Ho et al., 2016)

Improving fishery management through the incorporation of traditional strategies and ecosystem management into fisheries management strategies (Weng et al., 2014)

Mangrove rehabilitation (Harkes et al., 2015)

*Bioengineering**Assisted evolution and relocation*

Human- assisted evolution (Harvey et al., 2018)

*Nature based solutions*

Afforestation of greenbelt in shrimp farming communities (Ahmed and Diana, 2015)

Maintain the structural complexity of fish habitats (Bell et al., 2018)

*Social:**Improving access to/ storage of natural resources*

Develop water irrigation facilities with proper drainage systems (Ahmed and Diana, 2015)

Flexible arrangements to allocate more of the tuna resources to local food security (Dunstan et al., 2017)

*Improving agricultural or fisheries practices*

Sustain recruitment and production of demersal fish (Bell et al., 2018)

Introduction of coastal fish breeding programs and sea ranching to enhance diversity of key species (Dasgupta et al., 2017)

Improvements in fishery management (Hobday et al., 2015; Gaines et al., 2018), including harvest policies that are adaptive to changing demographics (Gaines et al., 2018), reduced fishing effort and catch (Cheung et al., 2018; Jones et al., 2018), adopting precautionary principle (Hobday et al., 2015).

Diversify fishing methods (Ho et al., 2016) by transferring fishing efforts from reefs to large pelagic fish (Bell et al., 2018), implement near shore fish aggregating devices (Valmonte-Santos et al., 2016; Dunstan et al., 2017; Bell et al., 2018), develop fisheries for small pelagic species (Bell et al., 2018), improving post-harvest methods (Bell et al., 2018)

Improved post-harvest methods and food storage systems to stockpile tuna and small pelagic when good catches are made (Dunstan et al., 2017)

Coastal fisheries: targeting of coastal pelagic (but this is difficult for small-scale fishermen) (Weng et al., 2014)

Culture of prawn, shrimp, and fish with salt-tolerant and drought-resistant rice varieties (Ahmed and Diana, 2015)

Dike cropping (fruits and vegetables) and social forestation (Ahmed and Diana, 2015)

Increasing the diversity of seafood commodities (Ho et al., 2016)

Increasing aquaculture productivity (Ho et al., 2016)

Creating diverse marketing channels (Ho et al., 2016)

Promote sustainable growth of fisheries (Valmonte-Santos et al., 2016)

Reduce operational costs (Valmonte-Santos et al., 2016)

Development of aquaculture (Valmonte-Santos et al., 2016)

Responsive management to reflect changes in stock distribution (Pinsky et al., 2018)

Flexible management practices (no-take areas, gear restrictions) (Dunstan et al., 2017)

Restoration of deserted shrimp farms (Harkes et al., 2015)

Supporting nature-based industries

*Sustainable resource use*

Adjusting the scale of the fisheries (Ho et al., 2016)

*Maintaining or switching livelihoods*

Implementation of alternative livelihood programs for small-scale coastal communities (Dunstan et al., 2017)

Facilitating the fishing community's learning of alternative skills (Shaffiril et al., 2017)

Encouraging community-based entrepreneurship of small-scale shrimp farmers (Galappaththi et al., 2017)

*Community participatory programmes*

Stakeholder participation (Harvey et al., 2018)

Increased stakeholder participation and community-based grass-root planning (Salim et al., 2014)

Better communication with communities (through facilitators; appropriate mediums; appropriate times; pictures) (Cvitanovic et al., 2016; Dunstan et al., 2017)

Participatory climate change adaptation planning for fishermen (Shaffiril et al., 2017)

Scenario-based stakeholder engagement (Finkbeiner et al., 2018)

Participatory conservation strategies (Harvey et al., 2018)

*Developing adaptive networks*

Effective use of social networks (Cvitanovic et al., 2016)

Strengthening social relationships (Shaffiril et al., 2017) for disaster preparation and cooperation within networks (Shaffiril et al., 2017)

Strengthening local social networks (Cvitanovic et al., 2016)

*Sustainable household management*

Strategies that build certain high-risk groups' networks (Novak Colwell et al., 2017)

*Improving access to community services*

Strengthening early warning systems in fisheries (Ho et al., 2016)

Increase investment in transportation and other infrastructural needs (Valmonte-Santos et al., 2016)

*Empowering communities and addressing inequality*

Develop capacity (Weng et al., 2014)

Autonomous and facilitative adaptation (Finkbeiner et al., 2018)

Guarantee access rights (Faraco et al., 2016) through recognition and protection of tenure (Gourlie et al., 2018)

Strategies that build certain high-risk groups' networks (Novak Colwell et al., 2017)

*Building socio-ecological resilience*

Enhancing societal adaption (Cvitanovic et al., 2016; Valmonte-Santos et al., 2016)

Sustainable socio-ecological systems (Harvey et al., 2018)

Multifaceted efforts that simultaneously tackle exposure, sensitivity and adaptive capacity (Islam et al., 2013)

Protection for local workers (Gourlie et al., 2018)

Community awareness and preparedness for disaster management (weather forecast, shelters) (Ahmed and Diana, 2015)

Strengthening civil society value in poor fishing communities (Cahaya, 2015)

*Governance:**Adopting/ mainstreaming sustainability policies*

Improve sustainable management of coastal fisheries through legislative action and regulatory implementation (Gourlie et al., 2018)

Sustainable conservation policies (Gourlie et al., 2018)

design and implement management strategies that are robust to the uncertainties of changing marine ecosystems (Busch et al., 2016)

Climate Compatible Development (Harkes et al., 2015)



*Improving disaster response programmes*

Emergency preparedness programs (Dunstan et al., 2017)

Preparedness for disaster management (disaster warning, cyclone shelters) (Ahmed and Diana, 2015)

Strengthening early warning systems in fisheries (Hobday et al., 2015; Ho et al., 2016)

Community awareness and preparedness for disaster management (weather forecast, shelters) (Ahmed and Diana, 2015)

*Improving implementation and coordination of policies*

Greater attention to trade-offs in decision-making regarding climate adaptation (Finkbeiner et al., 2018)

Improve sustainable management of coastal fisheries through legislative action and regulatory implementation (Gourlie et al., 2018)

Adaptively managing implementation strategies (Le Cornu et al., 2017)

Minimise conflicts between fishing nations (Asch et al., 2018) through support for co-management strategies (Gourlie et al., 2018)

Trading country-based allocations of fishing effort (Asch et al., 2018)

Strengthen international cooperation (Ho et al., 2016)

Flexible frameworks (Faraco et al., 2016)

Support for institutional coordination and policy cohesion (Gourlie et al., 2018)

Enabling policy and legislative environments (Heenan et al., 2015)

Aligning management measures (Heenan et al., 2015) with good governance and institutions (Heenan et al., 2015)

Resolve economic and political concerns that influence fisheries (Valmonte-Santos et al., 2016)

Empower actors to continuously learn and improve governance institutions (Nurse-Bray et al., 2018)

Lack of consistent frameworks and agreements across Pacific Islands (Cvitanovic et al., 2016)

Developing effective strategies and policy frameworks for managing adaptation of coastal communities to climate change (Colburn et al., 2016)

Application of international standards (Harkes et al., 2015)

Financial and regulatory mechanisms supporting aquaculture (Harkes et al., 2015)

*Development controls*

Adequate enforcement mechanisms (Gourlie et al., 2018)

*Evidence-based implementation*

Transparent resource management (Gourlie et al., 2018)

*Improving ICM/ MPAs*

Marine Protected Areas (Valmonte-Santos et al., 2016) to buffer against uncertainty in management, environmental fluctuations, directional change and extreme events, conserving biodiversity, repairing damaged fish stocks, creation of habitat forming areas, promote genetic diversity that provides raw material for adaptation to climate change (Roberts et al., 2017)

Marine protected areas (Faraco et al., 2016; Dasgupta et al., 2017; Roberts et al., 2017; Asch et al., 2018; Jones et al., 2018) that include marine spatial planning for climate change (Le Cornu et al., 2017; Cheung et al., 2018; Harvey et al., 2018)

Marine protected areas, positioning reserves in areas expected to warm less or not at all (Bruno et al., 2018)

Holistic adaptation planning using CBA and ICM (Ahmed and Diana, 2015)

MPAs may impact communities through Fisheries closures (Bennett et al., 2016)

Identify appropriate climate-informed defence points for managing Large Marine Reserves with appropriate strategies for management (Busch et al., 2016)

*Horizontal/ vertical integration of governance*

Decentralisation and co-management (Harkes et al., 2015)

*Developing partnerships and building capacity*

Participatory conservation strategies (Harvey et al., 2018) and co-management of fisheries (Nurse-Bray et al., 2018; Pinsky et al., 2018)

Motivate stakeholders to self-organise, design and reform their institutions (Nurse-Bray et al., 2018)

Mobilise resources for decision-making and implementations (Nurse-Bray et al., 2018)

Support for principles of fair governance, building relationships, two-way dialogues between government and industry, enhanced governance and leadership (Nurse-Bray et al., 2018)

*Improving access to community services*

Flexible arrangements to allocate more of the tuna resources to local food security (Dunstan et al., 2017)

Flexible licencing provisions (Dunstan et al., 2017)

Guarantee access rights (Faraco et al., 2016) through recognition and protection of tenure (Gourlie et al., 2018)

*Pursuing climate justice*

Increase allocation of area of the EEZ available to small-scale fishers (Dunstan et al., 2017)

*Economic:*

*Improving financial resources availability*

Enhancing fishermen's access to credit (Shaffiril et al., 2017)

Includes fisheries agency budget planning to ensure funds are available for maintenance and repair of FADs (Dunstan et al., 2017)

Fuel and gear subsidies (Dunstan et al., 2017)

*Improving access to insurance products*

Creation of social safety nets e.g. insurance programs for SSF, community insurance banks for communities (Dunstan et al., 2017)

Reducing fishing risks through affordable insurance policies (Shaffiril et al., 2017) and innovative context-appropriate insurance practices (Shaffiril et al., 2017)

Economic diversification

Diversifying incomes for subsistence shrimp farmers (Galappaththi et al., 2017)

Increasing access to international funding programmes

*Knowledge:*

*Better monitoring and modelling*

Scientific needs: ecosystem modelling to social science, economics, international politics and conflict resolution (Weng et al., 2014)

Monitoring, verification and management (Weng et al., 2014)

Effective monitoring and evaluative mechanisms (Le Cornu et al., 2017; Gourlie et al., 2018)

Climate model literacy training for marine biological researchers (Payne et al., 2017)

Better understanding climate stressors through enhanced social indicator modelling (Colburn et al., 2016)

Integrated end-to-end models that explore trade-offs (Hobday et al., 2015)

*Improving planning processes*

Identify areas of high risk and factors contributing to risk (Salim et al., 2014)

Improved adaptation science (Cvitanovic et al., 2016)

*Improving forecasting and early warning systems*

Improved marine ecological forecasting (Payne et al., 2017)

Develop effective prediction tools (Dunstan et al., 2017)

Community awareness and preparedness for disaster management (weather forecast, shelters) (Ahmed and Diana, 2015)

Seasonal forecasting of fisheries (Asch et al., 2018)

Improved forecasting (Ho et al., 2016)

Predicting productivity, spatial distribution and phenological changes (Payne et al., 2017)

Predicting human elements of the system (Payne et al., 2017)

Considering trade-offs in forecasting (Payne et al., 2017)

Horizontal and vertical range shifts in coastal fishes, eastward shifts of tuna stocks in the tropical Pacific, improved habitat in the east and declines in the Warm Pool region

*Improving decision support frameworks*

Acquiring reliable data to base decisions on and data sharing (Pinsky et al., 2018)

Use of a vulnerability indices to inform adaptation planning (Johnson et al., 2016)

Holistic adaptation planning using CBA and ICM (Ahmed and Diana, 2015)

Establishing mechanisms of food security classification management (Ho et al., 2016)

Appropriate design (Le Cornu et al., 2017)

Avoidance measures of climate risk and production uncertainty (Ho et al., 2016)

Develop tools to incorporate social vulnerability indicators into policy making (Colburn et al., 2016)

*Improving participatory processes*

Scientists working with communities (Cvitanovic et al., 2016) through participatory research approaches (Cvitanovic et al., 2016)

Engaging key actors in relevant forms of knowledge exchange (Cvitanovic et al., 2016; Faraco et al., 2016; Le Cornu et al., 2017; Payne et al., 2017; Finkbeiner et al., 2018)

Incorporating science with community needs and decision making at all scales (Cvitanovic et al., 2016) and participatory (Valmonte-Santos et al., 2016; Nursey-Bray et al., 2018) research approaches (Cvitanovic et al., 2016)

co-producing knowledge with subsistence shrimp farmers (Galappaththi et al., 2017)

*Coordinating top down and bottom up approaches*

Bottom up approach to fisheries management (Salim et al., 2014)

Co-ordination with existing on-ground activities (Cvitanovic et al., 2016)

*Integrating knowledge systems*

Collecting and integrating diverse sources of information (Le Cornu et al., 2017)

Improving fishery management through the incorporation of traditional strategies and ecosystem management into fisheries management strategies (Weng et al., 2014)

Traditional knowledge (Johnson et al., 2016)

Recognition and support for local communities and traditional management (Gourlie et al., 2018)

*Improving location and context specific knowledge*

Increased investigation of natural resource management issues through a gendered lens (Novak Colwell et al., 2017)

Adaptive management strategies based on market intelligence (Rodríguez-Rodríguez and Bande Ramudo, 2017)

*Improving scientific communication*

The use of mobile technology to warn fishermen of threats (Shaffiril et al., 2017)

Information for improved fisheries management strategies (Weng et al., 2014)

Data, research and information sharing (Gourlie et al., 2018)

Information exchange between stakeholders (Heenan et al., 2015)

*Stakeholder identification, outreach and education*

Community training programmes with sharing of technical knowledge and awareness (Salim et al., 2014)

Informing fishermen of the value and importance of having insurance (Shaffiril et al., 2017)

Education of a marine fish-eating culture (Ho et al., 2016)

Support and train stakeholders to use forecast models effectively, engaging end-users (Payne et al., 2017)

Provide technical assistance to subsistence fishers (Valmonte-Santos et al., 2016)

*Multiple adaptation responses used*

Reduction in local anthropogenic stressors (Harvey et al., 2018)

Ecosystem based adaption measures which respond to local vulnerability context (Faraco et al., 2016)

CBA and ICM (Ahmed and Diana, 2015)

Improving fishery management through the incorporation of traditional strategies and ecosystem management into fisheries management strategies (Weng et al., 2014)

Synergistic responses addressing social, governance and knowledge responses (Dunstan et al., 2017)

Synergistic social adaptation strategies should be applied (Shaffiril et al., 2017)

Holistic adaptation planning using CBA and ICM (Ahmed and Diana, 2015)

**Benefits**

*Ecological:*

Ecosystem/ ecological resilience supported

Reduction of human stressors in MPAs promotes ecosystem recovery and prevents biodiversity loss (Roberts et al., 2017)

Maintain healthy reefs (Harvey et al., 2018)

Supports development of shrimp industry with less damage to mangroves and salt marshes (Harkes et al., 2015)

*Physical processes supported*

High abundance of mesopelagic fish in open ocean MPAs may enhance CO<sub>2</sub> absorption and buffer acidification near the surface through excretion of gut carbonate, protect apex predators that confer increased stability to coastal habitats that buffer climate-induced instabilities (Roberts et al., 2017)

Reduced fishing pressure on reef resources (Valmonte-Santos et al., 2016)

*Coastal infrastructure resilience increased*

*Increased biodiversity*

Reduction of human stressors in MPAs promotes ecosystem recovery and prevents biodiversity loss (Hobday et al., 2015; Roberts et al., 2017)

Preserve species with large home ranges (Jones et al., 2018)

*Habitat range shifts accommodated*

MPAs provide steppingstones for dispersal and safe landing zones for climate migrants (Roberts et al., 2017) maintaining high levels of ecological and evolutionary connectivity (Jones et al., 2018)

*Improved organismal fitness*

Increased reproductive outputs (Cheung et al., 2018)

*Genetic heterogeneity supported*

Increased genetic variability (Cheung et al., 2018; Jones et al., 2018)

*Strengthened socio-ecological system*

Promotion of socio-ecological resilience (Ahmed and Diana, 2015; Harkes et al., 2015)

*Social:**Access to sustainable ecosystem services*

Improved ecosystem services (Faraco et al., 2016)

Preservation of marine resources (Cahaya, 2015)

Reduction of human stressors in MPAs enhances livelihoods and ecosystem services (Roberts et al., 2017)

Increases in maximum catch potential (Asch et al., 2018) and global fishery yield (Gaines et al., 2018)

Helps sustain the contribution of coastal fisheries to food security (Bell et al., 2018)

Ensure food security (Heenan et al., 2015; Asch et al., 2018; Finkbeiner et al., 2018) by replenishing depleted stocks (Bell et al., 2018)

Higher fish production (Valmonte-Santos et al., 2016)

Increased catch per unit of effort (Valmonte-Santos et al., 2016)

Reduction in reliance on fish imports (Valmonte-Santos et al., 2016)

