Chapter 3: Oceans and Coastal Ecosystems and their Services
Supplementary Material

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SM3.1 Section 3.1

SM3.1.1 SROCC Burning Embers

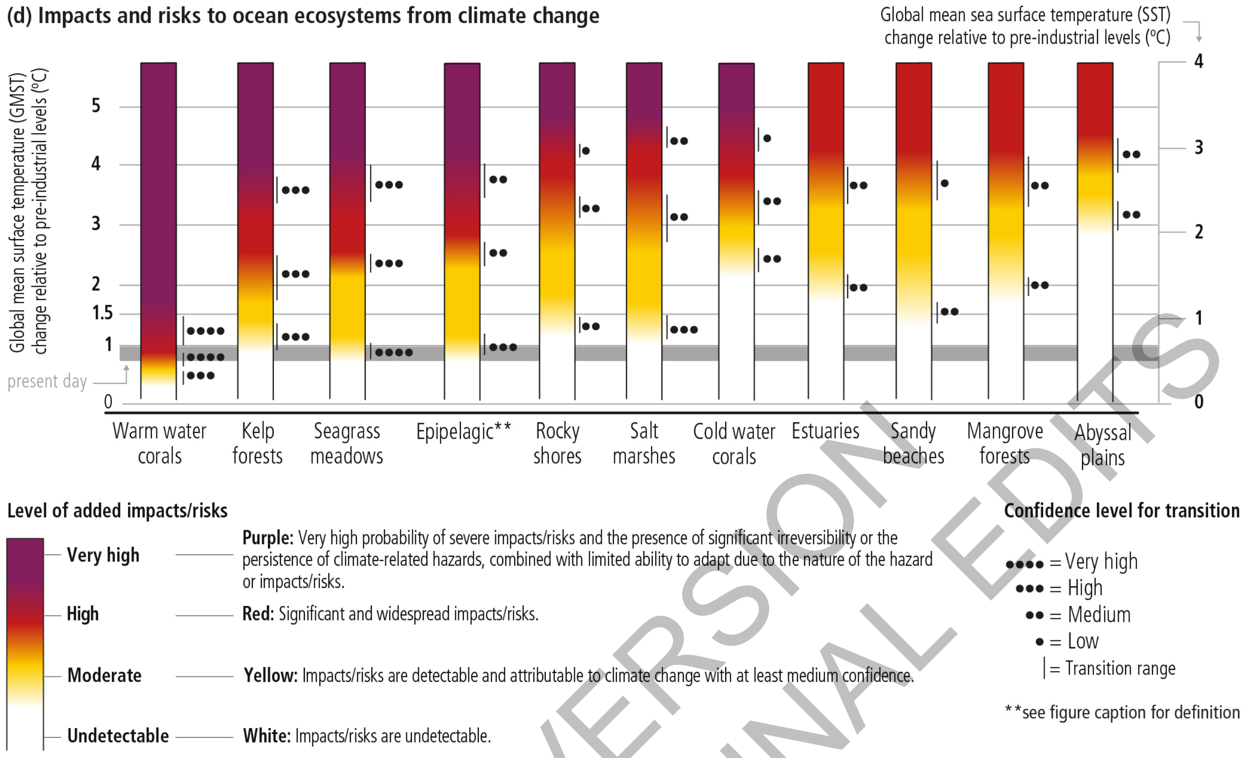

Figure SM3.1: Projected impacts and risks for ocean regions and ecosystems. As assessed by SROCC (IPCC, 2019

SM3.2 Section 3.3

SM3.2.1 Combined Climate Stressors

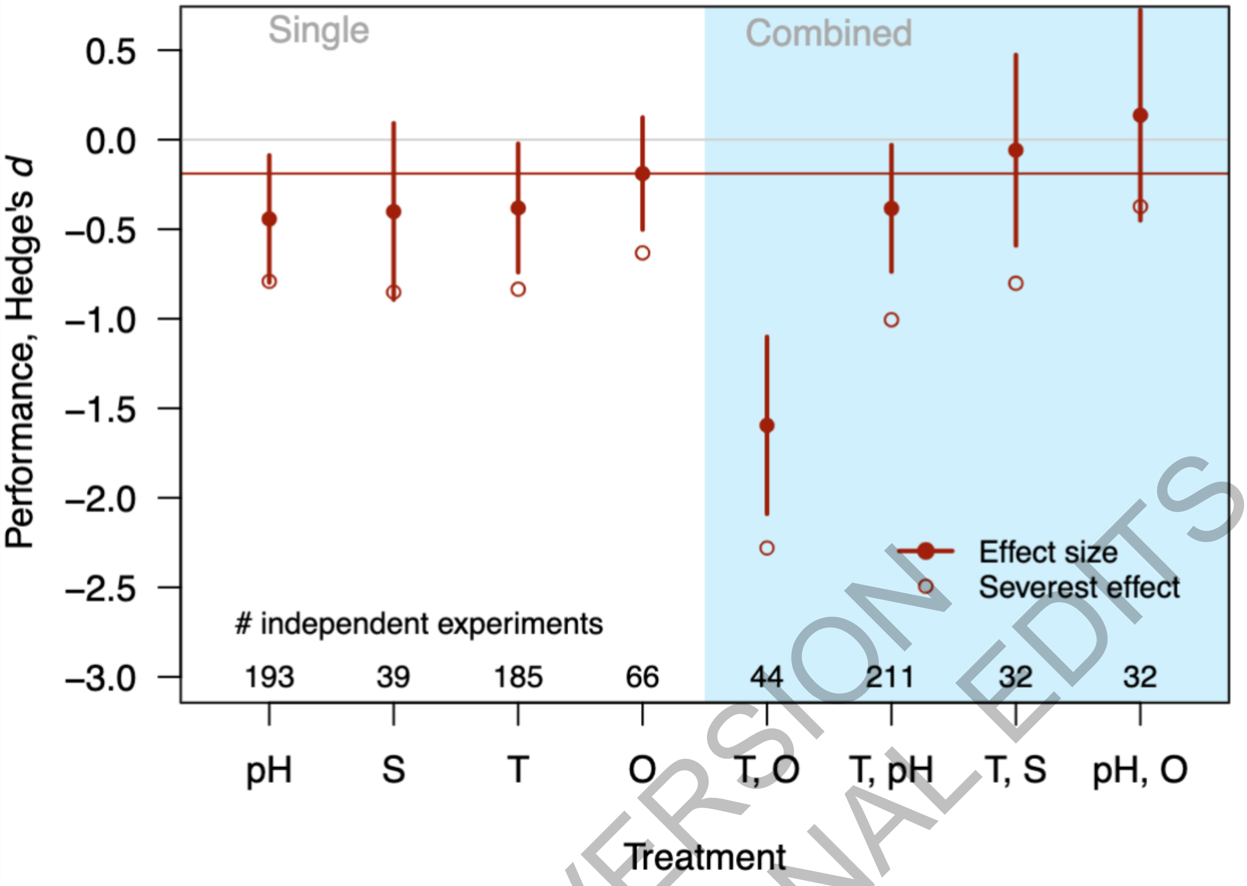

Figure SM3.2: The effects of single and combined stressors on the performance of marine ectothermic animals. Performance relates to survival, development, condition, growth, calcification and metabolism, which ultimately modulate population extinction risk. Solid symbols and vertical bars, effect size ±95% confidence (*extremely likely*) intervals. The interaction of rising temperature and oxygen limitation has the most detrimental effect on organismal performance. S = salinity, T = temperature, O = Oxygen. Modified from Reddin et al. (2020).