Supports development of shrimp industry with less damage to mangroves and salt marshes (Harkes et al., 2015)

*Improved access to resources**Human systems supported**Improved socio-economic services*

Enhanced food security (Cvitanovic et al., 2016; Le Cornu et al., 2017; Gaines et al., 2018) and nutritional status of Pacific Island countries (Valmonte-Santos et al., 2016)

Healthier shrimp industry (Harkes et al., 2015)

*Improved employment and livelihoods*

Reduction of human stressors in MPAs enhances livelihoods and ecosystem services (Roberts et al., 2017)

Sustaining livelihoods (Harkes et al., 2015; Harvey et al., 2018) through securing employment (Le Cornu et al., 2017)

Uplifting the living standard of fishermen (Cahaya, 2015) by supporting local livelihoods (Heenan et al., 2015; Faraco et al., 2016; Payne et al., 2017; Finkbeiner et al., 2018; Gourlie et al., 2018), well-being (Gourlie et al., 2018), culture (Finkbeiner et al., 2018) and sovereignty (Finkbeiner et al., 2018)

Prevent and reduce poverty (Faraco et al., 2016; Payne et al., 2017)

Facilitates diversification of effort (Gourlie et al., 2018)

Supports livelihoods and contributes to food security and wellbeing of coastal and freshwater systems (Galappaththi et al., 2017)

*Improved health*

Reduces disease through lower use of chemicals (Harkes et al., 2015)

*Improved community participation*

*Improved integration of knowledge systems*

*Empowering women and children*

*Increased adaptive capacity*

Increased adaptive capacity (Cvitanovic et al., 2016)

social transformation towards sustainability (Galappaththi et al., 2017)

*Improved disaster preparedness*

*Empowered communities*

Empowerment of communities (capacity building) (Ahmed and Diana, 2015)

Empowering small-scale fishers (Bell et al., 2018)

Facilitates community-level ownership of adaptation (Gourlie et al., 2018)

*Improved community cohesion*

Incentivises collective action (Faraco et al., 2016)

*Reduced inequality*

Increases equity (shared benefits) and productivity (Harkes et al., 2015)

*Governance:*

*Political and institutional capacity developed*

*Strengthened participatory governance*

Co-management enhances ownership over decision-making processes (Nurse-Bray et al., 2018)

*Better planning processes supported*

Co-management promotes greater sensitivity to socio-economic and ecological constraints (Nurse-Bray et al., 2018)

Ensures measures are appropriate for the local context (Le Cornu et al., 2017)

Address complex issues like climate change by contributing to reduce uncertainty and by

avoiding or, at least limiting, the unbalance of pre-existing governance systems (Rodríguez-Rodríguez and Bande Ramudo, 2017)

*Improved coordination and decision making*

*Improved implementation and policies*

Sustainable fisheries management (Gourlie et al., 2018)

*Better communication*

Improved communication (Cvitanovic et al., 2016)

*Improved transparency and trust*

Co-management improves management outcomes, promotes collective ownership, increases compliance; ensures better monitoring, control and surveillance, encourages diverse knowledge sharing (Nurse-Bray et al., 2018)

Trust building (Cvitanovic et al., 2016)

*Climate justice advanced*

Maintenance of common property rights over resources (Faraco et al., 2016)

*Reduced conflict*

Minimise conflicts between fishing nations (Asch et al., 2018) including with new fish stocks (Pinsky et al., 2018)

*Improved security*

Maintain security (Finkbeiner et al., 2018)

*Improved adaptive management*

Aid disaster preparedness (Asch et al., 2018)

Improved climate adaption decision-making (Finkbeiner et al., 2018)

Enable adaptive capacity in fisheries management (Nurse-Bray et al., 2018)

Allows for better informed adaptive responses (Payne et al., 2017)

MPAs provide steppingstones for dispersal and safe landing zones for climate migrants (Roberts et al., 2017) maintaining high levels of ecological and evolutionary connectivity (Jones et al., 2018)

Require adaptive management and consideration of the cumulative effects (Gourlie et al., 2018)

Enhances the analytical capabilities within fisheries, enhancing informed ecosystem based fisheries management and policy decisions (Colburn et al., 2016)

*Development supported*

*Economic:*

*Increased revenue/ income*

Export creation opportunities, commercial development and the creation of jobs (Valmonte-Santos et al., 2016)

Better bargaining power producers and higher production lead to higher profits (Harkes et al., 2015)

*Increased financial resources available*

Subsidies required to support adaptations (Bell et al., 2018)

Promote economic growth (Asch et al., 2018)

Possibility of funding mechanisms (Gourlie et al., 2018)

*Reduced operational and capital costs*

*Investment strengthened*

*Knowledge:*

*Informed decision making tools*

Collection of key information (Gourlie et al., 2018)

Reduce risks and uncertainties associated with seafood supply (Ho et al., 2016)

Create a more integrated picture of climate change (Colburn et al., 2016)

Enhances the analytical capabilities within fisheries, enhancing informed ecosystem based fisheries management and policy decisions (Colburn et al., 2016)

Provides a blueprint for strengthening the production and use of climate-related information needed promote effective fisheries management in a changing climate (Busch et al., 2016)

Better knowledge inputs on markets behaviour may help avoiding or limiting i) too much anticipated

and highly uncertain responses, rushing for mitigation without clear evidence, and ii) short-term reactions, tending to overexploitation of natural resources as a way to maintain producers income (Rodríguez-Rodríguez and Bande Ramudo, 2017)

*Improved co-production of knowledge*

Improved understanding of strategies outcomes for at risk groups and gender (Novak Colwell et al., 2017)

Stimulates exchange of information and knowledge (Harkes et al., 2015)

*Improved relevance of products*

Understanding both high-level processes and individual-level relationships, provides valuable insight into people's livelihood choices that traditional models of gender and the environment do not (Novak Colwell et al., 2017)

*Improved education and outreach*

*Improved awareness*

*Co-benefits*

*Constraints and limitations*

*Physical:*

Geographic remoteness from markets of reasonable size (Valmonte-Santos et al., 2016)

*Ecological:*

Complex interactions between species and habitats (Bell et al., 2018)

Certain responses may demand higher energy use and thus increase CO<sub>2</sub> emissions, The construction of shrimp farms leads to the removal of above and below ground carbon, along with the potential for future carbon sequestration, increased shrimp farms require mangroves to be removed for space and pollute surface water (Harkes et al., 2015)

*Social:*

Less developed coastal countries have a high dependence on the oceans for food and livelihood, while having limited adaptive capacity (Cheung et al., 2018)

Lack of trust among local communities and external scientists (Cvitanovic et al., 2016)

Engagement of end-users in climate change science (Cvitanovic et al., 2016)

Limiting adaption and diversification options (Faraco et al., 2016)

Uneven socio-economic impacts of climate change (Finkbeiner et al., 2018)

Difficulty in balancing social and ecological objectives (Finkbeiner et al., 2018)

Involves reforms for many stock (Gaines et al., 2018)

Limited assets (Cahaya, 2015)

Lack of bargaining power (Cahaya, 2015)

Reduction of aquaculture and degradation of aquaculture areas ((Ho et al., 2016)

Lack of effective adaptation strategies ((Ho et al., 2016)

Dependency on marine fisheries for livelihoods, lack of alternative livelihood (Islam et al., 2013)

Lack of physical, natural and financial capital (Islam et al., 2013)

Small scale fisheries are extremely intricate social-ecological systems (Le Cornu et al., 2017)

Inshore resources are heavily exploited and offshore resources are difficult to access for subsistence fishers (Valmonte-Santos et al., 2016), Slow development in aquaculture (Valmonte-Santos et al., 2016)

High fuel costs, lack of appropriate fishing gear and limited infrastructure (Valmonte-Santos et al., 2016) in a highly competitive industry



Lack of awareness of coastal communities of the consequences of over-exploitation (Valmonte-Santos et al., 2016)

Limited interaction between stakeholders (Valmonte-Santos et al., 2016)

High likelihood of individuals employing reactive strategies that may threaten their longer-term livelihood sustainability (Novak Colwell et al., 2017)

Lack of intersectionality in resource management research (Novak Colwell et al., 2017)

#### *Governance:*

Conflicts between fishing nations as stocks migrate (Asch et al., 2018; Gaines et al., 2018)

Emerging conflict between maximizing yield of target species and maintaining ecosystem structure/function. Solutions to one of the conflicts may work against a solution for another (Hobday et al., 2015)

Lack of fisheries management and conservation plans (Cheung et al., 2018)

Lack of consideration of climate risk in species conservation planning (Cheung et al., 2018)

Lack of cohesive and connected co-management frameworks within fisheries management arrangements (Nurse-Bray et al., 2018)

Co-management lacks resources and legislation conducive to building fishery support (Nurse-Bray et al., 2018)

Lack of effective international coordination (Cheung et al., 2018; Gaines et al., 2018)

Effective management in Pacific Island communities (Cvitanovic et al., 2016)

Inappropriate governance structures (Heenan et al., 2015; Cvitanovic et al., 2016)

Lack of political and technical support (Cvitanovic et al., 2016)

Lack of consistent frameworks and agreements between Pacific Island nations and local government levels (Cvitanovic et al., 2016)

Problems with access to and management of natural resources (Faraco et al., 2016)

Poor biodiversity and conservation policies (Faraco et al., 2016)

Limited financial and political support (Faraco et al., 2016)

Coastal fisheries receive less attention from government managers (Gourlie et al., 2018)

Legislation gaps (Gourlie et al., 2018)

Legally challenging (Jones et al., 2018), difficulties with enforcing compliance beyond national jurisdiction (Jones et al., 2018)

The current legal framework does not directly account for changing distributions (Pinsky et al., 2018)

Prevailing weak management of fish stocks globally (Pinsky et al., 2018)

Minimal cooperation between regional fishing management organisations on the potential for future shared stocks (Pinsky et al., 2018)

Judicial decisions do not always resolve conflicts and require adherence by the parties (Pinsky et al., 2018)

Limited institutional capacities (Valmonte-Santos et al., 2016)

Concerns about managing displaced fishing efforts with MPAs (Roberts et al., 2017)

Lack of institutional and financial support to establish buffer zones; although there are shrimp farmers associations, the activities of individual farms, are not coordinated; Access to loans and insurance is difficult as interest rates are high and government support is lacking; absence of a specific law for aquaculture (Harkes et al., 2015)

#### *Economic:*

Lack of resources (Cvitanovic et al., 2016; Bell et al., 2018)

Weak capital structures (Cahaya, 2015)

Limited financial and technical resources (Valmonte-Santos et al., 2016)

MPAs under-resourced i.r.o. Lack of staff, lack of equipment, lack of funding (Roberts et al., 2017)

Global market and demographic shifts (Le Cornu et al., 2017)

*Knowledge:*

Lack of frequent data collection (Heenan et al., 2015) and management updates (Gaines et al., 2018)

Lack of access to data and science (Cahaya, 2015)

Lack of scientific knowledge and studies (Rodríguez-Rodríguez and Bande Ramudo, 2017). Risks of mismanagement resulting from lack of scientific knowledge, focus on market intelligence may distract from the root causes of system degradation (Rodríguez-Rodríguez and Bande Ramudo, 2017)

Lack of studies relating to fish migration and live-release by-catch survival rates, great deal of coordination required to collect some indicators, difficult to collect indicators as the open sea is so vast (Hobday et al., 2015)

Future projections of ocean conditions are uncertain (Cheung et al., 2018) and it is difficult to predict where fish distribution will shift to (Gaines et al., 2018)

Limited knowledge on the sensitivity and adaptive capacity of marine species to climate change and fishing (Cheung et al., 2018)

Cultural differences between western science and cultural knowledge (Cvitanovic et al., 2016)

Challenges related to defining the human component of ecological systems (Payne et al., 2017)

Gap between climate modelling and marine science communities (Payne et al., 2017)

Access to forecast data, focus of marine science has been on describing rather than predicting systems, complexity of biological systems, difficulty observing life in the ocean (Payne et al., 2017)

Lack of awareness and engagement by fishers surrounding climate issues (Salim et al., 2014)

Uncertainty surrounding the environmental tolerances and adaptability for most species when planning MPAs (Bruno et al., 2018)

Inadequate communication and support with local communities i.r.o. MPA management (Roberts et al., 2017)

Knowledge of climate-induced impacts and vulnerability on the local-scale of fishery-based livelihoods is limited (Islam et al., 2013)

Research that is too focussed on gender can further marginalize other women and also large segments of the male population, great potential to exacerbate existing inequitable power structures (Novak Colwell et al., 2017)

*Costs*

*Physical:*

Inundation of infrastructure to allow for mangroves to migrate inland (Bell et al., 2018)

Vandalism and natural disasters (Valmonte-Santos et al., 2016)

*Economic:*

Expensive to raise and plant seedlings (Bell et al., 2018)

Resources required for monitoring (Bell et al., 2018)

Unequal distribution of costs and benefits (Faraco et al., 2016)

MPAs are a viable low-tech and cost effective adaption strategy (Roberts et al., 2017)

*Knowledge:*

Forecast may be used and interpreted incorrectly (Payne et al., 2017)

Forecasts may fail in a technical sense (Payne et al., 2017)

Participatory research approaches need to be sustained (Cvitanovic et al., 2016)

Human System: Coastal Tourism

Adaptation responses

*Physical:*

*Hard engineering responses*

High financial investments for construction of hard protection structures (Rangel-Buitrago et al., 2015)

Regulated tidal exchange infrastructure (MacDonald et al., 2017)

*Managed retreat and coastal realignment*

Large coastal managed realignment projects (MacDonald et al., 2017)

*Ecological:*

*Nature based solutions*

Natural resource management (Papageorgiou, 2016) and economic evaluations of ecosystem value (Hernández-Delgado, 2015)

*Social:*

*Sustainable resource use*

Sustainable water use management (Papageorgiou, 2016; Klinsky et al., 2017)

Promote wise allocation of coastal and marine tourism activities so as to mitigate environmental degradation (Papageorgiou, 2016)

*Empowering communities and addressing inequality*

Improving stakeholders in the tourism industry's understanding of their vulnerability to climate change to empower them to take appropriate actions to adapt (Tapsuwan and Rongrongmuang, 2015)

*Governance:*

*Developing partnerships and building capacity*

Developing public-private partnerships (Klinsky et al., 2017)

*Economic:*

*Improving financial resources availability*

Involving the tourism industry in adaption finance (Klinsky et al., 2017)

Adaptation taxes and levies (Klinsky et al., 2017)

Adaptation strategies to counteract market share losses induced by climate change (Bujosa et al., 2015)

*Improving access to insurance products*

Risk transfer mechanisms (Klinsky et al., 2017)

*Improving access to international funding programmes*

Adaptation funds (Klinsky et al., 2017)

*Knowledge:*

*Better monitoring and modelling*

Hadley Centre Coupled Model (HadCM3) and Canadian Global Climate Model (CGCM2) (Bujosa et al., 2015)

*Improving decision support frameworks*

Matrix of exposition degree versus adaptive capacity. Diagram for Integrated Coastal Vulnerability Assessment (Lins-de-Barros, 2017)

Generic management framework (MCDA) (Michailidou et al., 2016)

Protection Motivation Theory (PTM) framework (Tapsuwan and Rongrongmuang, 2015)

Social representation of managed realignment (Schliephack and Dickinson, 2017)

Using marine spatial planning to organize and plan coastal and marine tourism activities (Papageorgiou, 2016)

*Stakeholder identification, outreach and education*

Changing perceptions of key stakeholders (Klinsky et al., 2017)

*Multiple adaptation responses used*

Natural resource management, Governance, Economic efficiency and welfare maximization (Hernández-Delgado, 2015)

Benefits

*Physical:*

*Physical processes supported*

Restores intertidal habitat by removing or breaching built infrastructure so the land behind them floods, allowing the intertidal habitat to migrate inland (MacDonald et al., 2017)

*Hard engineering responses*

Many protection structures have been built and installed in response to local stakeholder pressure (Rangel-Buitrago et al., 2015)

*Ecological:*

*Ecosystem/ ecological resilience supported*

Coastal protection services offered by ecosystems (Hernández-Delgado, 2015)

Promotes resilience against climate change effects (Papageorgiou, 2016)

*Increased biodiversity*

Biodiversity benefits provided by ecosystems supports coastal tourism (Hernández-Delgado, 2015)

*Social:*

*Improving access to/ storage of natural resources*

Healthy ecosystems improve access to services like fisheries, construction materials, medicines, cosmetics and the aquarium trade (Hernández-Delgado, 2015)

Intertidal habitats provide significant ecosystem services, such as carbon sequestration in accreting sediments, flood defences for coastal communities, hunting of wintering wildfowl and nursery areas for commercially-caught fish (MacDonald et al., 2017)

*Human systems supported*

A more resilient tourism industry (Bujosa et al., 2015; Hernández-Delgado, 2015; Klinsky et al., 2017)

Ensures that that coastal and marine space is not overwhelmed by tourism facilities and activities (Papageorgiou, 2016)

*Increased adaptive capacity*

Enhanced adaptation to climate change effects (Papageorgiou, 2016)