SM3.2.2 Understanding Sources Uncertainty in Climate Projections from Marine Ecological Models

The use of global and regional marine ecosystem and fisheries models (e.g., in ensembles such as Fish-MIP, Tittensor et al., 2018) provides opportunities to investigate the influence of different sources of uncertainty on model projections at different temporal and spatial scales. Fish-MIP global modelling experiments have shown that different model assumptions regarding the effects of temperature and changes in primary and secondary production, combined with the degree of food-web complexity and feedbacks, can lead to substantial differences in marine animal biomass under future projections under separate and combined physical and biogeochemical drivers (Heneghan et al., 2021). These include directional differences in projections, particularly at smaller spatial scales (Tittensor et al., 2018), and in comparison with regional marine ecosystem models (Pethybridge et al., 2020). It is clear that much more work is needed to advance the nature of coupling physical, biogeochemical and ecological models as well as appropriate combinations of models and data across different scales.

Global Fish-MIP model ensemble experiments have been restricted to the use of only a few ESMs which does not provide enough information to assess whether there is a decrease in the uncertainty of Fish-MIP models compared with CMIP ensembles (Lotze et al., 2019). Single-model ensembles have been used, however, to assess the relative influence of different sources of uncertainty on impacts of regional projections, spanning a wider range of ESM outputs (Payne et al., 2016). For example, using a regional model of the Bering Sea, Reum et al. (2020) showed that in the short- to medium-term ecological processes contributed substantially to model uncertainty, but that ESM and scenario uncertainty became the overriding sources of variation in the long-term. Similar results have been found with species distribution models at the global scale, but when examined for single species or regions, internal variability of ecological models also can be very large (Cheung et al., 2016a; Cheung et al., 2016b), highlighting the need to track multiple sources of uncertainty for confidence assessment in models.

SM3.3 Section 3.4

SM3.3.1 Assessment of the Impact of Storms and Tropical Cyclones on Estuaries and Soft-Sediment Coasts

Estuarine ecosystems and their phytoplankton (Carrasco Navas-Parejo et al., 2020), vegetation (Mo et al., 2020), fish (Matich et al., 2020) and birds (Field et al., 2019; Wilkinson et al., 2019), can be resilient to the impacts of storms and tropical cyclones (*medium confidence*). Nevertheless, the passage of storms can also manifest subtly in, for example, reduced body condition of juvenile fish (Matich et al., 2020), and can also have counterintuitive effects by, for example, reducing erosion rates by moving sediments onshore (Wang et al., 2020). In some instances, heavy precipitation can flush estuaries, resulting in net erosion; in others, runoff from adjacent land can increase nutrient loads, causing or exacerbating eutrophication, stimulating HABs (Phlips et al., 2020) and sometimes causing large-scale marine mammal, bird, and fish kills (Adams et al., 2019).

Effects of tropical cyclones on mangroves are variable (*high confidence*). They range from beneficial (Castañeda-Moya et al., 2020; Feher et al., 2020), through minor damage (Armitage et al., 2019) or recovery over a period of less than a decade (Branoff, 2020), culminating in regime shifts involving peat collapse and transition to mudflats (Chambers et al., 2019; Osland et al., 2020). Saltmarsh vegetation is more resilient to intense storms (*medium confidence*) (Armitage et al., 2019; Mo et al., 2020), with sediments showing limited amounts of long-term erosion, and sometimes even accretion (Xie et al., 2017), especially when suspended sediments are not advected too far away from the site of erosion (Leonardi et al., 2018).

On sandy beaches (Section 3.4.2.6), although extreme storms can both remove and create habitat for shorebirds, losses of existing habitat are generally small, even when considering only the impacted portion of species' distributions (Maslo et al., 2019). When considering the full species' distributions, impacts are often negligible (Field et al., 2019). Projected loss of beach habitat to SLR and urbanisation remains a substantial risk, however.

SM3.3.2 Additional Background for the Assessment of Semi-Enclosed Seas (SES)

Recent warming and changes in other environmental conditions in SES, with ecological and biogeochemical ramifications, have been attributed to climate change (*high confidence*) (e.g., Adloff et al., 2015; Shirvani et al., 2015; The BACC II Author Team, 2015). The Persian Gulf, characterized by extreme seasonal fluctuations in temperature and salinity, has shown an increase in frequency of extreme events, increases in salinity and declines in oxygen content. The latter changes, combined with substantial reduction in freshwater discharge and an increase in coastal eutrophication, have triggered changes in biogeochemical cycles (*high confidence*) (Al-Said et al., 2018; Ben-Hasan et al., 2018; Al-Yamani and Naqvi, 2019; Ben-Hasan and Christensen, 2019). In the Red Sea, ocean acidification and MHWs are the main climate-impact drivers, along with warming (*high confidence*) (Steiner et al., 2018; Genevier et al., 2019). Increasing MHW frequency, decreases in precipitation, accelerating SLR and extreme winter weather events have been reported for the Mediterranean Sea (*high confidence*) (Adloff et al., 2015; Cramer et al., 2018; Darmaraki et al., 2019). Important changes in thermohaline circulation have been reported in the Black Sea, including erosion of the cold intermediate layer that controls the important exchange of oxygen between surface and deep water masses (*high confidence*) (Cannaby et al., 2015; Miladinova et al., 2017). In the Baltic Sea, changes in rainfall and river runoff have been described, with a decreased influx of seawater (from the North Sea) and prolonged hypoxia in deeper parts of the basin representing major stressors for different ecosystem components (*high confidence*) (The BACC II Author Team, 2015; Räisänen, 2017).

The size and number of OMZs are increasing worldwide and in most SES (*high confidence*) (Global Ocean Oxygen Network, 2018), with growing impacts on fish species and ecosystem functioning. In the Persian Gulf and Red Sea, increasing nutrient loads associated with coastal activities and warming has increased the size of OMZs (*high confidence*) (Al-Said et al., 2018; Lachkar et al., 2019). OMZs represent an even greater problem in the Black and Baltic Seas, with broad implications for ecosystem function and services (e.g. Levin et al., 2009), especially where actions to reduce nutrient loading from land have not been unable to reduce the OMZ coverage (*high confidence*) (Carstensen et al., 2014; Miladinova et al., 2017; Global Ocean Oxygen Network, 2018). In the Baltic Sea, OMZs are affecting the spawning areas of cod, *Gadus morhua* (*high confidence*) (Hinrichsen et al., 2016), while in the Black Sea, the combined effect of OMZs and warming is influencing the distribution and physiology of fish species, and their migration and schooling behavior in the overwintering grounds (*medium confidence*) (Güraslan et al., 2017). Cascading effects on food webs have been reported in the Baltic, where detrimental effects of changing oxygen levels on zooplankton production, pelagic and piscivorous fish are influencing seasonal succession and species composition of phytoplankton (*high confidence*) (Viitasalo et al., 2015).

SM3.3.3 Calculating Changes in Phenology Shifts

SM3.3.3.1 Database

This analysis updates the database of Poloczanska et al. (2013), which had 109 time-series from 31 studies and was used in AR5 WGII Chapter 30 (Hoegh-Guldberg et al., 2014). The new studies were found by searching ISI Web of Science and Google Scholar using keywords “phenology” and “marine”. As in the original database, all observations had to meet three criteria:

- Criterion 1. Time series had to be at least 19 years in duration to minimise bias associated with short-term responses to natural climate variability (median time series duration was 45 years).
- Criterion 2. The end date of the time series had to be 1990 or later.
- Criterion 3. Studies had to directly test, or at a minimum discuss, their results in relation to expected impacts of climate change (Poloczanska et al., 2013).

This process resulted in the addition of 306 time series from 79 studies.

Each observation in the database was a time series of a species or a group of species (e.g., total zooplankton). Observations included cases where phenological responses were consistent with climate change (earlier occurrence with warming), inconsistent with climate change, or there was no change. Data were included from time series that were continuous (n = 388), intermittent (n = 14), and from two periods in time (n = 13). Quantitative estimates of shifts in phenology were taken directly from the published papers, calculated from information in tables or the Supplement, or digitised from figures. We used data reported as days per decade to examine mean rates of shifts.

To avoid duplication and to minimise spatial autocorrelation, the latitude and longitude of each observation was used to assign each observation to a Longhurst Province, a commonly used global bioregionalisation (Longhurst et al., 1995). We considered time series of the same species in different Longhurst Provinces as unique observations, but where we found multiple time series for the same species in a Longhurst Province, we used the mean phenological shift and randomly selected an observation for consistency (see Analysis below). The data used in the analysis below are available in Table SM3.1.

SM3.3.3.2 Analysis

To estimate rates of consistency with climate change among taxonomic groups (taxa), we analysed the observations using a generalised linear model with a binomial error structure and a binary response variable (0 = Not consistent; 1 = Consistent) (n = 413). To analyse the magnitude and direction of observed phenological shifts (days per decade) by different taxonomic groups, we used a linear model with a normal error structure (n = 312). In both models, the same four predictors were used. The first was taxonomic group (with levels for Phytoplankton, Zooplankton, Meroplankton, Benthic invertebrates, Plants, Fish, Reptiles, Seabirds, Mammals), so we could test for differences across groups in Consistency and the magnitude and direction of phenological shift. We included the remaining predictors to account for potential issues associated with publication bias (Parmesan and Yohe, 2003). The second predictor in the models, number of species in each study, was included because previous analyses have found that studies that included few species (e.g., single species studies) tend to have a larger effect size (Parmesan and Yohe, 2003). The third predictor was the duration of the study, because shorter studies might be more likely to report more consistent impacts of climate change and greater phenology shifts. The final predictor included was the mid-year of the time series, to test whether more-recent time series might be more likely to observe more consistent impacts of climate change and greater phenology shifts, as climate change accelerates. For modelling consistency, we removed from the model any taxonomic group that had no variance (i.e., all time series were consistent with climate change) because their inclusion destabilised error estimation. These points were plotted in the final output without error (since it is impossible to determine error without variance).

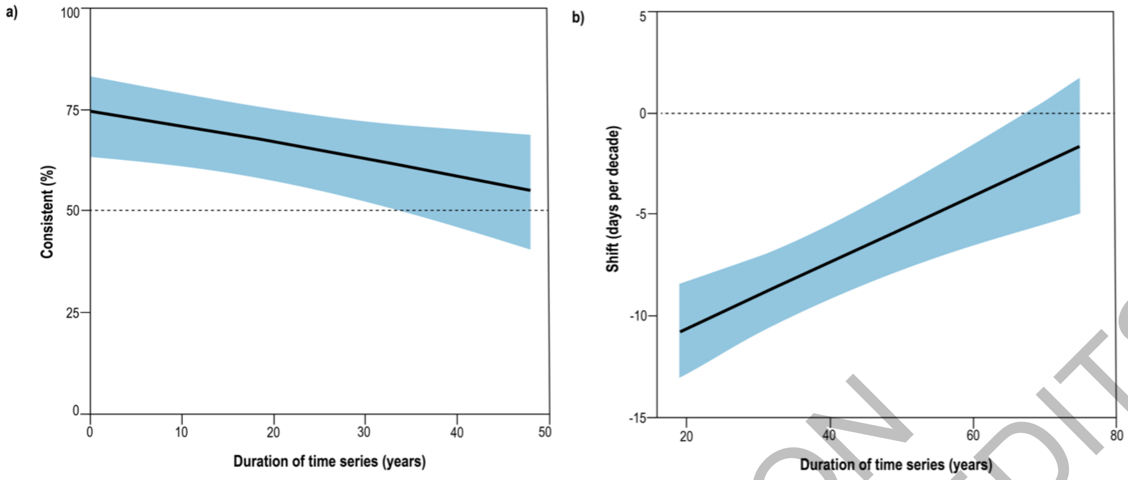

Figure SM3.3: Observed responses to climate change based on a systematic review of the Web of Science for marine phenology studies longer than 19 years in duration. Error envelopes indicate 95% (*extremely likely*) confidence interval. (a) Proportion of phenology observations (showing means and extremely likely range) that are attributed to climate change (i.e., generally showing earlier timing) by duration of study in years (adjusted for taxon). The dashed line at 0.5 indicates random chance. (b) Shifts in timing that are attributed to climate change by duration of study (adjusted for taxon). The dashed line at 0 indicates no shift. Negative shifts are earlier, positive shifts are later. The observations summarised in panels (a) and (b) have been collected over the global oceans (see locations in Figure 3.16a) and include n=297,277 observations of phenology shifts that are attributed (at least partly) to climate change, and n=1168 observations of phenology shifts that are inconsistent with climate change (see Section 3.4.3.2).