*Governance:*

*Development supported*

Fostering development (Klinsky et al., 2017)

*Economic:**Increased revenue/ income*

Generate employment (Klinsky et al., 2017)

Increased tax revenues (Klinsky et al., 2017)

Justifying the value of protecting natural resources (Klinsky et al., 2017)

Ensures good environmental conditions for the tourism industry to prosper (Papageorgiou, 2016)

*Reduced conflict*

Minimises conflicts and create synergies among sectors (Papageorgiou, 2016)

*Knowledge:**Improving decision support frameworks*

Multi-criteria decision-making assessments improved (Lins-de-Barros, 2017)

Allows for benchmarking when choosing interventions/measures/alternatives by taking into consideration local specific characteristics (Michailidou et al., 2016)

Social representation of managed realignment shapes wider understandings of climate change adaptation (Schliephack and Dickinson, 2017)

*Co-benefits**Constraints and limitations**Governance:*

Public policy changes and reliability (Klinsky et al., 2017)

Non-transparent and unreliable political systems (Klinsky et al., 2017)

Need to update current legislation with strong coastal management laws (Rangel-Buitrago et al., 2015)

The performance of managed realignment specifically in delivering ecosystem services and biodiversity benefits in England has been questioned (MacDonald et al., 2017)

*Social:*

Cumulative effects of coastal tourism may affect multiple ecosystem functions, compromise food security and sovereignty, public health, local economies and people's livelihood sustainability in still largely unknown ways (Hernández-Delgado, 2015)

*Economic:*

Development of international tourism flows (Klinsky et al., 2017)

Knowledge; Unclear magnitudes and time scales of regional and local climate change impacts (Klinsky et al., 2017)

Reluctance to finance adaptation in the tourism sector (Klinsky et al., 2017)

Finding sustainable arrangements for funding and financing coastal management legislation (Rangel-Buitrago et al., 2015)

*Knowledge:*

Unclear magnitudes and time scales of regional and local climate change impacts (Klinsky et al., 2017)

This paper focused on a specific destination with unique features and a tailored managed realignment strategy. Strategies, features of tourism interest and use values will vary in other destinations (Schliephack and Dickinson, 2017)

Fuzzy and multidisciplinary nature of tourism creates difficulty in identifying synergies and conflicts; coastal and marine tourism are generally perceived as non-threatening activities to other human uses. Requires much more time and effort than less effective responses (Papageorgiou, 2016)

## Costs

### *Governance:*

Need for government incentive and frameworks (Klinsky et al., 2017)

### *Economic:*

The overall costs of climate change (CC) may be equivalent to losing at least 5% of the global gross domestic product each year (Bujosa et al., 2015)

The greater the uncertainty associated with biophysical estimates, the less easy it is to determine how economically valuable a strategy like managed realignment may be. Intertidal sediment accretion is dynamic and site-dependent, such that applying values from other sites could be inaccurate (MacDonald et al., 2017)

Human System: Government systems

Adaptation responses

### *Ecological:*

#### *Ecosystem restoration and protection*

Enhancing coral reefs and mangroves for ecosystem services (Gallo et al., 2017)

### *Social:*

#### *Developing adaptive networks*

Network building (Aylett, 2015)

### *Governance:*

Adopting/ mainstreaming sustainability policies

Investment and policies for adaptation to climate change (Buurman and Babovic, 2016)

Mainstreaming and integration of adaptation policies (Aylett, 2015)

Apply a precautionary approach until accurate science is available (Johnson et al., 2018)

#### *Improving disaster response programmes*

Integrative risk management (Gerkenmeier and Ratter, 2018)

#### *Improving implementation and coordination of policies*

Improving synergies (Aylett, 2015; Rosendo et al., 2018)

Supporting marine and coastal Nationally Determined Contributions (NDCs) (Gallo et al., 2017)

Aligning the policies of local authorities (Porter et al., 2015)

Development of targets and statutory duties for local authorities (Porter et al., 2015)

Cross-sectorial approaches (Serrao-Neumann et al., 2013)

Modern legislation and administrative solutions (Vikolainen et al., 2017)

Formal institutional reforms (Aylett, 2015)

Crosscutting action across multiple sectors of urban life carried out by a variety of actors, coordinated policy responses across multiple sectors (Aylett, 2015)

Multi-functionality – a solution that meets societal demands and generates socio-economic and environmental opportunities (Vikolainen et al., 2017)

Adequate governance and management systems (Johnson et al., 2018)

Increase co-operation between contracting parties and marine sub-regions (Gormley et al., 2015)

### *Improving ICM/ MPAs*

Marine protected areas (Gallo et al., 2017; Johnson et al., 2018)

Improving ICM/ MPAs (Rosendo et al., 2018)

Incorporating climate science into Marine Protected Areas network processes. Consider how marine biodiversity will change in the future. Design criteria for climate change resilience (Hopkins et al., 2016)

Area-Based Management Tools. Evaluate levels of connectivity to see where new alternative areas are best located (Johnson et al., 2018)

Develop adaptive management strategies for Priority Marine Habitats and increase MPAs in some sub-regions (Gormley et al., 2015)

Bi-directional knowledge sharing and stakeholder participation in ICZM (Abelshausen et al., 2015)

*Horizontal/ vertical integration of governance*

Multi-level governance systems (Serrao-Neumann et al., 2013)

Increase co-operation between contracting parties and marine sub-regions (Gormley et al., 2015)

*Developing partnerships and building capacity*

Strengthen capacity of local marine institutions (Gallo et al., 2017)

Community governance responses (Nunn et al., 2014) including empowering community leaders to make appropriate decisions, bolstering stakeholder awareness of the science surrounding climate change (Nunn et al., 2014)

Strengthening local governance (Paterson et al., 2017)

Building capacity at a local level (Paterson et al., 2017)

Building collaborative networks between municipal agencies (Aylett, 2015)

Improve collaborative efforts (Johnson et al., 2018)

*Pursuing climate justice*

Climate change research must include equity issues (Klinsky et al., 2017)

*Knowledge:*

*Better monitoring and modelling*

Improve scientific climate models and marine observations (Gallo et al., 2017; Johnson et al., 2018)

Monitoring processes at the coast (Gerkenmeier and Ratter, 2018)

Strong monitoring frameworks ; employing an adaptive approach to the overall management of an MPA network (Hopkins et al., 2016)

Draw up an Atlantic-wide assessment and monitoring programme (Johnson et al., 2018)

The use of predictive Species Distribution Modelling (SDM) methods (Gormley et al., 2015)

*Improving forecasting and early warning systems*

*Improving decision support frameworks*

Development of more policy-focused adaptation science (Porter et al., 2015)

Scenario planning, mathematical modelling, multi-criteria analysis, adaptation pathways approach to decision making (Buurman and Babovic, 2016)

Incorporating climate science into Marine Protected Areas network processes (Hopkins et al., 2016)

*Improving participatory processes*

Risk analysis and assessment, using stakeholder perceptions to define risk, improving multi-stakeholder partnerships, participative and flexible risk management processes (Gerkenmeier and Ratter, 2018; Rosendo et al., 2018)

Bi-directional knowledge sharing and stakeholder participation in ICZM includes stakeholders as co-designers and co-decision makers (Abelshausen et al., 2015)

*Integrating knowledge systems*

Takes traditional values into account and ensures that responses meet the needs of the stakeholders (Abelshausen et al., 2015)

*Improving location and context specific knowledge*

Assessing and addressing knowledge gaps (Cooley et al., 2016)

*Stakeholder identification, outreach and education*

Educational programmes (Aylett, 2015)

Increased education and outreach programmes (Cooley et al., 2016)

Creates a platform that allows for bi-directional knowledge sharing and improves social learning (Abelshausen et al., 2015)

*Multiple adaptation responses used*

Benefits

*Physical:**Supporting physical processes*

Major sink for CO<sub>2</sub> and for the heat resulting from the associated greenhouse effect (Johnson et al., 2018)

*Ecological:**Ecosystem restoration and protection*

Promotes the sustainable use, development and protection of coastal environments (Rosendo et al., 2018)

Enhance the resilience of species and habitats to climate change impacts (Hopkins et al., 2016)

Provide important habitat for resident and migratory species of fish, sea birds and marine mammals (Johnson et al., 2018)

Protecting biodiversity and setting appropriate conservation priorities (Gormley et al., 2015)

Raises the potential for habitat restoration as well as the risks posed by non-indigenous species as niches become available (Gormley et al., 2015)

*Social:**Sustainable resource use*

Promotes the sustainable use, development and protection of coastal environments (Rosendo et al., 2018)

*Improved employment and livelihoods*

Improved human wellbeing (Klinsky et al., 2017)

*Improved community participation*

Anchors coastal risk management within society; strengthens multi-risk, multi-scale and multi-stakeholder perspectives; enhance participation and communication between stakeholders (Gerkenmeier and Ratter, 2018; Rosendo et al., 2018)

*Increased adaptive capacity*

Help marine resource-dependent communities adapt to existing acidification (Cooley et al., 2016; Rosendo et al., 2018)

*Improving access to community services*

Provide cultural services that are important to (coastal) nations and their citizens (Johnson et al., 2018)

*Reduced inequality*

A focus on equity establishes long-term legitimacy for strategies (Klinsky et al., 2017), informing implications of trade-offs for diverse individuals and groups (Klinsky et al., 2017)



*Governance:**Better planning processes supported*

Enhanced consideration of social processes in risk management (Gerkenmeier and Ratter, 2018; Rosendo et al., 2018)

Improve future systematic conservation planning (Johnson et al., 2018)

*Improved implementation and policies*

Improved service delivery (Aylett, 2015)

Improved rationality and effectiveness of policy making (Serrao-Neumann et al., 2013; Rosendo et al., 2018)

Reduced policy contradictions (Serrao-Neumann et al., 2013)

Reduced trade-offs (Serrao-Neumann et al., 2013)

*Improved transparency and trust*

Improved transparency (Serrao-Neumann et al., 2013)

*Horizontal/ vertical integration of governance*

Support the local implementation of national climate change policy; bridges different administrative scales (national, regional, local) (Rosendo et al., 2018)

*Improved adaptive management*

Improved governance for climate adaptation (Serrao-Neumann et al., 2013)

Enables management for a changing climate (Gormley et al., 2015)

Addresses disruption to habitat connectivity and the coherence of MPA networks if these habitats become fragmented, highlights certain theoretical problems (Gormley et al., 2015)

*Economic:**Increased revenue/ income*

Economic growth and innovation (Vikolainen et al., 2017)

*Increased financial resources available*

Financial incentives for countries reliant on marine fisheries (Gallo et al., 2017)

*Knowledge:**Informed decision making tools*

Real Options Analysis and Adaption Pathways allows for increased flexibility, takes into account uncertainties associated with climate change, better policies and investments, prepares for various future outcomes (Buurman and Babovic, 2016)

*Improved co-production of knowledge*

Multi-functional natural infrastructure helps develop knowledge and innovation (Vikolainen et al., 2017)

*Co-benefits**Constraints and limitations**Physical:*

Impacts of climate change are not confined to spatial or sectorial boundaries (Serrao-Neumann et al., 2013)

Preference for hard measures by local authorities (Vikolainen et al., 2017)

*Social:*

Measures can stall when larger coalitions of individuals are needed for approval (Cooley et al., 2016)

*Governance:*

Competing local priorities (Aylett, 2015)

Silo culture in local governance agencies (Aylett, 2015)

Lack of capacity (Serrao-Neumann et al., 2013; Aylett, 2015; Porter et al., 2015)

Lack of a champion to push adaption policy at the local level (Porter et al., 2015)

Lack of effective coordination across sectors (Serrao-Neumann et al., 2013)

Institutional weakness of environmental agencies (Aylett, 2015) and institutional fragmentation (Porter et al., 2015)

No single model for the institutionalisation of local climate adaptation planning (Aylett, 2015)

Organisational complexity, nascent and varied efforts to effectively institutionalise adaption planning (Aylett, 2015)

Complex, interlinked systems with manifold uncertainties (Buurman and Babovic, 2016)

Leadership challenges (Aylett, 2015; Cooley et al., 2016)

Lack of local government jurisdiction over key policy areas (Aylett, 2015)

No national approach to coastal management (Vikolainen et al., 2017)

Difficulty mainstreaming climate change into existing departmental functions (Aylett, 2015)

Unwillingness of senior management to depart from established job descriptions and departmental mandates (Aylett, 2015)

Inconsistency between local measures (Cooley et al., 2016)

Political will drives the consideration of marine issues within national climate action plans (Gallo et al., 2017)

Lack of political support (Serrao-Neumann et al., 2013; Porter et al., 2015)

Practical implementation of Integrated Risk Management Approach is a major challenge (Gerkenmeier and Ratter, 2018)

Coastal management is not viewed as a priority by national government (Vikolainen et al., 2017)

Lack of awareness among key community decision makers about climate change and associated environmental sustainability (Nunn et al., 2014)

Inappropriateness of traditional decision-making structures for dealing with climate change (Nunn et al., 2014)

Short-term views of resource management and sustainability held by many community decision makers (Nunn et al., 2014)

Shifting of responsibility from central government towards local actors has not been accompanied by adequate human or financial resources (Paterson et al., 2017)

Structural barriers faced by local authorities (Paterson et al., 2017)

Personalities are often the basis of interaction and not organisational structures (Paterson et al., 2017)

Poor coordination between levels of government (Porter et al., 2015) and within organisations (Vikolainen et al., 2017)

Climate adaptation is not viewed as important as meeting immediate obligation by local authorities (Porter et al., 2015)

Time lag between policy development, implementation and on-ground outcomes (Serrao-Neumann et al., 2013)

Legislative barriers (Serrao-Neumann et al., 2013)

Different stages of development of coastal management policy and legislation in countries; difficulties relating to defining the roles and responsibilities of different levels of government; lack of funding to

undertake climate change impact assessments; financial and human capacity constraints (Rosendo et al., 2018)

Personnel; relevant skills; and sustainable mechanisms for collaboration and coordination of coastal issues across different sectors and stakeholders

*Economic:*

Resource related challenges (Serrao-Neumann et al., 2013; Aylett, 2015; Porter et al., 2015; Cooley et al., 2016)

Large cities are prioritised in terms of human and economic assets and political visibility (Paterson et al., 2017)

Mismatch between the aspirations of the community and the finite funds available at national level (Vikolainen et al., 2017)

Few MPA programmes have directly considered climate change in the design, management or monitoring of an MPA network, adaptive management of MPA networks is important but hard to implement, Conflict exists between local and national initiatives with differing priorities and differing capacities to implement MPAs or MPA networks; The slow process of implementation; jurisdictional complexity of the MPA process; legal or political barriers and realities (Hopkins et al., 2016)

A large portion of the sea lies beyond national jurisdiction; more research is needed on the impacts of pH and reduction in the Atlantic Meridional Overturning Circulation to complete impact assessments; lack of climate models with high precision for a 20–50 year time horizon, lack of research related to ecosystem responses (Johnson et al., 2018)

*Economic:*

Focus on ICM at the local level will divert resources from other competing issues (Rosendo et al., 2018)

*Knowledge:*

Challenges related to information and awareness (Aylett, 2015)

Problem framing arises from the aims of dominant policy actors (Paterson et al., 2017)

Information needed for effective decision-making is centralised at a national level (Paterson et al., 2017)

Technical-cognitive barriers to adaption (Porter et al., 2015)

Lack of usable scientific information (Porter et al., 2015)

Focus on immediate risks (Porter et al., 2015)

Lack of examples of environmental policy integration emerging from practice (Serrao-Neumann et al., 2013)

Limited understanding of the concept of integration for climate adaptation (Serrao-Neumann et al., 2013)

Structural inequality and different worldviews constrain planning with a focus on equity (Klinsky et al., 2017)

Assumptions that concerns for equity thwart climate action (Klinsky et al., 2017)

Model uncertainties at high resolution; current marine management strategies are concerned with managing the status quo; regional differences in the predicted changes and some countries will experience greater/different changes than others (Gormley et al., 2015)

Great reluctance for change affects the implementation of ICZM; level of power of stakeholders and the level to which stakeholders are embedded in the top-down tradition; difference in interpretation of ICZM; corruption and lack of political will. Social learning takes a long time and is not an immediate response, often making it inappropriate to deal with immediate issues (Abelshausen et al., 2015)

Costs

*Social:*

Focus on climate adaptation at the local scale results in trade-offs which may result in serious justice implications (Paterson et al., 2017)

*Governance:*

Possibility of piecemeal and localised resilience that accentuates rather than helps overcome social inequalities (Paterson et al., 2017)

*Economic:*

Financial support needed for least developed countries (Gallo et al., 2017)

Incentives and compensation provided by government in the case of planned retreat (Serrao-Neumann et al., 2013)

Human System: Human health

Adaptation responses

*Governance:*

*Improving implementation and coordination of policies*

Changes in industry practices (Jacobs et al., 2015)

*Economic:*

*Improving financial resources availability*

Effective allocation of technologies and resources (Wu et al., 2016)

*Knowledge:*

*Better monitoring and modelling*

Modelling approaches to inform adaption strategies (Jacobs et al., 2015)

Improving understanding of climate change patterns (Wu et al., 2016)

*Improving forecasting and early warning systems*

Improve prediction of spatial-temporal process of climate change and infectious diseases (Wu et al., 2016)

Establish early warning systems (Wu et al., 2016)

*Improving decision support frameworks*

Improving understanding of compound disease-specific health effects (Wu et al., 2016)

*Stakeholder identification, outreach and education*

Education (Jacobs et al., 2015)

Raising public awareness (Wu et al., 2016)

*Multiple adaptation responses used*

Benefits

*Social:*

*Improved health*

Alleviate the negative health impacts of climate change (Wu et al., 2016)

*Knowledge:*

*Informed decision making tools*

Enhanced prediction over time and spatial scales relevant to public health intervention (Jacobs et al., 2015)

Inform adaption and mitigation efforts to minimize risk of disease (Jacobs et al., 2015)

*Co-benefits*

*Constraints and limitations*

*Social:*

Social and economic factors play a significant role in adaptation to infectious diseases, including differing vulnerabilities (Wu et al., 2016)

Lack of effective communication and public health systems in developing countries (Wu et al., 2016)

*Economic:*

Inadequate financial and medical resources in developing nations (Wu et al., 2016)

*Knowledge:*

Limited studies on the effects of climate change on coastal water-borne pathogens (Jacobs et al., 2015)

Models do not account for changing demographics, intervention strategies and sanitation practices (Jacobs et al., 2015)

Challenges with predicting extreme weather events and their health impacts (Wu et al., 2016)

Peer review literature does not agree on the health effects of changes in climate variables (Wu et al., 2016)

*Costs*

*Governance:*

Developing countries will need assistance from developed countries (Wu et al., 2016)

## SM5.7 Observed Changes in the Ocean and Related Impacts in Support of Figure 5.24

Figure 5.24 shows the synthesis of regional consequences and impacts in ocean assessed in Chapter 5. Tables SM5.10a, SM5.10b and SM5.10c give respectively the links to the specific section in this chapter or in AR5 WG1 or WG2 reports where appropriate. Table SM5.10a refers to the ocean Physical Changes, Table SM5.10b refers to the ocean Ecosystems and Table SM10.c refers to the Human systems and Ecosystems services columns of the assessments.

**Table SM5.10a:** The observed physical changes in the ocean covered by Chapter 5. The regions are shown in Figure 5.24, hazards column is the observed change for the period defined by the start and ends dates, and direction is either increase, decrease or neutral. Detection column is the observed changes for the period, and attribution column is whether there is a detectable human influence in the change and the reference column points to the traceable evidence from this Chapter or from the AR5 WG1 or WG2 report. Some trends analyse and attributed based on zonal averages depending on the particular variable and quality of attribution. Temperature: means averages of temperature 0-700m depth layer, Oxygen: means change in oxygen levels in the oxygen minimum zone or from the surface to 1000m, Ocean pH: changes in pH at the surface of the ocean, Sea Level: changes in mean sea sea-level. The standard likelihood and confidence language is used to indicate the level of confidence in the assessment.

| Region           | Hazards     | Notes             | Data types     | Start year | End year | Direction of changes  | Detection         | Attribution | Reference                        |
|------------------|-------------|-------------------|----------------|------------|----------|-----------------------|-------------------|-------------|----------------------------------|
| EBUS             | Temperature | Ocean Temperature | <i>In situ</i> | 1960       | 2017     | Increase and Decrease | Low               | NA          | {5.2, Box 5.3}                   |
| EBUS             | Oxygen      | Oxygen            | <i>In situ</i> | 1990       | 2010     | Neutral               | Low               | NA          | {5.2, Box 5.3}                   |
| EBUS             | Ocean pH    | pH                | <i>In situ</i> | 1993       | 2016     | Decrease              | Very Likely       | Likely      | {5.2, Box 5.3}                   |
| EBUS             | SLR         | m                 | In situ/Sat.   | 1996       | 2015     | Increase              | Virtually Certain | Medium      | {4.2.2.4}                        |
| Tropical Pacific | Temperature | Ocean Temperature | <i>In situ</i> | 1970       | 2017     | Neutral               | Low               | NA          | {5.2.2.2, AR5 WG1, Section 10.9} |
| Tropical Pacific | Oxygen      | Oxygen            | <i>In situ</i> | 1970       | 2015     | Decrease              | Medium            | Low         | {5.2.2.4}                        |
| Tropical Pacific | Ocean pH    | pH                | <i>In situ</i> | 1970       | 2016     | Decrease              | Very Likely       | Likely      | {5.2.2.3, SM 5.1 Table SM5.3}    |
| Tropical Pacific | SLR         | m                 | In situ/Sat.   | 1996       | 2015     | Increase              | Virtually Certain | medium      | {4.2.2.6}                        |
| North Pacific    | Temperature | Ocean Temperature | <i>In situ</i> | 1970       | 2017     | Increase              | high              | medium      | {5.2.2.2, AR5 WG1, Section 10.9} |
| North Pacific    | Oxygen      | Oxygen            | <i>In situ</i> | 1970       | 2010     | Decrease              | Medium            | Low         | {5.2.2.4}                        |

|                        |                     |                   |                     |      |      |          |                   |        |   |
|------------------------|---------------------|-------------------|---------------------|------|------|----------|-------------------|--------|---|
| North Pacific          | Ocean pH            | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very Likely       | Likely | {5.2.2.3, SM 5.1 Table SM5.3}                           |
| North Pacific          | SLR                 | m                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | virtually certain | Medium | {4.2.2.6}   |
| Tropical Atlantic      | Temperature         | Ocean Temperature | <i>In situ</i>      | 1970 | 2017 | Increase | High              | Medium | {5.2.2.2, AR5 WG1, Section 10.9}                        |
| Tropical Atlantic      | Oxygen              | Oxygen            | <i>In situ</i>      | 1970 | 2010 | Decrease | Low               | Low    | {5.2.2.4}   |
| Tropical Atlantic      | Ocean pH            | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very likely       | Likely | {5.2.2.3, SM 5.1 Table SM5.3}                           |
| Tropical Atlantic      | SLR                 | m                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | virtually certain | Medium | {4.2.2.6}   |
| North Atlantic         | Temperature         | Ocean Temperature | <i>In situ</i>      | 1970 | 2017 | Increase | High              | Medium | {5.2.2.2, AR5 WG1, Section 10.9}                        |
| North Atlantic         | Oxygen              | Oxygen            | <i>In situ</i>      | 1990 | 2010 | Decrease | Low               | Low    | {5.2.2.4}   |
| North Atlantic         | Ocean pH            | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very Likely       | Likely | {5.2.2.3, SM 5.1 Table SM5.3}                           |
| North Atlantic         | SLR                 | m                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | Virtually Certain | Medium | {4.2.2.6}   |
| Tropical Indian Ocean  | Temperature         | Ocean Temperature | <i>In situ</i>      | 1970 | 2017 | Increase | High              | Medium | {5.2.2.2, AR5 WG1, Section 10.9}                        |
| Tropical Indian Ocean  | Oxygen              | Oxygen            | <i>In situ</i>      | 1970 | 2010 | decrease | Low               | Low    | {5.2.2.3}   |
| Tropical Indian Ocean  | Ocean pH            | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very likely       | Likely | {5.2.2.3} also supplementary information SM 5.2 Table 1 |
| Tropical Indian Ocean  | SLR                 | M                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | virtually certain | medium | {4.2.2.6}   |
| Temperate Indian Ocean | Temperature         | Ocean Temperature | <i>In situ</i>      | 1970 | 2017 | increase | high              | medium | {5.2.2.2, AR5 WG1, Section 10.9}                        |
| Temperate Indian Ocean | Oxygen              | Oxygen            | <i>In situ</i>      | 1970 | 2010 | Neutral  | Low               | NA     | {5.2.2.4}   |
| Temperate Indian Ocean | Ocean acidification | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very likely       | Likely | {5.2.2.3, SM 5.1 Table SM5.3}                           |
| Temperate Indian Ocean | SLR                 | m                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | virtually certain | medium | {4.2.2.6}   |
| South Pacific          | Temperature         | Ocean Temperature | <i>In situ</i>      | 1970 | 2017 | Increase | High              | Medium | {5.2.2.2, AR5 WG1, Section 10.9}                        |
| South Pacific          | Oxygen              | Oxygen            | <i>In situ</i>      | 1970 | 2010 | Neutral  | Low               | NA     | {5.2.2.4}   |
| South Pacific          | Ocean acidification | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very Likely       | Likely | {5.2.2.3, SM 5.1 Table SM5.3}                           |
| South Pacific          | SLR                 | m                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | virtually certain | medium | {4.2.2.6}   |
| South Atlantic         | Temperature         | Ocean Temperature | <i>In situ</i>      | 1970 | 2017 | Increase | High              | Medium | {5.2.2.2, AR5 WG1, Section 10.9}                        |
| South Atlantic         | Oxygen              | Oxygen            | <i>In situ</i>      | 1990 | 2010 | Decrease | Low               | Low    | {5.2.2.4}   |
| South Atlantic         | Ocean acidification | pH                | <i>In situ</i>      | 2000 | 2010 | Decrease | Very Likely       | Likely | {5.2.2.3, SM 5.1 Table SM5.3}                           |
| South Atlantic         | SLR                 | m                 | <i>In situ/Sat.</i> | 1996 | 2015 | Increase | virtually certain | medium | {4.2.2.6}   |

**Table SM5.10b:** The observed impacts in selected coastal and ocean ecosystems from 1940 to the present day covered by Chapter 5. The regions are shown in Figure 5.24, ecosystem column is the assessed ecosystem types in Chapter 5. The observed direction of impacts are either positive, negative, or both position and negative. Detection column is the confidence level assessed for the observed impacts, and attribution column is whether there is the level of confidence on whether the detected impacts are contributed by climate change.

| Region         | Ecosystems       | Direction of impacts  | Impact types  | Detection | Attribution | Reference |
|----------------|------------------|-----------------------|---|-----------|-------------|-----------|
| EBUS           | Epipelagic       | Negative              | Shift in biogeography, mass mortality of organisms, decrease in abundance   | medium    | low         | {Box 5.3} |
| EBUS           | Coral            | NA                    | NA  | NA        | NA          | NA        |
| EBUS           | Coastal wetlands | NA                    | NA  | NA        | NA          | NA        |
| EBUS           | Kelp forest      | Negative              | Shift to turfs, reduction in recruitment  | high      | medium      | {5.3.6}   |
| EBUS           | Rocky shores     | NA                    | NA  | NA        | NA          | NA        |
| EBUS           | Deep sea         | NA                    | NA  | NA        | NA          | NA        |
| North Atlantic | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | high      | high        | {5.2.3}   |
| North Atlantic | Coral            | Negative              | Shift in depth distribution   | low       | low         | {Box 5.2} |
| North Atlantic | Coastal wetlands | Positive and negative | Increase in area in some sub-tropical area but expansion of one vegetation, invasion by grazers impacting vegetated habitats. | high      | medium      | {5.3.2}   |
| North Atlantic | Kelp forest      | Negative              | Shift to turfs and algae  | high      | medium      | {5.3.6}   |
| North Atlantic | Rocky shores     | Negative              | Changes in species composition  | high      | high        | {5.3.5}   |
| North Atlantic | Deep sea         | NA                    | NA  | NA        | NA          | NA        |
| North Pacific  | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | high      | medium      | {5.2.3}   |
| North Pacific  | Coral            | NA                    | NA  | NA        | NA          | NA        |
| North Pacific  | Coastal wetlands | Positive and negative | Increase in area in some sub-tropical area but expansion of one vegetation, invasion by grazers impacting vegetated habitats. | high      | medium      | {5.3.2}   |
| North Pacific  | Kelp forest      | Negative              | Shift to turfs and aglae, increase tropical sargassum species, reduction in recruitment and recovery                          | high      | medium      | {5.3.6}   |
| North Pacific  | Rocky shores     | Negative              | Changes in species composition  | medium    | medium      | {5.3.5}   |
| North Pacific  | Deep sea         | Positive or negative  | Benthic communities   | low       | low         | {5.4.2.4} |
| South Atlantic | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | medium    | medium      | {5.2.3}   |
| South Atlantic | Kelp forest      | Negative              | Replacement by turfs  | High      | Low         | {5.3.6}   |
| South Atlantic | Coral            | NA                    | NA  | NA        | NA          | NA        |
| South Atlantic | Coastal wetlands | Negative              | Increased mortality of vegetation, loss of habitats, changes in   | High      | medium      | {5.3.2}   |

|                        |                  |                       |   |           |        |         |
|------------------------|------------------|-----------------------|---|-----------|--------|---------|
|                        |                  |                       | community and ecosystem structure   |           |        |         |
| South Atlantic         | Rocky shores     | NA                    | NA  | NA        | NA     | NA      |
| South Pacific          | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | medium    | medium | {5.2.3} |
| South Pacific          | Kelp forest      | Negative              | Loss of canopy forming species, shift to turfs  | High      | low    | {5.3.6} |
| South Pacific          | Coral            | Negative              | Coral bleaching   | very high | high   | {5.3.4} |
| South Pacific          | Coastal wetlands | Negative              | Increased mortality of vegetation, loss of habitats, changes in community and ecosystem structure                             | High      | medium | {5.3.2} |
| Temperate Indian Ocean | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | medium    | low    | {5.2.3} |
| Temperate Indian Ocean | Coral            | NA                    | NA  | NA        | NA     | NA      |
| Temperate Indian Ocean | Coastal wetlands | Positive and negative | Increase in area in some sub-tropical area but expansion of one vegetation, invasion by grazers impacting vegetated habitats. | High      | medium | {5.3.2} |
| Temperate Indian Ocean | Kelp forest      | Negative              | Shift to turfs, reduction in recovery   | medium    | low    | {5.3.6} |
| Temperate Indian Ocean | Rocky shores     | Negative              | Changes in species composition  | Low       | low    | {5.3.5} |
| Temperate Indian Ocean | Deep sea         | NA                    | NA  | NA        | NA     | NA      |
| Tropical Atlantic      | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | High      | medium | {5.2.3} |
| Tropical Atlantic      | Coral            | Negative              | Coral bleaching   | very high | high   | {5.3.2} |
| Tropical Atlantic      | Coastal wetlands | Negative              | Increased mortality of vegetation, loss of habitats, changes in community and ecosystem structure                             | High      | medium | {5.3.2} |
| Tropical Atlantic      | Kelp forest      | NA                    | NA  | NA        | NA     | NA      |
| Tropical Atlantic      | Rocky shores     | NA                    | NA  | NA        | NA     | NA      |
| Tropical Atlantic      | Deep sea         | NA                    | NA  | NA        | NA     | NA      |
| Tropical Indian Ocean  | Epipelagic       | Negative              | Alteration of biogeography/phenology /community structure   | medium    | low    | {5.2.3} |
| Tropical Indian Ocean  | Coral            | Negative              | Coral bleaching   | very high | high   | {5.3.2} |



|                       |                  |          |   |                 |        |         |
|-----------------------|------------------|----------|---|-----------------|--------|---------|
| Tropical Indian Ocean | Coastal wetlands | Negative | Increased mortality of vegetation, loss of habitats, changes in community and ecosystem structure | High            | medium | {5.3.2} |
| Tropical Indian Ocean | Kelp forest      | NA       | NA  | NA              | NA     | NA      |
| Tropical Indian Ocean | Rocky shores     | NA       | NA  | NA              | NA     | NA      |
| Tropical Pacific      | Coastal wetland  | Negative | Increased mortality of vegetation, loss of habitats, changes in community and ecosystem structure | high confidence | medium | {5.3.2} |
| Tropical Pacific      | Kelp forest      | Negative | Loss of canopy forming species, shift to turfs  | High            | low    | {5.3.6} |
| Tropical Pacific      | Rocky shores     | NA       | NA  | NA              | NA     | NA      |
| Tropical Pacific      | Deep sea         | NA       | NA  | NA              | NA     | NA      |
| Tropical Pacific      | Epipelagic       | Negative | Alteration of biogeography/phenology /community structure   | medium          | medium | {5.2.3} |
| Tropical Pacific      | Coral            | Negative | Coral bleaching   | very high       | high   | {5.3.4} |

**Table SM5.10c:** The observed impacts of selected human systems and ecosystem services from 1940 to the present day covered by Chapter 5. The regions are shown in Figure 5.24, ecosystem services column is the assessed ecosystem types in Chapter 5. The observed direction of impacts are either positive, negative, or both position and negative. Detection column is the confidence level assessed for the observed impacts, and attribution column is whether there is the level of confidence on whether the detected impacts are contributed by climate change.