Table SM3.1: Data used to create Figure 3.16 in Section 3.4.3. Longhurst codes: NECS = Northeast Atlantic shelves, PSAW = Western Pacific subarctic gyres, SARC = Atlantic sub-Arctic, NWCS = Northwest Atlantic shelves, ARCT = Atlantic Arctic, CCAL = California Current, APLR = Austral Polar, NADR = North Atlantic Drift, NASE = Northeast Atlantic subtropical gyre, BRAZ = Brazilian current coast, MEDI = Mediterranean Sea, BPLR = Boreal polar, ALSK = Alaska coastal downwelling, FKLD = Southwest Atlantic shelves, CARB = Caribbean, SANT = Subantarctic water ring, AUSW = Western Australian and Indonesian coast, GFST = Gulf Stream, BERS = North Pacific epicontinental Sea, KURO = Kuroshio current, PSAW = Western Pacific subarctic gyres, SANT = Subarctic water ring, EAFR = East African coast.

Reference	Database	Longhurst	Latitude	Longitude	Group	Species	LastYear	MidYear	Duration	NumOfReps	Consistent	Shift
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Acartia clausi*	2012	2000	25	24	1	-6.4
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Acartia* spp.	1998	1982	45	49	1	-0.81
(Costello et al., 2006)	AR5	NWCS	41.50	-71.35	Holozooplankton	*Acartia tonsa*	2003	1977	53	2	1	0
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Actinotrocha* spp.	1994	1984	21	25	1	NA
(Descamps et al., 2019)	Current	PSAW	52.35	-176.93	Seabirds	*Aethia cristatella*	2015	2001.5	28	16	0	0
(Descamps et al., 2019)	Current	PSAW	52.35	-176.93	Seabirds	*Aethia psittacula*	2015	2003	25	16	1	-0.08
(Descamps et al., 2019)	Current	PSAW	52.35	-176.93	Seabirds	*Aethia pusilla*	2015	1998.5	34	16	0	0.09
(Descamps et al., 2019)	Current	PSAW	52.35	-176.93	Seabirds	*Aethia pygmaea*	2015	2001.5	28	16	1	-0.18
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Aglantha digitale*	1994	1984	21	25	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Agonus cataphractus*	2013	1986.5	54	30	1	NA
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Alaurina* spp.	1994	1984	21	25	1	NA
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Alca torda*	2006	1990.5	36	7	0	-0.04
(Descamps et al., 2019)	Current	SARC	70.37	31.13	Seabirds	*Alca torda*	2013	1997.5	32	16	1	-0.03
(Bucci et al., 2020)	Current	NWCS	44.90	-66.70	Phytoplankton	*Alexandrium catenella*	2014	2001	27	1	1	-7.5
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*All other colourless dinoflagellates*	2012	2000	25	24	0	6.4
(Moe et al., 2009)	AR5	ARCT	77.00	15.55	Seabirds	*Alle alle*	2012	1992.5	46	2	1	-0.66
(Lombardo et al., 2019)	Current	NWCS	36.00	-76.50	Fish	*Alosa aestivalis*	2016	1994.5	44	1	1	-4.33
(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Fish	*Alosa alosa*	2010	1997.5	26	7	1	NA
(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Holozooplankton	*Alosa bifilosa*	2010	1997.5	26	7	1	NA
(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Fish	*Alosa fallax*	2010	1997.5	26	7	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Alosa pseudoharengus*	2015	1992.5	48	35	1	-3

(Cobb, 2020)	Current	NWCS	43.27	-70.98	Fish	*Alosa pseudoharengus and Alosa aestivalis*	2016	1997.5	38	1	1	-3.5
(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Fish	*Alosa reguis*	2010	1997.5	26	7	0	NA
(Quinn and Adams, 1996)	Current	CCAL	45.64	-121.94	Fish	*Alosa sapidissima*	1992	1965	55	1	1	-6.89
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Alosa sapidissima*	2012.5	1993.25	48	35	1	-4
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Amblyraja radiate*	2014	1990.5	48	35	0	NA
(Burthe et al., 2012)	Current	NECS	56.50	-1.50	Fish	*Ammodytes marinus*	2006	1994.5	24	4	0	2.58
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Ammodytes tobianus*	2013	1986.5	54	30	0	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Holozooplankton	*Amphidinium crassum*	2016	2004.5	24	29	1	-7.24
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Anarhichas lupus*	2014	1990.5	48	35	1	NA
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Meroplankton	*Anemone larvae*	2012	2000	25	24	1	-1.6
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Anguilla anguilla*	2013	1986.5	54	30	0	NA
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Anguilla rostrata*	2013	1999.5	28	9	1	-0.1
(Chambers et al., 2014)	Current	AUSW	-28.77	113.85	Seabirds	*Anous stolidus*	2010	2000.5	20	4	0	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Aphanizomenon* spp.	2016	2004.5	24	29	1	-3.03
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	Appendicularians	2012	2000	25	24	0	2
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Aptenodytes forsteri*	2004	1977	55	9	0	0.31
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	Arachnactes	1994	1984	21	25	1	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Argentina sialis*	2008	1979.5	58	43	0	2
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Argyropelecus sladeni*	2008	1979.5	58	43	1	-5.85
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Arnoglossus laterna*	2013	1986.5	54	30	0	NA
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Asterias rubens*	1994	1984	21	25	1	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Asterionellopsis glacialis*	2011	1985.166	45	49	1	-9.5
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Atherina presbyter*	2013	1986.5	54	30	0	NA
(Van Walraven et al., 2015)	Current	NECS	53.57	6.94	Holozooplankton	*Aurelia aurita*	2010	1985	51	2	1	-7.66