| Region           | Human systems and ecosystem services | Direction of changes | Impact types                                    | Detection | Attribution | Reference             |
|------------------|--------------------------------------|----------------------|---|-----------|-------------|-----------------------|
| EBUS             | Fisheries                            | Negative             | Species composition and catch potential         | medium    | low         | {Box 5.3}             |
| EBUS             | Tourism                              | Negative             | Tourism opportunities                           | low       | low         | {Box 5.3}             |
| EBUS             | Carbon sequestration                 | NA                   | NA  | NA        | NA          | {Box 5.3}             |
| EBUS             | Habitat service                      | Negative             | Modification of habitat conditions              | low       | Low         | {Box 5.3}             |
| EBUS             | Transportation and shipping          | NA                   | NA  | NA        | NA          | NA                    |
| EBUS             | Culture                              | NA                   | NA  | NA        | NA          | NA                    |
| Tropical Pacific | Fisheries                            | Negative             | Species composition and catch potential         | high      | low         | {5.4.1.1}             |
| Tropical Pacific | Tourism                              | NA                   | NA  | NA        | NA          | {5.4.2.3.2}           |
| Tropical Pacific | Carbon sequestration                 | Negative             | Loss of coastal blue carbon habitat             | high      | Low         | {5.3, 5.4.2, 5.5.1.2} |
| Tropical Pacific | Habitat service                      | Negative             | Loss/degradation of habitat and their functions | high      | medium      | {5.4.3}               |
| Tropical Pacific | Transportation and shipping          | NA                   | NA  | NA        | NA          | NA                    |

|                       |                             |          |   |        |        |                        |
|-----------------------|-----------------------------|----------|---|--------|--------|------------------------|
| Tropical Pacific      | Culture                     | NA       | NA  | NA     | NA     | NA                     |
| North Pacific         | Fisheries                   | Negative | Species composition and catch potential           | high   | low    | {5.4.1.1}              |
| North Pacific         | Tourism                     | Negative | Tourism opportunities                             | high   | low    | {5.4.2.3.2}            |
| North Pacific         | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat               | high   | medium | {5.3, 5.4.2, 5.5.1.2}  |
| North Pacific         | Habitat service             | Negative | Loss/degradation of habitat and their functions   | high   | medium | {5.4.3}                |
| North Pacific         | Transportation and shipping | NA       | NA  | NA     | NA     | NA                     |
| North Pacific         | Culture                     | Negative | Food and ceremonial use of marine resources       | high   | low    | {5.4.2.1.3, 5.4.2.2.1} |
| Tropical Atlantic     | Fisheries                   | Negative | Change in species composition and catch potential | high   | medium | {5.4.1.1}              |
| Tropical Atlantic     | Tourism                     | NA       | NA  | NA     | NA     | {5.4.2.3.2}            |
| Tropical Atlantic     | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat               | High   | Low    | {5.3, 5.4.2, 5.5.1.2}  |
| Tropical Atlantic     | Habitat service             | Negative | Loss/degradation of habitat and their functions   | High   | medium | {5.4.3}                |
| Tropical Atlantic     | Transportation and shipping | NA       | NA  | NA     | NA     | NA                     |
| Tropical Atlantic     | Culture                     | NA       | NA  | NA     | NA     | NA                     |
| North Atlantic        | Fisheries                   | Negative | Species composition and catch potential           | high   | high   | {5.4.1.1}              |
| North Atlantic        | Tourism                     | NA       | NA  | NA     | NA     | {5.4.2.3.2}            |
| North Atlantic        | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat               | high   | Medium | {5.3, 5.4.2, 5.5.1.2}  |
| North Atlantic        | Habitat service             | Negative | Loss/degradation of habitat and their functions   | high   | medium | {5.4.3}                |
| North Atlantic        | Transportation and shipping | NA       | NA  | NA     | NA     | NA                     |
| North Atlantic        | Culture                     | Negative | Changes in coastal livelihood                     | medium | low    | {5.4.2.3.1, 5.4.2.2.1} |
| Tropical Indian Ocean | Fisheries                   | Negative | Species composition and catch potential           | low    | low    | {5.4.1.1}              |
| Tropical Indian Ocean | Tourism                     | NA       | NA  | NA     | NA     | {5.4.2.3.2}            |
| Tropical Indian Ocean | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat               | high   | medium | {5.3, 5.4.2, 5.5.1.2}  |
| Tropical Indian Ocean | Habitat service             | Negative | Loss/degradation of habitat and their functions   | medium | medium | {5.4.3}                |
| Tropical Indian Ocean | Transportation and shipping | NA       | NA  | NA     | NA     | NA                     |

|                        |                             |          |   |        |        |                       |
|------------------------|-----------------------------|----------|---|--------|--------|-----------------------|
| Tropical Indian Ocean  | Culture                     | NA       | NA  | NA     | NA     | NA                    |
| Temperate Indian Ocean | Fisheries                   | Negative | Species composition and catch potential         | low    | low    | {5.4.1.1}             |
| Temperate Indian Ocean | Tourism                     | NA       | NA  | NA     | NA     | {5.4.2.3.2}           |
| Temperate Indian Ocean | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat             | high   | Low    | {5.3, 5.4.2, 5.5.1.2} |
| Temperate Indian Ocean | Habitat service             | Negative | Loss/degradation of habitat and their functions | medium | low    | {5.4.3}               |
| Temperate Indian Ocean | Transportation and shipping | NA       | NA  | NA     | NA     | NA                    |
| Temperate Indian Ocean | Culture                     | NA       | NA  | NA     | NA     | NA                    |
| South Pacific          | Fisheries                   | Negative | Species composition and catch potential         | high   | low    | {5.4.1.1}             |
| South Pacific          | Tourism                     | Negative | Perception of local and international tourisms  | Low    | Low    | {5.4.2.3.2}           |
| South Pacific          | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat             | high   | Low    | {5.3, 5.4.2, 5.5.1.2} |
| South Pacific          | Habitat service             | Negative | Loss/degradation of habitat and their functions | high   | medium | {5.4.3}               |
| South Pacific          | Transportation and shipping | NA       | NA  | NA     | NA     | NA                    |
| South Pacific          | Culture                     | Negative | Influences on perceptions, values, traditions   | high   | low    | {5.4.2.2.1}           |
| South Atlantic         | Fisheries                   | Negative | Species composition and catch potential         | medium | low    | {5.4.1.1}             |
| South Atlantic         | Tourism                     | NA       | NA  | NA     | NA     | {5.4.2.3.2}           |
| South Atlantic         | Carbon sequestration        | Negative | Loss of coastal blue carbon habitat             | high   | Low    | {5.3, 5.4.2, 5.5.1.2} |
| South Atlantic         | Habitat service             | Negative | Loss/degradation of habitat and their functions | medium | low    | {5.4.3}               |
| South Atlantic         | Transportation and shipping | NA       | NA  | NA     | NA     | NA                    |
| South Atlantic         | Culture                     | NA       | NA  | NA     | NA     | NA                    |

## References

- Abedin, M. A., U. Habiba and R. Shaw, 2014: Community Perception and Adaptation to Safe Drinking Water Scarcity: Salinity, Arsenic, and Drought Risks in Coastal Bangladesh. *International Journal of Disaster Risk Science*, **5** (2), 110-124, doi:10.1007/s13753-014-0021-6.
- Abelshausen, B., T. Vanwing and W. Jacquet, 2015: Participatory integrated coastal zone management in Vietnam: Theory versus practice case study: Thua Thien Hue province. *Journal of Marine and Island Cultures*, **4** (1), 42-53, doi:<https://doi.org/10.1016/j.imic.2015.06.004>.
- Adams, D. K. et al., 2011: Surface-generated mesoscale eddies transport deep-sea products from hydrothermal vents. *Science*, **332** (6029), 580-583, doi:10.1126/science.1201066.
- Ahmed, N. and J. S. Diana, 2015: Threatening “white gold”: Impacts of climate change on shrimp farming in coastal Bangladesh. *Ocean & Coastal Management*, **114**, 42-52, doi:<https://doi.org/10.1016/j.ocecoaman.2015.06.008>.
- Ahmed, N. and M. Glaser, 2016: Can “Integrated Multi-Trophic Aquaculture (IMTA)” adapt to climate change in coastal Bangladesh? *Ocean & Coastal Management*, **132**, 120-131, doi:<https://doi.org/10.1016/j.ocecoaman.2016.08.017>.
- Alongi, D. M., 2015: The impact of climate change on mangrove forests. *Current Climate Change Reports*, **1** (1), 30-39.
- Antwi-Agyeia, P., A. J. Dougill, L. C. Stringer and S. N. A. Codjoe, 2018: Adaptation opportunities and maladaptive outcomes in climate vulnerability hotspots of northern Ghana. *Climate Risk Management*, **19** (2018), 83-93.
- Arntz, W. E., T. Brey, J. Tarazona and A. Robles, 1987: Changes in the structure of a shallow sandy-beach community in Peru during an El Niño event. *South African Journal of Marine Science*, **5** (1), 645-658.
- Arntz, W. E. et al., 2006: El Niño and similar perturbation effects on the benthos of the Humboldt, California, and Benguela Current upwelling ecosystems. *Adv. Geosci.*, **6**, 243-265, doi:10.5194/adgeo-6-243-2006.
- Arora, V. K. et al., 2013: Carbon–concentration and carbon–climate feedbacks in CMIP5 Earth system models. *Journal of Climate*, **26** (15), 5289-5314.
- Asadabadi, A. and E. Miller-Hooks, 2017: Assessing strategies for protecting transportation infrastructure from an uncertain climate future. *Transportation Research Part A: Policy and Practice*, **105**, 27-41.
- Asch, R. G., W. W. L. Cheung and G. Reygondeau, 2018: Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. *Marine Policy*, **88**, 285-294, doi:<https://doi.org/10.1016/j.marpol.2017.08.015>.
- Ataur Rahman, M. and S. Rahman, 2015: Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh. *Weather and Climate Extremes*, **7**, 84-95, doi:<https://doi.org/10.1016/j.wace.2014.12.004>.
- Audefroy, J. F. and B. N. C. Sánchez, 2017: Integrating local knowledge for climate change adaptation in Yucatán, Mexico. *International Journal of Sustainable Built Environment*, **6** (1), 228-237, doi:10.1016/j.ijbsbe.2017.03.007.
- Aylett, A., 2015: Institutionalizing the urban governance of climate change adaptation: Results of an international survey. *Urban Climate*, **14**, 4-16, doi:10.1016/j.uclim.2015.06.005.
- Baco, A. R. et al., 2017: Defying dissolution: discovery of deep-sea scleractinian coral reefs in the North Pacific. *Scientific reports*, **7** (1), 5436.
- Barbier, E. B., 2015a: Climate change impacts on rural poverty in low-elevation coastal zones. *Estuarine, Coastal and Shelf Science*, **165**, A1-A13, doi:<https://doi.org/10.1016/j.ecss.2015.05.035>.
- Barbier, E. B., 2015b: Valuing the storm protection service of estuarine and coastal ecosystems. *Ecosystem Services*, **11**, 32-38.
- Bates, N. et al., 2014: A Time-Series View of Changing Ocean Chemistry Due to Ocean Uptake of Anthropogenic CO<sub>2</sub> and Ocean Acidification. *Oceanography*, **27** (1), 126-141, doi:10.5670/oceanog.2014.16.
- Beck, M. W. et al., 2018: The global flood protection savings provided by coral reefs. *Nature Communications*, **9** (1), 2186, doi:10.1038/s41467-018-04568-z.
- Becker, A. H. et al., 2016: A method to estimate climate-critical construction materials applied to seaport protection. *Global Environmental Change*, **40**, 125-136.
- Becker, A. H., P. Matson, M. Fischer and M. D. Mastrandrea, 2015: Towards seaport resilience for climate change adaptation: Stakeholder perceptions of hurricane impacts in Gulfport (MS) and Providence (RI). *Progress in Planning*, **99**, 1-49.
- Beetham, E., P. S. Kench and S. Popinet, 2017: Future Reef Growth Can Mitigate Physical Impacts of Sea-Level Rise on Atoll Islands. *Earth's Future*, **5** (10), 1002-1014, doi:10.1002/2017ef000589.
- Bell, J. D. et al., 2018: Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands. *Marine Policy*, **88**, 303-314, doi:<https://doi.org/10.1016/j.marpol.2017.05.019>.
- Bennett, N. J., A. Kadfak and P. Dearden, 2016: Community-based scenario planning: a process for vulnerability analysis and adaptation planning to social–ecological change in coastal communities. *Environment, Development and Sustainability*, **18** (6), 1771-1799, doi:10.1007/s10668-015-9707-1.
- Bentsen, M. et al., 2013: The Norwegian Earth System Model, NorESM1-M – Part 1: Description and basic evaluation of the physical climate. *Geosci. Model Dev.*, **6** (3), 687-720, doi:10.5194/gmd-6-687-2013.
- Benzeev, R., N. Hutchinson and D. A. Friess, 2017: Quantifying fisheries ecosystem services of mangroves and tropical artificial urban shorelines. *Hydrobiologia*, **803** (1), 225-237, doi:10.1007/s10750-017-3299-8.

- Betzold, C. and I. Mohamed, 2017: Seawalls as a response to coastal erosion and flooding: a case study from Grande Comore, Comoros (West Indian Ocean). *Regional Environmental Change*, **17** (4), 1077-1087, doi:10.1007/s10113-016-1044-x.
- Brooke, S. et al., 2013: Temperature tolerance of the deep-sea coral *Lophelia pertusa* from the southeastern United States. *Deep Sea Research Part II: Topical Studies in Oceanography*, **92**, 240-248.
- Broto, V. C., E. Boyd and J. Ensor, 2015: Participatory urban planning for climate change adaptation in coastal cities: lessons from a pilot experience in Maputo, Mozambique. *Current Opinion in Environmental Sustainability*, **13**, 11-18, doi:<https://doi.org/10.1016/j.cosust.2014.12.005>.
- Brown, J. M. et al., 2018: A coastal vulnerability assessment for planning climate resilient infrastructure. *Ocean & Coastal Management*, **163**, 101-112.
- Bruno, J. F. et al., 2018: Climate change threatens the world's marine protected areas. *Nature Climate Change*, **8** (6), 499-503, doi:10.1038/s41558-018-0149-2.
- Bujosa, A., A. Riera and C. M. Torres, 2015: Valuing tourism demand attributes to guide climate change adaptation measures efficiently: The case of the Spanish domestic travel market. *Tourism Management*, **47**, 233-239, doi:<https://doi.org/10.1016/j.tourman.2014.09.023>.
- Busch, D. S. et al., 2016: Climate science strategy of the US National Marine Fisheries Service. *Marine Policy*, **74**, 58-67, doi:10.1016/j.marpol.2016.09.001.
- Büscher, J. V., A. U. Form and U. Riebesell, 2017: Interactive Effects of Ocean Acidification and Warming on Growth, Fitness and Survival of the Cold-Water Coral *Lophelia pertusa* under Different Food Availabilities. *Frontiers in Marine Science*, **4**, 119, doi:10.3389/fmars.2017.00101.
- Buurman, J. and V. Babovic, 2016: Adaptation Pathways and Real Options Analysis: An approach to deep uncertainty in climate change adaptation policies. *Policy and Society*, **35** (2), 137-150, doi:<https://doi.org/10.1016/j.polsoc.2016.05.002>.
- Byrne, R. H., S. Mecking, R. A. Feely and X. Liu, 2010: Direct observations of basin-wide acidification of the North Pacific Ocean. *Geophysical Research Letters*, **37** (2), -n/a, doi:10.1029/2009GL040999.
- Cahaya, A., 2015: Fishermen Community in the Coastal Area: A Note from Indonesian Poor Family. *Procedia Economics and Finance*, **26**, 29-33, doi:[https://doi.org/10.1016/S2212-5671\(15\)00801-1](https://doi.org/10.1016/S2212-5671(15)00801-1).
- Carcedo, C., S. Fiori and C. Bremec, 2015: Macrobenthic surf zone communities of temperate sandy beaches: spatial and temporal patterns. *Marine Ecology*, **36** (3), 326-336, doi:10.1111/maec.12143.
- Carcedo, M. C., S. M. Fiori and C. S. Bremec, 2017: Zonation of macrobenthos across a mesotidal sandy beach: Variability based on physical factors. *Journal of sea research*, **121**, 1-10.
- Carro, I., Seijo, L., Nagy, G.J., Lagos, X. and Gutiérrez, O., 2018: Building capacity on ecosystem-based adaption strategy to cope with extreme events and sea-level rise on the Uruguayan coast. *International Journal of Climate Change Strategies and Management*, **10** (4), 504 - 522, doi:<https://doi.org/10.1108/IJCCSM-07-2017-0149>.
- Carstensen, D. et al., 2010: Recurrent, thermally-induced shifts in species distribution range in the Humboldt current upwelling system. *Marine environmental research*, **70** (3), 293-299, doi:<https://doi.org/10.1016/j.marenvres.2010.06.001>.
- Carter, J. G., 2018: Urban climate change adaptation: Exploring the implications of future land cover scenarios. *Cities*, **77**, 73-80.
- Celentano, E. and O. Defeo, 2016: Effects of climate on the mole crab *Emerita brasiliensis* on a dissipative beach in Uruguay. *Marine Ecology Progress Series*, **552**, 211-222.
- Cheng, L. et al., 2017: Improved estimates of ocean heat content from 1960 to 2015. *Science Advances*, **3** (3), e1601545, doi:10.1126/sciadv.1601545.
- Cheung, W. W. L., M. C. Jones, G. Reygondeau and T. L. Frölicher, 2018: Opportunities for climate-risk reduction through effective fisheries management. *Global Change Biology*, **2108**, 1-15, doi:10.1111/gcb.14390.
- Ciccarelli, D. et al., 2017: Development of a coastal dune vulnerability index for Mediterranean ecosystems: A useful tool for coastal managers? *Estuarine, Coastal and Shelf Science*, **187**, 84-95, doi:10.1016/j.ecss.2016.12.008.
- Cinner, J. E. et al., 2018: Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change*, **8** (2), 117-123, doi:10.1038/s41558-017-0065-x.
- Colburn, L. L. et al., 2016: Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. *Marine Policy*, **74**, 323-333, doi:10.1016/j.marpol.2016.04.030.
- Colin, M., F. Palhol and A. Leuxe, 2016: Adaptation of transport infrastructures and networks to climate change. *Transportation Research Procedia*, **14**, 86-95.
- Comte, A. and L. H. Pendleton, 2018: Management strategies for coral reefs and people under global environmental change: 25 years of scientific research. *Journal of Environmental Management*, **209**, 462-474, doi:<https://doi.org/10.1016/j.jenvman.2017.12.051>.
- Cooley, S. R., C. R. Ono, S. Melcer and J. Roberson, 2016: Community-Level Actions that Can Address Ocean Acidification. *Frontiers in Marine Science*, **2** (128), 1-12.
- Cvitanovic, C. et al., 2016: Linking adaptation science to action to build food secure Pacific Island communities. *Climate Risk Management*, **11**, 53-62, doi:10.1016/j.crm.2016.01.003.
- Dadon, J. R., 2005: Changes in the intertidal community structure after a mass mortality event in sandy beaches of Argentina. *Contributions to Zoology*, **74** (1/2).