(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	Autotrophic dinoflagellate biomass	2012	2000	25	24	0	1.6
(Ramp et al., 2015)	Current	NWCS	49.90	-64.50	Mammals	*Balaenoptera physalus*	2010	1997	27	2	1	-10.37
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Bathylagus pacificus*	2008	1979.5	58	43	0	4.6
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Bathylagus wesethi*	2008	1979.5	58	43	0	4.4
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Belone belone*	2013	1986.5	54	30	1	NA
(Schlüter et al., 2010)	AR5	NECS	54.18	7.90	Holozooplankton	*Beroe gracilis*	2004	1989.5	30	2	1	-9.33
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	Bodonids	2012	2000	25	24	1	-5.2
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Brevoortia tyrannus*	2013	1999.5	28	9	1	-10.9
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Brosme brosme*	2014	1990.5	48	35	0	NA
(McGinty et al., 2011)	Current	NADR	49.50	-9.00	Holozooplankton	*Calanus finmarchicus*	2008	1983	51	7	1	-1.56
(McGinty et al., 2011)	Current	NASE		-15.00	Holozooplankton	*Calanus finmarchicus*	2008	1983	51	7	1	-0.59
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Calanus finmarchicus*	2006.4	1984.7	45	49	1	-1.84
(McGinty et al., 2011)	Current	SARC	60.00	-10.00	Holozooplankton	*Calanus finmarchicus*	2008	1983	51	7	1	-2.97
(Persson et al., 2012)	Current	SARC	66.33	33.66	Holozooplankton	*Calanus glacialis*	2010	1987	47	2	1	NA
(McGinty et al., 2011)	Current	NADR	49.50	-9.00	Holozooplankton	*Calanus helgolandicus*	2008	1983	51	7	1	-2.3
(McGinty et al., 2011)	Current	NASE	41.00	-15.00	Holozooplankton	*Calanus helgolandicus*	2008	1983	51	7	1	-1.48
(McGinty et al., 2011)	Current	NECS	53.00	-6.00	Holozooplankton	*Calanus helgolandicus*	2008.4	1989.9	39	7	1	0.94
(McGinty et al., 2011)	Current	SARC	60.00	-10.00	Holozooplankton	*Calanus helgolandicus*	2008	1983	51	7	1	-2.08
(Burthe et al., 2012)	Current	NECS	56.50	-1.50	Holozooplankton	*Calanus I-IV*	2006	1994.5	24	4	1	-6.33
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Callionymus lyra*	2013	1986.5	54	30	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Cancer borealis*	2014	1990.5	48	35	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Cancer irroratus*	2014	1990.5	48	35	1	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Candacia armata*	2007	1990	45	49	1	0.73
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	*Carcinus maenas*	1994	1984	21	25	1	NA

(Monsinjon et al., 2019)	Current	BRAZ	-12.57	-38.00	Reptiles	*Caretta caretta*	2014	2001.5	26	1	1	-2.2
(Mazaris et al., 2008)	AR5	MEDI	37.73	20.89	Reptiles	*Caretta caretta*	2002	1993	19	1	1	-11.58
(Hawkes et al., 2007)	AR5	NWCS	33.83	-77.95	Reptiles	*Caretta caretta*	2005	1994	23	1	1	0
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Catharacta maccormicki*	2004	1977	55	9	0	0.11
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Centropages hamatus*	2002	1980	45	49	1	-3.13
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Centropages typicus*	2008.666	1990.333	45	49	1	-4.47
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Centropritstis striata*	2014	1990.5	48	35	1	NA
(Sauve et al., 2019)	Current	BPLR	71.33	-155.68	Seabirds	*Cepphus grylle mandtii*	2017	1996.5	42	1	1	-1.86
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium furca*	2011	1985.166	45	49	1	-2.49
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium fusus*	2011	1985.166	45	49	1	-8.22
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium horridum*	2009	1983.5	45	49	1	-4.84
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium lineatum*	2009	1983.5	45	49	1	-4.08
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium longipes*	2009	1983.5	45	49	0	-0.21
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium macroceros*	2009	1983.5	45	49	1	-8.79
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Ceratium tripos*	2009	1983.5	45	49	1	-7.27
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Ceratoscopelus townsendi*	2008	1979.5	58	43	1	-0.7
(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Ceratulina pelagica*	2015	1988.5	54	8	1	0.39
(Bertram et al., 2001)	AR5	ALSK	50.87	-129.08	Seabirds	*Cerorhinca monocerata*	2007	1996	25	4	1	-4.44
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Chaetoceros (Hyalochaete)*	2016	1987	59	12	1	-1.75
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Chaetoceros (Phaeoceros)*	2016	1987	59	12	0	-0.34
(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Chaetoceros* spp.	2015.333	1993.833	54	8	1	-10.43
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	Chaetognaths	2007	1990	45	49	1	-2.13
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Chauliodus macouni*	2008	1979.5	58	43	1	-0.6

(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Chelidonichthys lucerna*	2013	1986.5	54	30	1	NA
(Émond et al., 2020)	Current	NWCS	47.50	-63.00	Meroplankton	*Chionoecetes opilio*	2012	1997	31	2	1	NA
(Guinder et al., 2010)	Current	FKLD	-38.72	-62.27	Phytoplankton	*Chl-a*	2007	1992.5	30	1	1	-12.33
(Philippart et al., 2003)	AR5	NECS	53.00	4.80	Phytoplankton	*Chl-a*	2011.5	1998.625	29	2	1	-0.42
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Chromis punctipinnis*	2008	1979.5	58	43	0	3
(Van Walraven et al., 2015)	Current	NECS	53.57	6.94	Holozooplankton	*Chrysaora hysoscella*	2010	1985	51	2	1	-10.01
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Chrysochromulina* spp.	2016	2004.5	24	29	0	1.94
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	*Cirripede ciprid*	2007	1990	45	49	1	1.52
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	*Cirripede nauplii*	2003	1992	21	25	1	1.6
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Citharichthys sordidus*	2008	1979.5	58	43	0	2.95
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Citharichthys stigmaeus*	2008	1979.5	58	43	0	16
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Clione limacina*	2002	1980	45	49	0	3.21
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Clupea harengus*	2004.5	1985.75	54	30	1	-7.69
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Clupea harengus*	2014	1990.5	48	35	1	NA
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	Coccolithophore	2012	2000	25	24	0	9.6
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	Colourless flagellates	2012	2000	25	24	1	-7.2
(Burthe et al., 2012)	Current	NECS	56.50	-1.50	Holozooplankton	*Copepod nauplii*	2009	1997.25	24	4	1	-2.11
(Edwards et al., 2006)	AR5	NECS	56.00	3.00	Holozooplankton	Copepods	2005	1981.5	48	1	1	NA
(Edwards et al., 2006)	AR5	NECS	55.00	5.00	Holozooplankton	*Corycaeus* spp.	2002	1980	45	49	0	5.57
(Philippart et al., 2003)	AR5	NECS	53.00	4.80	Invertebrates	*Crangon crangon*	2001	1992	19	2	1	-30.39
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	Crangonidae	1994	1984	21	25	1	NA
(Cherkiss et al., 2020)	Current	CARB	25.16	-80.83	Reptiles	*Crocodylus acutus*	2016	1998.25	39	1	1	-5.8
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	Ctenophores	2012	2000	25	24	1	-26.4
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	Cumacea	2002	1980	45	49	1	-2.77
(Hosia et al., 2014)	Current	NECS	58.42	8.75	Holozooplankton	*Cyanea* spp.	2010.5	1993.5	19	1	0	2.59

(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Cyclopterus lumpus*	2013	1986.5	54	30	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Cyclothone signata*	2008	1979.5	58	43	1	-4.35
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Cylindrotheca closterium*	2016	1987	59	12	0	-0.68
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	*Cyphonautes larvae*	2002	1980	45	49	1	-2.72
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Danaphos oculatus*	2008	1979.5	58	43	1	-9.3
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Daption capense*	2004	1977	55	9	0	1.28
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	*Decapod larvae*	2007	1990	45	49	1	-0.99
(Hauser et al., 2017)	Current	BPLR	69.47	-171.69	Mammals	*Delphinapterus leucas*	2012	2002.5	20	1	1	11.33
(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Detonula pumila*	2015	1988.5	54	8	1	-4.33
(Wiltshire and Manly, 2004)	AR5	NECS	54.18	7.90	Phytoplankton	Diatoms	2009	1994.125	41	1	1	-4.55
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Dicentrarchus labrax*	2013	1986.5	54	30	0	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Dinobryon faculiferum*	2016	2004.5	24	29	1	-16.3
(Tunin-Ley et al., 2009)	AR5	NASE	41.00	-14.00	Phytoplankton	Dinoflagellates	2005	1956.5	98	1	1	NA
(Hjerne et al., 2019)	Current	NECS	58.80	17.63	Phytoplankton	Dinoflagellates	2011	1997.25	35	1	1	-3.76
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Dinophysis acuminata*	2016	2004.5	24	29	1	-16.37
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Dinophysis* spp.	2009	1983.5	45	49	1	-4.73
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Diogenichthys attanticus*	2008	1979.5	58	43	1	-2.3
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Ditrichocorycaeus anglicus*	2012	2000	25	24	0	0.8
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Ditylum brightwelli*	2015.5	1987.75	59	12	1	-2.94
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Dolichospermum* spp.	2016	2004.5	24	29	1	-27.45
(Langan et al., 2021)	Current	NWCS	41.50	-71.40	Fish	*Doryteuthis pealeii*	2016	1987.5	58	5	1	-2.88
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Holozooplankton	*Ebria tripartita*	2016	2004.5	24	29	1	-24.99
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	*Echinocardium cordatum*	1994	1984	21	25	1	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	*Echinoderm larvae*	2007	1990	45	49	1	-7.16

(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Fish	*Engraulis encrasicolus*	2011.5	1992	26	7	1	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Engraulis mordax*	2008	1979.5	58	43	1	-3
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Eucampia zodiacus*	2015.666	1987.5	59	12	0	6.23
(Hindell et al., 2012)	Current	SANT	-54.62	158.85	Seabirds	*Eudyptes schlegeli*	1999	1981.5	36	1	1	-1.08
(Cullen et al., 2009)	AR5	AUSW	-38.50	145.16	Seabirds	*Eudyptula minor*	2002.5	1985.25	40	1	0	3.45
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Euterpina acutifrons*	2012	2000	25	24	0	5.2
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Eutriptiella* spp.	2016	2004.5	24	29	1	-0.28
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Evadne* spp.	2003	1988.25	45	49	1	-6.41
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	Fish eggs	2002.666	1988	45	49	1	-5.84
(Greve et al., 1996)	AR5	NECS	54.19	7.90	Meroplankton	Fish larvae	1998.8	1986.4	19	25	1	-17.68
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Fragilaria* spp.	2009	1983.5	45	49	1	-4.09
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Fratercula arctica*	2006	1990.5	36	7	0	1.11
(Descamps et al., 2019)	Current	SARC	69.07	15.17	Seabirds	*Fratercula arctica*	2016	1999	35	16	1	-0.32
(Bertram et al., 2001)	AR5	ALSK	50.87	-129.08	Seabirds	*Fratercula cirrhata*	2005.333	1992.333	25	4	1	-7.24
(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Fratercula corniculata*	2015	2001.5	28	16	0	0.26
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Fritillaria borealis*	1994	1984	21	25	0	NA
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Fulmarus glacialis*	2006	1988.5	36	7	1	0.16
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Fulmarus glacialoides*	2004	1977	55	9	0	3.87
(Morgan et al., 2013)	Current	GFST	43.00	-51.00	Fish	*Gadus morhua*	2009	1992	35	2	0	6.35
(McQueen and Marshall, 2017)	Current	NECS	53.50	-5.00	Fish	*Gadus morhua*	2013.666	1994.833	32	2	1	-10.57
(Morgan et al., 2013)	Current	NWCS	48.00	-51.00	Fish	*Gadus morhua*	2012.333	1990.5	38	2	0	10.66
(McQueen and Marshall, 2017)	Current	SARC	60.00	1.00	Fish	*Gadus morhua*	2014	1999.5	30	2	1	-6.58
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	*Galathea* spp.	1994	1984	21	25	1	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	Gammarid amphipods	2007	1990	45	49	1	-0.97
(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Fish	*Gasterosteus aculeatus*	2011.5	1992	26	7	1	NA
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	Gastropod larvae	2003	1992	21	25	1	0.8

(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Guindardia delicatula*	2015	1988.5	54	8	1	-11.8
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*Gyrodinium* spp.	2012	2000	25	24	1	-15.6
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Gyrosigma* spp.	2016	1987	59	12	1	0.4
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Harpacticoida*	2002	1980	45	49	1	-4.98
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Helicolenus dactylopterus*	2014	1990.5	48	35	1	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Hemiselmis* spp.	2016	2004.5	24	29	0	7.57
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Hemitripterus americanus*	2014	1990.5	48	35	1	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Heterocapsa rotunda*	2016	2004.5	24	29	1	-15.74
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Heterocapsa triquetra*	2016	2004.5	24	29	0	10.65
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Hippoglossina oblonga*	2015	1989	48	35	1	-3.14
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Hippoglossoides platessoides*	2014	1990.5	48	35	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Hippoglossus hippoglossus*	2014	1990.5	48	35	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Homarus americanus*	2014	1990.5	48	35	1	NA
(Émond et al., 2020)	Current	NWCS	47.50	-63.00	Meroplankton	*Hyas* spp.	2012	1997	31	2	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Hyperoplus lanceolatus*	2013	1986.5	54	30	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Icichthys lockingtoni*	2008	1979.5	58	43	1	-5.6
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Idiacanthus antrostomus*	2008	1979.5	58	43	1	-3
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Illex illecebrosus*	2014	1990.5	48	35	1	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Holozooplankton	*Katablepharis* spp.	2016	2004.5	24	29	1	-7.28
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*Katodinium* spp.	2012	2000	25	24	1	-3.2
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Labidocera wollastoni*	2002	1980	45	49	1	-2.52
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Lagodon rhomboides*	2013	1999.5	28	9	1	-1.5
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	Lamellibranch larvae	2002.666	1988	45	49	1	4.22
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Lanice conchilega*	1994	1984	21	25	1	NA