- DasGupta, R. and R. Shaw, 2015: An indicator based approach to assess coastal communities' resilience against climate related disasters in Indian Sundarbans. *Journal of Coastal Conservation*, **19** (1), 85-101, doi:10.1007/s11852-014-0369-1.
- Dasgupta, S. et al., 2017: The Impact of Aquatic Salinization on Fish Habitats and Poor Communities in a Changing Climate: Evidence from Southwest Coastal Bangladesh. *Ecological Economics*, **139**, 128-139, doi:<https://doi.org/10.1016/j.ecolecon.2017.04.009>.
- Dhar, T. K. and L. Khirfan, 2016: Community-based adaptation through ecological design: lessons from Negril, Jamaica. *Journal of Urban Design*, **21** (2), 234-255, doi:10.1080/13574809.2015.1133224.
- Domingues, C. M. et al., 2008: Improved estimates of upper-ocean warming and multi-decadal sea-level rise. *Nature*, **453**, 1090, doi:10.1038/nature07080  
<https://www.nature.com/articles/nature07080#supplementary-information>.
- Dore, J. E. et al., 2009: Physical and biogeochemical modulation of ocean acidification in the central North Pacific. *Proceedings of the National Academy of Sciences*, **106** (30), 12235, doi:10.1073/pnas.0906044106.
- Doughty, C. L. et al., 2017: Impacts of mangrove encroachment and mosquito impoundment management on coastal protection services. *Hydrobiologia*, **803** (1), 105-120, doi:10.1007/s10750-017-3225-0.
- Dufresne, J.-L. et al., 2013: Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5. *Climate Dynamics*, **40** (9-10), 2123-2165.
- Dunne, J. P. et al., 2012: GFDL's ESM2 Global Coupled Climate-Carbon Earth System Models. Part I: Physical Formulation and Baseline Simulation Characteristics. *Journal of Climate*, **25** (19), 6646-6665, doi:10.1175/JCLI-D-11-00560.1.
- Dunstan, P. K. et al., 2017: How can climate predictions improve sustainability of coastal fisheries in Pacific Small-Island Developing States? *Marine Policy*, doi:10.1016/j.marpol.2017.09.033.
- Elliff, C. I. and I. R. Silva, 2017: Coral reefs as the first line of defense: Shoreline protection in face of climate change. *Marine environmental research*, **127**, 148-154, doi:<https://doi.org/10.1016/j.marenvres.2017.03.007>.
- Elshorbagy, A., K. Lindenau and H. Azinfar, 2018: Risk-based quantification of the impact of climate change on storm water infrastructure. *Water Science*, **32** (1), 102-114, doi:10.1016/j.wsj.2017.12.003.
- Espinete, X., A. Schweikert, N. van den Heever and P. Chinowsky, 2016: Planning resilient roads for the future environment and climate change: Quantifying the vulnerability of the primary transport infrastructure system in Mexico. *Transport Policy*, **50**, 78-86.
- Esteban, M. et al., 2017: Awareness of coastal floods in impoverished subsiding coastal communities in Jakarta: Tsunamis, typhoon storm surges and dyke-induced tsunamis. *International Journal of Disaster Risk Reduction*, **23**, 70-79, doi:10.1016/j.ijdrr.2017.04.007.
- Faraco, L. F. D. et al., 2016: Vulnerability Among Fishers in Southern Brazil and its Relation to Marine Protected Areas in a Scenario of Declining Fisheries. *Desenvolvimento e Meio Ambiente*, **38** (1), 51-76, doi:10.5380/dma.v38i0.45850.
- Feller, I. C., D. A. Friess, K. W. Krauss and R. R. Lewis, 2017: The state of the world's mangroves in the 21st century under climate change. *Hydrobiologia*, **803** (1), 1-12.
- Fillinger, L. and C. Richter, 2013: Vertical and horizontal distribution of *Desmophyllum dianthus* in Comau Fjord, Chile: a cold-water coral thriving at low pH. *PeerJ*, **1**, e194.
- Finkbeiner, E. M. et al., 2018: Exploring trade-offs in climate change response in the context of Pacific Island fisheries. *Marine Policy*, **88**, 359-364, doi:<https://doi.org/10.1016/j.marpol.2017.09.032>.
- Fiori, S. et al., 2004: Field and laboratory observations of the mass mortality of the yellow clam, *Mesodesma mactroides*, in South America: The case of Isla del Jabali, Argentina. *Journal of Shellfish Research*, **23** (2), 451-456.
- Flato, G. et al., 2013: Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 741-866.
- Flecha, S. et al., 2015: Trends of pH decrease in the Mediterranean Sea through high frequency observational data: indication of ocean acidification in the basin. *Scientific reports*, **5**, 16770.
- Ford, J. D. et al., 2016: Community-based adaptation research in the Canadian Arctic. *Wiley Interdisciplinary Reviews: Climate Change*, **7** (2), 175-191, doi:10.1002/wcc.376.
- Forzieri, G. et al., 2018: Escalating impacts of climate extremes on critical infrastructures in Europe. *Global Environmental Change*, **48**, 97-107, doi:<https://doi.org/10.1016/j.gloenvcha.2017.11.007>.
- Fox, A. D., L.-A. Henry, D. W. Corne and J. M. Roberts, 2016: Sensitivity of marine protected area network connectivity to atmospheric variability. *Royal Society Open Science*, **3** (11), 160494.
- Friedrich, E. and D. Kretzinger, 2012: Vulnerability of wastewater infrastructure of coastal cities to sea level rise: A South African case study. *Water SA*, **38** (5), 755-764.
- Frolicher, T. L., K. B. Rodgers, C. A. Stock and W. W. L. Cheung, 2016: Sources of uncertainties in 21st century projections of potential ocean ecosystem stressors. *Global Biogeochemical Cycles*, **30** (8), 1224-1243, doi:10.1002/2015gb005338.



- Gaines, S. D. et al., 2018: Improved fisheries management could offset many negative effects of climate change. *Science Advances*, **4** (8), doi:10.1126/sciadv.aao1378.
- Galappaththi, I. M., E. K. Galappaththi and S. S. Kodithuwakku, 2017: Can start-up motives influence social-ecological resilience in community-based entrepreneurship setting? Case of coastal shrimp farmers in Sri Lanka. *Marine Policy*, **86**, 156-163, doi:10.1016/j.marpol.2017.09.024.
- Gallagher, R. V., R. O. Makinson, P. M. Hogbin and N. Hancock, 2015: Assisted colonization as a climate change adaptation tool. *Austral Ecology*, **40** (1), 12-20, doi:10.1111/aec.12163.
- Gallo, N. D., D. G. Victor and L. A. Levin, 2017: Ocean commitments under the Paris Agreement. *Nature Climate Change*, **7**, 833, doi:10.1038/nclimate3422  
<https://www.nature.com/articles/nclimate3422#supplementary-information>.
- Gattuso, J.-P. et al., 2018: Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems. *Frontiers in Marine Science*, **5** (337), doi:10.3389/fmars.2018.00337.
- Gent, P. R. et al., 2011: The Community Climate System Model Version 4. *Journal of Climate*, **24** (19), 4973-4991, doi:10.1175/2011JCLI4083.1.
- Gerkenmeier, B. and B. M. W. Ratter, 2018: Governing coastal risks as a social process—Facilitating integrative risk management by enhanced multi-stakeholder collaboration. *Environmental Science & Policy*, **80**, 144-151, doi:<https://doi.org/10.1016/j.envsci.2017.11.011>.
- Gilman, E. L., J. Ellison, N. C. Duke and C. Field, 2008: Threats to mangroves from climate change and adaptation options: a review. *Aquatic botany*, **89** (2), 237-250.
- Giorgetta, M. A. et al., 2013: Climate and carbon cycle changes from 1850 to 2100 in MPI-ESM simulations for the Coupled Model Intercomparison Project phase 5. *Journal of Advances in Modeling Earth Systems*, **5** (3), 572-597, doi:10.1002/jame.20038.
- Goecke, S. D. and S. M. Carstenn, 2017: Fish communities and juvenile habitat associated with non-native *Rhizophora mangle* L. in Hawai'i. *Hydrobiologia*, **803** (1), 209-224, doi:10.1007/s10750-017-3182-7.
- González-Dávila, M., J. Santana-Casiano, M. Rueda and O. Llinás, 2010: The water column distribution of carbonate system variables at the ESTOC site from 1995 to 2004. *Biogeosciences*, **7** (10), 3067-3081.
- Goreau, T. J. F. and P. Prong, 2017: Biorock Electric Reefs Grow Back Severely Eroded Beaches in Months. *Journal of Marine Science and Engineering*, **5** (4), 48.
- Gori, A. et al., 2016: Physiological response of the cold-water coral *Desmophyllum dianthus* to thermal stress and ocean acidification. *PeerJ*, **4**, e1606, doi:10.7717/peerj.1606.
- Gormley, K. S. G. et al., 2015: Adaptive management, international co-operation and planning for marine conservation hotspots in a changing climate. *Marine Policy*, **53**, 54-66, doi:10.1016/j.marpol.2014.11.017.
- Gourlie, D. et al., 2018: Performing “A New Song”: Suggested Considerations for Drafting Effective Coastal Fisheries Legislation Under Climate Change. *Marine Policy*, **88**, 342-349, doi:<https://doi.org/10.1016/j.marpol.2017.06.012>.
- Gracia, A., N. Rangel-Buitrago, J. A. Oakley and A. T. Williams, 2018: Use of ecosystems in coastal erosion management. *Ocean & Coastal Management*, **156**, 277-289, doi:<https://doi.org/10.1016/j.ocecoaman.2017.07.009>.
- Hagedoorn, L. C. et al., 2019: Community-based adaptation to climate change in small island developing states: an analysis of the role of social capital. *Climate and Development*, 1-12, doi:10.1080/17565529.2018.1562869.
- Harkes, I. H. T. et al., 2015: Shrimp aquaculture as a vehicle for Climate Compatible Development in Sri Lanka. The case of Puttalam Lagoon. *Marine Policy*, **61**, 273-283, doi:10.1016/j.marpol.2015.08.003.
- Harvey, B. J., K. L. Nash, J. L. Blanchard and D. P. Edwards, 2018: Ecosystem-based management of coral reefs under climate change. *Ecology and Evolution*, **8** (12), 6354-6368, doi:10.1002/ece3.4146.
- Hayden, H. L. and E. F. Granek, 2015: Coastal sediment elevation change following anthropogenic mangrove clearing. *Estuarine, Coastal and Shelf Science*, **165**, 70-74, doi:10.1016/j.ecss.2015.09.004.
- Heenan, A. et al., 2015: A climate-informed, ecosystem approach to fisheries management. *Marine Policy*, **57**, 182-192, doi:10.1016/j.marpol.2015.03.018.
- Hennige, S. J. et al., 2015: Hidden impacts of ocean acidification to live and dead coral framework. *Proceedings. Biological sciences*, **282** (1813), doi:10.1098/rspb.2015.0990.
- Hernández-Delgado, E. A., 2015: The emerging threats of climate change on tropical coastal ecosystem services, public health, local economies and livelihood sustainability of small islands: Cumulative impacts and synergies. *Marine Pollution Bulletin*, **101** (1), 5-28, doi:<https://doi.org/10.1016/j.marpolbul.2015.09.018>.
- Hernández-González, Y. et al., 2016: *Perspectives on contentions about climate change adaptation in the Canary Islands: A case study for Tenerife*. European Union, Luxembourg.
- Herrmann, M. et al., 2011: Population structure, growth and production of the yellow clam *Mesodesma mactroides* (Bivalvia: Mesodesmatidae) from a high-energy, temperate beach in northern Argentina. *Helgoland Marine Research*, **65** (3), 285-297, doi:10.1007/s10152-010-0222-3.
- Herrmann, M. et al., 2009: Population Structure, Growth, and Production of the Wedge Clam *Donax hanleyanus* (Bivalvia: Donacidae) from Northern Argentinean Beaches. *Journal of Shellfish Research*, **28** (3), 511-526, doi:10.2983/035.028.0313.

- Hiwasaki, L., E. Luna, Syamsidik and J. A. Marçal, 2015: Local and indigenous knowledge on climate-related hazards of coastal and small island communities in Southeast Asia. *Climatic Change*, **128** (1), 35-56, doi:10.1007/s10584-014-1288-8.
- Ho, C.-H. et al., 2016: Mitigating uncertainty and enhancing resilience to climate change in the fisheries sector in Taiwan: Policy implications for food security. *Ocean & Coastal Management*, **130**, 355-372, doi:10.1016/j.ocecoaman.2016.06.020.
- Hobday, A. J. et al., 2015: Reconciling conflicts in pelagic fisheries under climate change. *Deep Sea Research Part II: Topical Studies in Oceanography*, **113**, 291-300, doi:10.1016/j.dsr2.2014.10.024.
- Hobday, A. J. et al., 2016: Planning adaptation to climate change in fast-warming marine regions with seafood-dependent coastal communities. *Reviews in Fish Biology and Fisheries*, **26** (2), 249-264, doi:10.1007/s11160-016-9419-0.
- Hopkins, C. R., D. M. Bailey and T. Potts, 2016: Perceptions of practitioners: Managing marine protected areas for climate change resilience. *Ocean & Coastal Management*, **128**, 18-28, doi:<https://doi.org/10.1016/j.ocecoaman.2016.04.014>.
- Hosoda, S., T. Ohira, K. Sato and T. Suga, 2010: Improved description of global mixed-layer depth using Argo profiling floats. *Journal of oceanography*, **66** (6), 773-787.
- Huxham, M. et al., 2015: Applying Climate Compatible Development and economic valuation to coastal management: A case study of Kenya's mangrove forests. *Journal of Environmental Management*, **157**, 168-181, doi:10.1016/j.jenvman.2015.04.018.
- Ishii, M. et al., 2017: Accuracy of Global Upper Ocean Heat Content Estimation Expected from Present Observational Data Sets. *SOLA*, **13**, 163-167.
- Islam, M. M., S. Sallu, K. Hubacek and J. Paavola, 2013: Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. *Regional Environmental Change*, **14** (1), 281-294, doi:10.1007/s10113-013-0487-6.
- Jacobs, J., S. K. Moore, K. E. Kunkel and L. Sun, 2015: A framework for examining climate-driven changes to the seasonality and geographical range of coastal pathogens and harmful algae. *Climate Risk Management*, **8**, 16-27, doi:<https://doi.org/10.1016/j.crm.2015.03.002>.
- Jamero, M. L., M. Onuki, M. Esteban and N. Tan, 2018: Community-based adaptation in low-lying islands in the Philippines: challenges and lessons learned. *Regional Environmental Change*, **18** (8), 2249-2260, doi:10.1007/s10113-018-1332-8.
- Jaramillo, E. et al., 2017: Macroscale patterns in body size of intertidal crustaceans provide insights on climate change effects. *Plos One*, **12** (5), e0177116, doi:10.1371/journal.pone.0177116.
- Jeong, H., H. Lee, H. Kim and H. Kim, 2014: Algorithm for economic assessment of infrastructure adaptation to climate change. *Proceedings of the International Symposium on Automation and Robotics in Construction*, **31**, 1.
- Jiang, W., C. Cornelisen, B. Knight and M. Gibbs, 2015: A pattern-oriented model for assessing effects of weather and freshwater discharge on black coral (*Antipathes fiordensis*) distribution in a fjord. *Ecological Modelling*, **304**, 59-68, doi:<https://doi.org/10.1016/j.ecolmodel.2015.02.020>.
- Jiao, N.-Z. et al., 2015: Climate change and anthropogenic impacts on marine ecosystems and countermeasures in China. *Advances in Climate Change Research*, **6** (2), 118-125, doi:<https://doi.org/10.1016/j.accre.2015.09.010>.
- Johnson, B. et al., 2016: Vulnerability Assessment of Coastal Fisher Households in Tamil Nadu, India: A Climate Change Perspective. *Indian Journal of Extension Education*, **52** (1&2), 20-26.
- Johnson, D., M. Adelaide Ferreira and E. Kenchington, 2018: Climate change is likely to severely limit the effectiveness of deep-sea ABMTs in the North Atlantic. *Marine Policy*, **87**, 111-122, doi:10.1016/j.marpol.2017.09.034.
- Jones, K. R. et al., 2018: The Location and Protection Status of Earth's Diminishing Marine Wilderness. *Current Biology*, **28** (15), 2506-2512.e3, doi:<https://doi.org/10.1016/j.cub.2018.06.010>.
- Jones, N. and J. R. A. Clark, 2014: Social capital and the public acceptability of climate change adaptation policies: a case study in Romney Marsh, UK. *Climatic Change*, **123**, 133-145.
- Jurjonas, M. and E. Seekamp, 2018: Rural coastal community resilience: Assessing a framework in eastern North Carolina. *Ocean & Coastal Management*, **162**, 137-150, doi:<https://doi.org/10.1016/j.ocecoaman.2017.10.010>.
- Kabisch, N., H. Korn, J. Stadler and A. Bonn, 2017: *Nature-based Solutions to Climate Change Adaptation in Urban Areas. Linkages between Science, Policy and Practice*. Theory and Practice of Urban Sustainability Transitions, Springer Open, 337 pp.
- Kaja, N. and M. Mellic, 2017: Climate change: Issues of Built Heritage Structures in the coastal region. *Journal of Scientific Research*, **13**, 54-60.
- Kamal, S., J. Warnken, M. Bakhtiyari and S. Y. Lee, 2017: Sediment distribution in shallow estuaries at fine scale: in situ evidence of the effects of three-dimensional structural complexity of mangrove pneumatophores. *Hydrobiologia*, **803** (1), 121-132, doi:10.1007/s10750-017-3178-3.
- Karlsson, M. and G. K. Hovelsrud, 2015: Local collective action: Adaptation to coastal erosion in the Monkey River Village, Belize. *Global Environmental Change*, **32**, 96-107, doi:<https://doi.org/10.1016/j.gloenvcha.2015.03.002>.
- Kelleway, J. J. et al., 2016: Seventy years of continuous encroachment substantially increases 'blue carbon' capacity as mangroves replace intertidal salt marshes. *Glob Chang Biol*, **22** (3), 1097-109, doi:10.1111/gcb.13158.



- Kitidis, V., I. Brown, N. Hardman-Mountford and N. Lefèvre, 2017: Surface ocean carbon dioxide during the Atlantic Meridional Transect (1995–2013); evidence of ocean acidification. *Progress in oceanography*, **158**, 65-75.
- Klinsky, S. et al., 2017: Why equity is fundamental in climate change policy research. *Global Environmental Change*, **44**, 170-173.
- Kochnowar, D., S. M. W. Reddy and R. E. Flick, 2015: Factors influencing local decisions to use habitats to protect coastal communities from hazards. *Ocean & Coastal Management*, **116**, 277-290, doi:<https://doi.org/10.1016/j.ocecoaman.2015.07.021>.
- Kurman, M. D. et al., 2017: Intra-Specific Variation Reveals Potential for Adaptation to Ocean Acidification in a Cold-Water Coral from the Gulf of Mexico. *Frontiers in Marine Science*, **4**, 111.
- Larsson, A. I. et al., 2014: Embryogenesis and larval biology of the cold-water coral *Lophelia pertusa*. *Plos One*, **9** (7), e102222, doi:10.1371/journal.pone.0102222.
- Le Cornu, E. et al., 2017: Spatial management in small-scale fisheries: A potential approach for climate change adaptation in Pacific Islands. *Marine Policy*, doi:10.1016/j.marpol.2017.09.030.
- Leon, J. X. et al., 2015: Supporting Local and Traditional Knowledge with Science for Adaptation to Climate Change: Lessons Learned from Participatory Three-Dimensional Modeling in BoeBoe, Solomon Islands. *Coastal Management*, **43** (4), 424-438, doi:10.1080/08920753.2015.1046808.
- Lercari, D. et al., 2018: Long-term structural and functional changes driven by climate variability and fishery regimes in a sandy beach ecosystem. *Ecological Modelling*, **368**, 41-51.
- Levin, L. A., 2018: Manifestation, Drivers, and Emergence of Open Ocean Deoxygenation. *Annual Review of Marine Science*, **10** (1), 229-260, doi:10.1146/annurev-marine-121916-063359.
- Levitus, S. et al., 2012: World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010. *Geophysical Research Letters*, **39** (10), doi:10.1029/2012GL051106.
- Lieske, D., T. Wade and L. A. Roness, 2014: Climate change awareness and strategies for communicating the risk of coastal flooding: A Canadian Maritime case example. *Estuarine, Coastal and Shelf Science*, **140**, 83-94.
- Linkon, S. B., 2018: *Autonomy in Building Process to Adapt the Climate Change Impacts: A Study of the Coastal Settlements in Bangladesh*. 2018.
- Lins-de-Barros, F. M., 2017: Integrated coastal vulnerability assessment: A methodology for coastal cities management integrating socioeconomic, physical and environmental dimensions - Case study of Região dos Lagos, Rio de Janeiro, Brazil. *Ocean & Coastal Management*, **149**, 1-11, doi:10.1016/j.ocecoaman.2017.09.007.
- Lirman, D. and S. Schopmeyer, 2016: Ecological solutions to reef degradation: optimizing coral reef restoration in the Caribbean and Western Atlantic. *PeerJ*, **4**, e2597, doi:10.7717/peerj.2597.
- Lyman, J. M. and G. C. Johnson, 2014: Estimating global ocean heat content changes in the upper 1800 m since 1950 and the influence of climatology choice. *Journal of Climate*, **27** (5), 1945-1957.
- MacDonald, M. A. et al., 2017: Benefits of coastal managed realignment for society: Evidence from ecosystem service assessments in two UK regions. *Estuarine, Coastal and Shelf Science*, doi:<https://doi.org/10.1016/j.ecss.2017.09.007>.
- Magnan, A. K. and V. K. E. Duvat, 2018: Unavoidable solutions for coastal adaptation in Reunion Island (Indian Ocean). *Environmental Science & Policy*, **89**, 393-400, doi:<https://doi.org/10.1016/j.envsci.2018.09.002>.
- Maier, C. et al., 2013: Respiration of Mediterranean cold-water corals is not affected by ocean acidification as projected for the end of the century. *Biogeosciences*, **10** (8), 5671-5680.
- Maier, C. et al., 2016: Effects of elevated pCO<sub>2</sub> and feeding on net calcification and energy budget of the Mediterranean cold-water coral *Madrepora oculata*. *Journal of Experimental Biology*, **219** (20), 3208-3217.
- Marfai, M. A., A. Sekaranom and P. Ward, 2015: Community responses and adaptation strategies toward flood hazard in Jakarta, Indonesia. *Natural Hazards: Journal of the International Society for the Prevention and Mitigation of Natural Hazards*, **75**, 1127-1144.
- Martínez, C. et al., 2017: Coastal erosion in central Chile: A new hazard? *Ocean & Coastal Management*, doi:10.1016/j.ocecoaman.2017.07.011.
- Martínez, C. I. P., W. H. A. Piña and S. F. Moreno, 2018: Prevention, mitigation and adaptation to climate change from perspectives of urban population in an emerging economy. *Journal of Cleaner Production*, **178**, 314-324.
- McLachlan, A. and O. Defeo, 2017: *The ecology of sandy shores*. Academic Press.
- Meehl, G. A. et al., 2011: Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods. *Nature Climate Change*, **1**, 360, doi:10.1038/nclimate1229  
<https://www.nature.com/articles/nclimate1229#supplementary-information>.
- Michailidou, A. V., C. Vlachokostas and N. Moussiopoulos, 2016: Interactions between climate change and the tourism sector: Multiple-criteria decision analysis to assess mitigation and adaptation options in tourism areas. *Tourism Management*, **55**, 1-12, doi:<https://doi.org/10.1016/j.tourman.2016.01.010>.
- Midorikawa, T. et al., 2012: Decreasing pH trend estimated from 35-year time series of carbonate parameters in the Pacific sector of the Southern Ocean in summer. *Deep Sea Research Part I: Oceanographic Research Papers*, **61**, 131-139.
- Midorikawa, T. et al., 2010: Decreasing pH trend estimated from 25-yr time series of carbonate parameters in the western North Pacific. *Tellus B*, **62** (5), 649-659.
- Mikellidou, C. V., L. M. Shakou, G. Boustras and C. Dimopoulos, 2018: Energy critical infrastructures at risk from climate change: A state of the art review. *Safety Science*, **110**, 110-120.

- Miller, D. D. et al., 2017: Adaptation strategies to climate change in marine systems. *Global Change Biology*, **24**, e1-e14.
- Miloshis, M. and C. A. Fairfield, 2015: Coastal wetland management: A rating system for potential engineering interventions. *Ecological Engineering*, **75**, 195-198.
- Monbaliu, J. et al., 2014: Risk assessment of estuaries under climate change: Lessons from Western Europe. *Coastal Engineering*, **87**, 32-49, doi:10.1016/j.coastaleng.2014.01.001.
- Moosavi, S., 2017: Ecological Coastal Protection: Pathways to Living Shorelines. *Procedia Engineering*, **196**, 930-938, doi:<https://doi.org/10.1016/j.proeng.2017.08.027>.
- Morato, T., R. Watson, T. J. Pitcher and D. Pauly, 2006: Fishing down the deep. *Fish and Fisheries*, **7** (1), 24-34, doi:10.1111/j.1467-2979.2006.00205.x.
- Movilla, J. et al., 2014: Resistance of two Mediterranean cold-water coral species to low-pH conditions. *Water*, **6** (1), 59-67.
- Mutombo, K. and A. Ölçer, 2016: Towards Port Infrastructure: A Global Port Climate Risk Analysis. *WMU Journal of Maritime Affairs*, **16**, 161, doi:10.1007/s13437-016-0113-9.
- Nagy, G. J., L. Seijo, J. E. Verocai and M. Bidegain, 2014: Stakeholders' climate perception and adaptation in coastal Uruguay. *International Journal of Climate Change Strategies and Management*, **6** (1), 63-84, doi:10.1108/IJCCSM-03-2013-0035.
- Nanlohy, H., A. N. Bambang, Ambariyanto and S. Hutabarat, 2015: Coastal Communities Knowledge Level on Climate Change as a Consideration in Mangrove Ecosystems Management in the Kotania Bay, West Seram Regency. *Procedia Environmental Sciences*, **23**, 157-163, doi:10.1016/j.proenv.2015.01.024.
- Narayan, S. et al., 2016: The Effectiveness, Costs and Coastal Protection Benefits of Natural and Nature-Based Defences. *Plos One*, **11** (5), e0154735, doi:10.1371/journal.pone.0154735.
- Naumann, M. S., C. Orejas and C. Ferrier-Pagès, 2014: Species-specific physiological response by the cold-water corals *Lophelia pertusa* and *Madrepora oculata* to variations within their natural temperature range. *Deep Sea Research Part II: Topical Studies in Oceanography*, **99**, 36-41.
- Nehren, U. et al., 2017: Sand Dunes and Mangroves for Disaster Risk Reduction and Climate Change Adaptation in the Coastal Zone of Quang Nam Province, Vietnam. In: Land Use and Climate Change Interactions in Central Vietnam: LUCi [Nauditt, A. and L. Ribbe (eds.)]. Springer Singapore, Singapore, 201-222.
- Nguyen, T. P., T. T. Luom and K. E. Parnell, 2017: Mangrove allocation for coastal protection and livelihood improvement in Kien Giang province, Vietnam: Constraints and recommendations. *Land Use Policy*, **63**, 401-407, doi:<https://doi.org/10.1016/j.landusepol.2017.01.048>.
- Nitto, D. D. et al., 2014: Mangroves facing climate change: landward migration potential in response to projected scenarios of sea level rise. *Biogeosciences*, **11** (3), 857-871.
- Novak Colwell, J. M., M. Axelrod, S. S. Salim and S. Velvizhi, 2017: A Gendered Analysis of Fisherfolk's Livelihood Adaptation and Coping Responses in the Face of a Seasonal Fishing Ban in Tamil Nadu & Puducherry, India. *World Development*, **98**, 325-337, doi:10.1016/j.worlddev.2017.04.033.
- Nunn, P. D., W. Aalbersberg, S. Lata and M. Gwilliam, 2014: Beyond the core: community governance for climate-change adaptation in peripheral parts of Pacific Island Countries. *Regional Environmental Change*, **14** (1), 221-235, doi:10.1007/s10113-013-0486-7.
- Nurse-Bray, M., P. Fidelman and M. Owusu, 2018: Does co-management facilitate adaptive capacity in times of environmental change? Insights from fisheries in Australia. *Marine Policy*, **96**, 72-80, doi:<https://doi.org/10.1016/j.marpol.2018.07.016>.
- Nurse-Bray, M., N. Harvey and T. Smith, 2015: Learning and local government in coastal South Australia: towards a community of practice framework for adapting to global change. *Regional Environmental Change*, **16** (3), 1-10.
- Olafsson, J. et al., 2009: Rate of Iceland Sea acidification from time series measurements. *Biogeosciences*, **6** (11), 2661-2668, doi:10.5194/bg-6-2661-2009.
- Onaka, S., H. Hashimoto, S. R. Nashreen Banu Soogun and A. Jheengut, 2015: Chapter 26 - Coastal Erosion and Demonstration Project as Coastal Adaptation Measures in Mauritius.[Esteban, M., H. Takagi and T. Shibayama (eds.)]. Butterworth-Heinemann, Boston, 561-577.
- Ondiviela, B. et al., 2014: The role of seagrasses in coastal protection in a changing climate. *Coastal Engineering*, **87** (Supplement C), 158-168, doi:10.1016/j.coastaleng.2013.11.005.
- Ortega, L., E. Celentano, E. Delgado and O. Defeo, 2016: Climate change influences on abundance, individual size and body abnormalities in a sandy beach clam. *Marine Ecology Progress Series*, **545**, 203-213.
- Ortega, L., E. Celentano, C. Finkl and O. Defeo, 2013: Effects of climate variability on the morphodynamics of Uruguayan sandy beaches. *Journal of Coastal Research*, **29** (4), 747-755.
- Osorio-Cano, J. D., A. F. Osorio and D. S. Peláez-Zapata, 2017: Ecosystem management tools to study natural habitats as wave damping structures and coastal protection mechanisms. *Ecological Engineering*, 282-295, doi:<https://doi.org/10.1016/j.ecoleng.2017.07.015>.
- Palacios, M. L. and J. R. Cantera, 2017: Mangrove timber use as an ecosystem service in the Colombian Pacific. *Hydrobiologia*, **803** (1), 345-358, doi:10.1007/s10750-017-3309-x.
- Palmer, M., K. Haines, S. Tett and T. Ansell, 2007: Isolating the signal of ocean global warming. *Geophysical Research Letters*, **34** (23).