(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Larus glaucescens*	2015	2004.5	22	16	1	-0.08
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	Larvacea	2002	1980	45	49	1	-6.68
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Leiostomus xanthurus*	2013	1999.5	28	9	1	-2.1
(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Leptocylindricus minimus*	2015	1988.5	54	8	1	-28.31
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Lestidiops ringens*	2008	1979.5	58	43	1	-7.3
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Leucoraja erinacea*	2014	1990.5	48	35	0	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Leucoraja ocellata*	2014	1990.5	48	35	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Leuroglossus stilbius*	2008	1979.5	58	43	0	1.2
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Limacina retroversa*	2002	1980	45	49	0	8.37
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Limanda ferruginea*	2014	1990.5	48	35	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Limanda limanda*	2013	1986.5	54	30	1	NA
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	*Liocarcinus* spp.	1994	1984	21	25	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Liparis liparis*	2013	1986.5	54	30	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Lipolagus ochotensis*	2008	1979.5	58	43	1	-3.2
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Liza aurata*	2013	1986.5	54	30	0	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Loligo pealeii*	2014	1990.5	48	35	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Lophius gastrophysus*	2014	1990.5	48	35	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Lyopsetta exilis*	2008	1979.5	58	43	1	-0.7
(Beukema et al., 2009)	AR5	NECS	53.00	6.00	Invertebrates	*Macoma balthica rubra*	2007	1988	39	1	1	-5.38
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Macronectes giganteus*	2004	1982	45	9	0	1.91
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Magelona* spp.	1994	1984	21	25	1	NA
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Medusae*	2012	2000	25	24	0	2.4
(Ramp et al., 2015)	Current	NWCS	49.90	-64.50	Mammals	*Megaptera novaeangliae*	2010	1998.5	24	2	1	-11.67
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Melamphaes lugubris*	2008	1979.5	58	43	0	3

(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Melanogrammus aeglefinus*	2014	1990.5	48	35	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Merluccius bilinearis*	2014	1990.5	48	35	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Merluccius productus*	2008	1979.5	58	43	1	-3
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*Mesodinium rubrum*	2014	2002.25	25	24	0	-14.28
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Metridia lucens*	2012	2000	25	24	1	-8.4
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Micropogonias undulatus*	2013	1999.5	28	9	1	-14.4
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Microsetella* spp.	2012	2000	25	24	0	11.2
(Costello et al., 2006)	AR5	NWCS	41.50	-71.35	Holozooplankton	*Mnemiopsis leidyi*	2003	1977	53	2	1	-11.13
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Monoraphidium contortum*	2016	2004.5	24	29	1	-13.92
(Peer and Miller, 2014)	Current	NWCS	37.52	-76.10	Fish	*Morone saxatilis*	2012	1995.5	20	1	1	-3
(Wanless et al., 2009)	AR5	NECS	55.00	-5.00	Seabirds	*Morus bassanus*	2007	1993.5	28	1	0	2.1
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Mugil cephalus*	2013	1999.5	28	9	1	-9.1
(Langan et al., 2021)	Current	NWCS	41.50	-71.40	Fish	*Myoxocephalus octodecemspinosus*	2016	1987.5	58	5	0	5.03
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Myoxocephalus scorpius*	2013	1986.5	54	30	1	NA
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Myrophis punctatus*	2013	1999.5	28	9	1	-14.5
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Myxocephalus octodecemspinosus*	2014	1990.5	48	35	1	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Nannobrachium regale*	2008	1979.5	58	43	0	0.7
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Nannobrachium ritteri*	2008	1979.5	58	43	1	-4.8
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Navicula* spp.	2016	1987	59	12	0	-1.57
(Bertram et al., 2001)	AR5	BERS	50.00	145.00	Holozooplankton	*Neocalanus plumchrus*	1996	1985.5	22	4	1	-22
(Bertram et al., 2001)	AR5	CCAL	48.65	-126.67	Holozooplankton	*Neocalanus plumchrus*	1998	1986.5	24	4	1	-13
(Mackas et al., 1998)	AR5	PSAE	50.00	-145.00	Holozooplankton	*Neocalanus plumchrus*	1996	1982	29	1	1	-10.34
(Chevillot et al., 2017)	Current	NECS	45.42	-0.86	Holozooplankton	*Neomysis integer*	2010	1997.5	26	7	1	NA
(McGeady et al., 2021)	Current	NECS	53.75	-4.75	Meroplankton	*Nephrops norvegicus*	2010	1996	29	1	1	-11.94
(Greve et al., 1996)	Current	NECS	54.19	7.90	Phytoplankton	*Noctiluca scintillans*	2003.75	1989.25	21	25	1	4.03