- Papageorgiou, M., 2016: Coastal and marine tourism: A challenging factor in Marine Spatial Planning. *Ocean & Coastal Management*, **129**, 44-48, doi:<https://doi.org/10.1016/j.ocecoaman.2016.05.006>.
- Pardo, D., S. Jenouvrier, H. Weimerskirch and C. Barbraud, 2017: Effect of extreme sea surface temperature events on the demography of an age-structured albatross population. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, **372** (1723), 20160143, doi:10.1098/rstb.2016.0143.
- Parmesan, C. et al., 2013: Beyond climate change attribution in conservation and ecological research. *Ecology Letters*, **16** (s1), 58-71, doi:10.1111/ele.12098.
- Paterson, S. K. et al., 2017: Size does matter: City scale and the asymmetries of climate change adaptation in three coastal towns. *Geoforum*, **81**, 109-119, doi:<https://doi.org/10.1016/j.geoforum.2017.02.014>.
- Payne, M. R. et al., 2017: Lessons from the First Generation of Marine Ecological Forecast Products. *Frontiers in Marine Science*, **4** (289), doi:10.3389/fmars.2017.00289.
- Peirson, W. et al., 2015: Opportunistic management of estuaries under climate change: A new adaptive decision-making framework and its practical application. *Journal of Environmental Management*, **163**, 214-223, doi:10.1016/j.jenvman.2015.08.021.
- Peng, L., M. G. Stewart and R. E. Melchers, 2017: Corrosion and capacity prediction of marine steel infrastructure under a changing environment. *Structure and Infrastructure Engineering*, **13** (8), 988-1001.
- Perkins, M. J. et al., 2015: Conserving intertidal habitats: What is the potential of ecological engineering to mitigate impacts of coastal structures? *Estuarine, Coastal and Shelf Science*, **167**, 504-515, doi:10.1016/j.ecss.2015.10.033.
- Perry, J., 2015: Climate change adaptation in the world's best places: A wicked problem in need of immediate attention. *Landscape and Urban Planning*, **133**, 1-11, doi:10.1016/j.landurbplan.2014.08.013.
- Petzold, J. and B. M. W. Ratter, 2015: Climate change adaptation under a social capital approach – An analytical framework for small islands. *Ocean & Coastal Management*, **112**, 36-43, doi:10.1016/j.ocecoaman.2015.05.003.
- Pinsky, M. L. et al., 2018: Preparing ocean governance for species on the move. *Science*, **360** (6394), 1189.
- Porter, J. J., D. Demeritt and S. Dessai, 2015: The right stuff? informing adaptation to climate change in British Local Government. *Global Environmental Change*, **35**, 411-422, doi:10.1016/j.gloenvcha.2015.10.004.
- Poumadère, M. et al., 2015: Coastal vulnerabilities under the deliberation of stakeholders: The case of two French sandy beaches. *Ocean & Coastal Management*, **105**, 166-176, doi:<https://doi.org/10.1016/j.ocecoaman.2014.12.024>.
- Pranzini, E., 2017: Shore protection in Italy: From hard to soft engineering ... and back. *Ocean & Coastal Management*, doi:10.1016/j.ocecoaman.2017.04.018.
- Rahimi, Mansour and M. Madni, 2014: Toward a resilience framework for sustainable engineered systems. *Procedia Computer Science*, **28**, 809-817.
- Ranasinghe, R., 2016: Assessing climate change impacts on open sandy coasts: A review. *Earth-Science Reviews*, **160**, 320-332, doi:<https://doi.org/10.1016/j.earscirev.2016.07.011>.
- Rangel-Buitrago, N. G., G. Anfuso and A. T. Williams, 2015: Coastal erosion along the Caribbean coast of Colombia: Magnitudes, causes and management. *Ocean & Coastal Management*, **114**, 129-144, doi:10.1016/j.ocecoaman.2015.06.024.
- Riascos, J. M. et al., 2009: Thriving and declining: climate variability shaping life-history and population persistence of *Mesodesma donacium* in the Humboldt Upwelling System. *Marine Ecology Progress Series*, **385**, 151-163.
- Riascos, J. M., O. Heilmayer, M. E. Oliva and J. Laudien, 2011: Environmental stress and parasitism as drivers of population dynamics of *Mesodesma donacium* at its northern biogeographic range. *ICES Journal of Marine Science*, **68** (5), 823-833, doi:10.1093/icesjms/fsr026.
- Roberts, C. M. et al., 2017: Marine reserves can mitigate and promote adaptation to climate change. *Proceedings of the National Academy of Sciences*.
- Robertson, L. M., J.-F. Hamel and A. Mercier, 2017: Feeding in deep-sea demosponges: Influence of abiotic and biotic factors. *Deep Sea Research Part I: Oceanographic Research Papers*, **127** (Supplement C), 49-56.
- Robins, P. E. et al., 2016: Impact of climate change on UK estuaries: A review of past trends and potential projections. *Estuarine, Coastal and Shelf Science*, **169**, 119-135.
- Rodríguez-Rodríguez, G. and R. Bande Ramudo, 2017: Market driven management of climate change impacts in the Spanish mussel sector. *Marine Policy*, **83**, 230-235, doi:<https://doi.org/10.1016/j.marpol.2017.06.014>.
- Roemmich, D. and J. Gilson, 2009: The 2004–2008 mean and annual cycle of temperature, salinity, and steric height in the global ocean from the Argo Program. *Progress in oceanography*, **82** (2), 81-100.
- Romañach, S. S. et al., 2018: Conservation and restoration of mangroves: Global status, perspectives, and prognosis. *Ocean & Coastal Management*, **154**, 72-82.
- Rosendo, S., L. Celliers and M. Mechisso, 2018: Doing more with the same: A reality-check on the ability of local government to implement Integrated Coastal Management for climate change adaptation. *Marine Policy*, **87**, 29-39, doi:<https://doi.org/10.1016/j.marpol.2017.10.001>.
- Runting, R. K., C. E. Lovelock, H. L. Beyer and J. R. Rhodes, 2017: Costs and Opportunities for Preserving Coastal Wetlands under Sea Level Rise. *Conservation Letters*, **10** (1), 49-57, doi:10.1111/conl.12239.
- Sakakibara, C., 2017: People of the Whales: Climate Change and Cultural Resilience Among Iñupiat of Arctic Alaska. *Geographical Review*, **107** (1), 159-184.



- Salgado, K. and M. L. Martinez, 2017: Is ecosystem-based coastal defense a realistic alternative? Exploring the evidence. *Journal of Coastal Conservation*, **21** (6), 837-848, doi:10.1007/s11852-017-0545-1.
- Salim, S. S. et al., 2014: *Vulnerability assessment of coastal fisher households in Kerala: A climate change perspective*. 99-104 pp.
- Sánchez-Arcilla, A. et al., 2016: Managing coastal environments under climate change: Pathways to adaptation. *Science of The Total Environment*, **572**, 1336-1352, doi:10.1016/j.scitotenv.2016.01.124.
- Scarano, F. R., 2017: Ecosystem-based adaptation to climate change: concept, scalability and a role for conservation science. *Perspectives in Ecology and Conservation*, **15** (2), 65-73, doi:10.1016/j.pecon.2017.05.003.
- Schaeffer-Novelli, Y. et al., 2016: Climate changes in mangrove forests and salt marshes. *Brazilian Journal of Oceanography*, **64** ((spe2)), 37-52.
- Schliephack, J. and J. E. Dickinson, 2017: Tourists' representations of coastal managed realignment as a climate change adaptation strategy. *Tourism Management*, **59**, 182-192, doi:<https://doi.org/10.1016/j.tourman.2016.08.004>.
- Schuckmann, K. v. and P.-Y. L. Traon, 2011: How well can we derive Global Ocean Indicators from Argo data? *Ocean Science*, **7** (6), 783-791.
- Schuerch, M. et al., 2018: Future response of global coastal wetlands to sea-level rise. *Nature*, **561** (7722), 231.
- Seiffert, R. and F. Hesser, 2014: Investigating climate change impacts and adaptation strategies in German estuaries. *Die Küste, 81 Modelling*, **81**, 551-563.
- Serrao-Neumann, S. et al., 2013: Improving cross-sectoral climate change adaptation for coastal settlements: insights from South East Queensland, Australia. *Regional Environmental Change*, **14** (2), 489-500, doi:10.1007/s10113-013-0442-6.
- Shaffril, H. A. M., A. A. Samah and J. Lawrence, 2017: Adapting towards climate change impacts: Strategies for small-scale fishermen in Malaysia. *Marine Policy*, **81**, 196-201.
- Sheaves, M. et al., 2016: Principles for operationalizing climate change adaptation strategies to support the resilience of estuarine and coastal ecosystems: An Australian perspective. *Marine Policy*, **68**, 229-240, doi:10.1016/j.marpol.2016.03.014.
- Sheng, Y. P. and R. Zou, 2017: Assessing the role of mangrove forest in reducing coastal inundation during major hurricanes. *Hydrobiologia*, **803** (1), 87-103, doi:10.1007/s10750-017-3201-8.
- Shindell, D. T. et al., 2013: Interactive ozone and methane chemistry in GISS-E2 historical and future climate simulations. *Atmos. Chem. Phys.*, **13** (5), 2653-2689, doi:10.5194/acp-13-2653-2013.
- Shope, J. B., C. D. Storlazzi, L. H. Erikson and C. A. Hegermiller, 2016: Changes to extreme wave climates of islands within the Western Tropical Pacific throughout the 21st century under RCP 4.5 and RCP 8.5, with implications for island vulnerability and sustainability. *Global and Planetary Change*, **141**, 25-38, doi:<https://doi.org/10.1016/j.gloplacha.2016.03.009>.
- Shumack, S. and P. Hesse, 2017: Assessing the geomorphic disturbance from fires on coastal dunes near Esperance, Western Australia: Implications for dune de-stabilisation. *Aeolian Research*, doi:10.1016/j.aeolia.2017.08.005.
- Sierra-Correa, P. C. and J. R. Cantera Kintz, 2015: Ecosystem-based adaptation for improving coastal planning for sea-level rise: A systematic review for mangrove coasts. *Marine Policy*, **51**, 385-393, doi:<https://doi.org/10.1016/j.marpol.2014.09.013>.
- Smith, R.-A. J. and K. Rhiney, 2016: Climate (in)justice, vulnerability and livelihoods in the Caribbean: The case of the indigenous Caribs in northeastern St. Vincent. *Geoforum*, **73**, 22-31, doi:<https://doi.org/10.1016/j.geoforum.2015.11.008>.
- Strand, R. et al., 2017: The response of a boreal deep-sea sponge holobiont to acute thermal stress. *Scientific reports*, **7** (1), 1660, doi:10.1038/s41598-017-01091-x.
- Sutton, A. J. et al., 2017: Variability and trends in surface seawater pCO<sub>2</sub> and CO<sub>2</sub> flux in the Pacific Ocean. *Geophysical Research Letters*, **44** (11), 5627-5636, doi:10.1002/2017GL073814.
- Sutton-Grier, A. E., K. Wowk and H. Bamford, 2015: Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science & Policy*, **51**, 137-148, doi:10.1016/j.envsci.2015.04.006.
- Takahashi, T. et al., 2014: Climatological distributions of pH, pCO<sub>2</sub>, total CO<sub>2</sub>, alkalinity, and CaCO<sub>3</sub> saturation in the global surface ocean, and temporal changes at selected locations. *Marine Chemistry*, **164**, 95-125, doi:10.1016/j.marchem.2014.06.004.
- Tapswan, S. and W. Rongrongmuang, 2015: Climate change perception of the dive tourism industry in Koh Tao island, Thailand. *Journal of Outdoor Recreation and Tourism*, **11**, 58-63, doi:10.1016/j.jort.2015.06.005.
- Thiagarajan, N. et al., 2013: Movement of deep-sea coral populations on climatic timescales. *Paleoceanography*, **28** (2), 227-236, doi:10.1002/palo.20023.
- Thorne, K. M. et al., 2017: Are coastal managers ready for climate change? A case study from estuaries along the Pacific coast of the United States. *Ocean & Coastal Management*, **143**, 38-50, doi:<https://doi.org/10.1016/j.ocecoaman.2017.02.010>.
- Thresher, R. E., J. M. Guinotte, R. J. Matear and A. J. Hobday, 2015: Options for managing impacts of climate change on a deep-sea community. *Nature Climate Change*, **5** (7), 635-639, doi:10.1038/nclimate2611.
- Torres, C. and N. Hanley, 2017: Communicating research on the economic valuation of coastal and marine ecosystem services. *Marine Policy*, **75**, 99-107, doi:<https://doi.org/10.1016/j.marpol.2016.10.017>.

- Triyanti, A., M. Bavinck, J. Gupta and M. A. Marfai, 2017: Social capital, interactive governance and coastal protection: The effectiveness of mangrove ecosystem-based strategies in promoting inclusive development in Demak, Indonesia. *Ocean & Coastal Management*, **150**, 3-11, doi:<https://doi.org/10.1016/j.ocecoaman.2017.10.017>.
- Valmonte-Santos, R., M. W. Rosegrant and M. M. Dey, 2016: Fisheries sector under climate change in the coral triangle countries of Pacific Islands: Current status and policy issues. *Marine Policy*, **67**, 148-155, doi:10.1016/j.marpol.2015.12.022.
- van der Nat, A., P. Vellinga, R. Leemans and E. van Slobbe, 2016: Ranking coastal flood protection designs from engineered to nature-based. *Ecological Engineering*, **87**, 80-90, doi:10.1016/j.ecoleng.2015.11.007.
- van Oppen, M. J. H. et al., 2017: Shifting paradigms in restoration of the world's coral reefs. *Global Change Biology*, **23** (9), 3437-3448, doi:10.1111/gcb.13647.
- Vázquez, N. G. et al., 2016: *Mass Mortalities Affecting Populations of the Yellow Clam <i>Amarilladesma mactroides</i> Along Its Geographic Range*. BLOONE, 739-745, 7 pp.
- Vikolainen, V., J. Flikweert, H. Bressers and K. Lulofs, 2017: Governance context for coastal innovations in England: The case of Sandscaping in North Norfolk. *Ocean & Coastal Management*, **145**, 82-93, doi:<https://doi.org/10.1016/j.ocecoaman.2017.05.012>.
- Villatoro, M. et al., 2014: An approach to assess flooding and erosion risk for open beaches in a changing climate. *Coastal Engineering*, **87**, 50-76, doi:10.1016/j.coastaleng.2013.11.009.
- Voldoire, A. et al., 2013: The CNRM-CM5. 1 global climate model: description and basic evaluation. *Climate Dynamics*, **40** (9-10), 2091-2121.
- von Schuckmann, K. et al., 2018: Copernicus marine service ocean state report. *Journal of Operational Oceanography*, **11** (sup1), S1-S142.
- Von Schuckmann, K. et al., 2014: Consistency of the current global ocean observing systems from an Argo perspective. *Ocean Science*, **10** (3), 547-557.
- Wadey, M., S. Brown, R. J. Nicholls and I. Haigh, 2017: Coastal flooding in the Maldives: an assessment of historic events and their implications. *Natural Hazards*, **89** (1), 131-159, doi:10.1007/s11069-017-2957-5.
- Waite, R. et al., 2015: Use of coastal economic valuation in decision making in the Caribbean: Enabling conditions and lessons learned. *Ecosystem Services*, **11**, 45-55, doi:10.1016/j.ecoser.2014.07.010.
- Ward, R. D., D. A. Friess, R. H. Day and R. A. MacKenzie, 2016: Impacts of climate change on mangrove ecosystems: a region by region overview. *Ecosystem Health and Sustainability*, **2** (4), p.e.01211.
- Watanabe, S. et al., 2011: MIROC-ESM: model description and basic results of CMIP5-20c3m experiments. *Geoscientific Model Development Discussions*, **4** (2), 1063-1128.
- Waters, J. F., F. J. Millero and C. L. Sabine, 2011: Changes in South Pacific anthropogenic carbon. *Global Biogeochemical Cycles*, **25** (4).
- Watson, E. B. et al., 2017: Anthropocene survival of southern New England's salt marshes. *Estuaries and Coasts*, **40** (3), 617-625.
- Weng, K., S. Nicol and A. J. Hobday, 2014: Fishery management, development and food security in the Western and Central Pacific in the context of climate change. *Deep Sea Research Part II Topical Studies in Oceanography*, **113**, 301-311, doi:DOI: 10.1016/j.dsr2.2014.10.025.
- Wigand, C. et al., 2017: A climate change adaptation strategy for management of coastal marsh systems. *Estuaries and Coasts*, **40** (3), 682-693.
- Williams, G. A. et al., 2016: Meeting the climate change challenge: Pressing issues in southern China and SE Asian coastal ecosystems. *Regional Studies in Marine Science*, **8**, 373-381, doi:10.1016/j.rsma.2016.07.002.
- Williams, N. L. et al., 2015: Quantifying anthropogenic carbon inventory changes in the Pacific sector of the Southern Ocean. *Marine Chemistry*, **174**, 147-160, doi:<https://doi.org/10.1016/j.marchem.2015.06.015>.
- Wise, R. M. et al., 2016: How climate compatible are livelihood adaptation strategies and development programs in rural Indonesia? *Climate Risk Management*, **12**, 100-114, doi:10.1016/j.crm.2015.11.001.
- Woodruff, S. C., 2018: City membership in climate change adaptation networks. *Environmental Science & Policy*, **84**, 60-68.
- Wu, T. et al., 2014: An overview of BCC climate system model development and application for climate change studies. *Journal of Meteorological Research*, **28** (1), 34-56, doi:10.1007/s13351-014-3041-7.
- Wu, X. et al., 2016: Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environ Int*, **86**, 14-23, doi:10.1016/j.envint.2015.09.007.
- Wynveen, C. J. and S. G. Sutton, 2015: Engaging the public in climate change-related pro-environmental behaviors to protect coral reefs: The role of public trust in the management agency. *Marine Policy*, **53**, 131-140, doi:10.1016/j.marpol.2014.10.030.
- Xue, L. et al., 2014: Temporal changes in surface partial pressure of carbon dioxide and carbonate saturation state in the eastern equatorial Indian Ocean during the 1962–2012 period. *Biogeosciences*, **11** (22), 6293-6305.
- Yando, E. S. et al., 2016: Salt marsh-mangrove ecotones: using structural gradients to investigate the effects of woody plant encroachment on plant–soil interactions and ecosystem carbon pools. *Journal of Ecology*, **104** (4), 1020-1031, doi:10.1111/1365-2745.12571.
- Yao, K. M. et al., 2016: Time variability of the north-western Mediterranean Sea pH over 1995–2011. *Marine environmental research*, **116**, 51-60.

Zikra, M., S. Suntoyo and L. Lukijanto, 2015: Climate Change Impacts on Indonesian Coastal Areas. *Procedia Earth and Planetary Science*, **14**, 57-63.