(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Nodularia* spp.	2016	2004.5	24	29	0	21.25
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Obelia* spp.	1994	1984	21	25	0	NA
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Oceanites oceanicus*	2004	1981.5	46	9	0	1.01
(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Oceanodroma furcata*	2015	1998.5	34	16	1	-0.74
(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Oceanodroma leucorhoa*	2015	2005	21	16	1	-0.53
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Odontella aurita*	2008	1983.666	45	49	1	-4.69
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Odontella sinensis*	2011	1985.166	45	49	1	3.41
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Oikopleura dioica*	1994	1984.25	21	25	1	-2.83
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Oithona* spp.	2007	1990	45	49	1	-1.65
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Oncaea* spp.	2012	2000	25	24	0	0.4
(Kovach et al., 2013)	Current	ALSK	58.38	-134.65	Fish	*Oncorhynchus clarkii*	2010	1995	31	2	1	-1.15
(Taylor, 2008)	Current	ALSK	58.38	-134.65	Fish	*Oncorhynchus gorbuscha*	2007.5	1992	34	1	1	-3.21
(Kovach et al., 2015)	Current	ALSK	58.38	-134.64	Fish	*Oncorhynchus keta*	2010	1995.5	30	4	1	-3.93
(Rubenstein et al., 2019)	Current	CCAL	49.65	-125.44	Fish	*Oncorhynchus keta*	2016.333	2003.333	34	2	1	-4.34
(Kovach et al., 2015)	Current	ALSK	58.38	-134.64	Fish	*Oncorhynchus kisutch*	2010	1995.5	30	4	1	-4.64
(Rubenstein et al., 2019)	Current	CCAL	49.65	-125.44	Fish	*Oncorhynchus kisutch*	2015	1998.5	34	2	1	-8
(Robards and Quinn, 2002)	Current	CCAL	47.44	-120.84	Fish	*Oncorhynchus mykiss*	1998	1977.125	49	1	0	-0.19
(Kovach et al., 2015)	Current	ALSK	58.38	-134.64	Fish	*Oncorhynchus nerka*	2010	1995.5	30	4	0	1.61
(Crozier et al., 2011)	Current	CCAL	46.24	-124.00	Fish	*Oncorhynchus nerka*	2000.333	1976	75	1	1	-4.22
(Kovach et al., 2015)	Current	ALSK	58.38	-134.64	Fish	*Oncorhynchus tshawytscha*	2010	1995.5	30	4	0	0.81
(Kovach et al., 2012)	Current	ALSK	58.38	-134.65	Fish	*Oncorhyncus gorbuscha*	2011	1997	29	1	1	NA
(Morita, 2018)	Current	KURO	43.27	141.37	Fish	*Oncorhyncus gorbuscha*	2017	2005	25	1	1	-2.92
(Chambers et al., 2014)	Current	AUSW	-32.30	115.69	Seabirds	*Onychoprion anaethetus*	2011	1998.5	26	4	0	NA
(Chambers et al., 2014)	Current	AUSW	-28.77	113.85	Seabirds	*Onychoprion fuscata*	2010	2000.5	20	4	0	NA

(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Oocystis* spp.	2016	2004.5	24	29	1	-54.08
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Ophiura* spp.	1994	1984	21	25	1	NA
(Ahas and Aasa, 2006)	AR5	NECS	58.20	24.30	Fish	*Osmerus eperlanus*	2003	1978.5	48	1	1	-0.08
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*Other ciliates*	2012	2000	25	24	1	-28.8
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Oxyjulis californica*	2008	1979.5	58	43	1	-6.9
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Pagodroma nivea*	2004	1987	35	9	0	-0.23
(Greve et al., 1996)	Current	NECS	54.19	7.90	Meroplankton	*Pagurus* spp.	1994	1984	21	25	0	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Para-pseudocalanus* spp.	1998	1982	45	49	1	-2.71
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Paralia sulcata*	2009	1983.5	45	49	1	-1.83
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Paralichthys albigutta*	2013	1999.5	28	9	1	-13.9
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Paralichthys californicus*	2008	1979.5	58	43	0	5.3
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Paralichthys dentatus*	2014.333	1992.5	48	35	1	-5.17
(Thaxton et al., 2020)	Current	NWCS	34.60	-77.20	Meroplankton	*Paralichthys lethostigma*	2013	1999.5	28	9	1	-2.8
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Paramysis* spp.	1994	1984	21	25	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Parophrys vetulus*	2008	1979.5	58	43	1	-1.8
(Moore et al., 2011)	AR5	NECS	50.58	-4.32	Invertebrates	*Patella depressa*	2007	1976.5	62	2	1	-10.2
(Moore et al., 2011)	AR5	NECS	50.58	-4.32	Invertebrates	*Patella vulgata*	2007	1976.5	62	2	0	3.3
(Langan et al., 2021)	Current	NWCS	41.50	-71.40	Fish	*Peprilus triacanthus*	2016	1987.5	58	5	1	-6.36
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Peridiniella catenata*	2016	2004.5	24	29	1	-38.61
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*Phaeocystis* spp.	2012	2000	25	24	1	-6
(Frederiksen et al., 2004)	AR5	NECS	56.18	-2.55	Seabirds	*Phalacrocorax aristotelis*	2005	1989.25	34	3	1	-3.72
(Descamps et al., 2019)	Current	BERS	57.13	-170.28	Seabirds	*Phalacrocorax urile*	2015	2000	31	16	1	-0.16
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Pholis gunnellus*	2013	1986.5	54	30	1	NA
(Burthe et al., 2012)	Current	NECS	56.50	-1.50	Phytoplankton	Phytoplankton Colour Index	2006	1994.5	24	4	1	-5.76
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Plagioselmis prolonga*	2016	2004.5	24	29	0	5.1

(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Planctonema lauterbornii*	2016	2004.5	24	29	0	3.14
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Planktolyngba* spp.	2016	2004.5	24	29	1	-26.63
(Schlüter et al., 2010)	AR5	NECS	54.18	7.90	Holozooplankton	*Pleurobrachia pileus*	2000.666	1987.833	30	2	1	-10.47
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Pleuronectes platessa*	2008.5	1986.75	54	30	0	-10
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Pleuronichthys verticalis*	2008	1979.5	58	43	0	5.6
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Podon* spp.	2002.666	1988	45	49	1	-2.52
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Pollachius pollachius*	2013	1986.5	54	30	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Pollachius virens*	2013	1986.5	54	30	0	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Pollachius virens*	2014	1990.5	48	35	1	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Meroplankton	Polychaete larvae	2007	1990	45	49	1	1.52
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Pomatoschistus minutus*	2013	1986.5	54	30	0	NA
(Diaz-Almela et al., 2007)	AR5	MEDI	41.00	7.00	Plants	*Posidonia oceanica*	2004	1988.5	32	1	1	NA
(Langan et al., 2021)	Current	NWCS	41.50	-71.40	Fish	*Prionotus evolans*	2016	1987.5	58	5	1	-7.74
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Proboscia alata*	2009	1983.5	45	49	1	-6.78
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Proboscia inermis*	2016	1987	59	12	0	1.68
(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Prorocentrum micans*	2015	1988.5	54	8	1	-8.65
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Prorocentrum* spp.	2009	1983.5	45	49	1	-5.72
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Protomyctophum crockeri*	2008	1979.5	58	43	1	-1.4
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Holozooplankton	*Protoperidinium bipes*	2016	2004.5	24	29	1	-21.35
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Holozooplankton	*Protoperidinium brevipes*	2016	2004.5	24	29	1	-2.76
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Protoperidinium* spp.	2010	1989	45	49	1	-3.85
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Pseudo-nitzschia delicatissima*	2016	1987	59	12	1	-3.35
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Pseudo-nitzschia seriata*	2016	1987	59	12	1	-1.46

(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Pseudo-nitzschia* spp.	2015	1988.5	54	8	1	-28.31
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Pseudocalanus elongatus*	2007	1990	45	49	1	-4.09
(Persson et al., 2012)	Current	SARC	66.33	33.66	Holozooplankton	*Pseudocalanus minutus*	2010	1987	47	2	1	NA
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Pseudopedinella* spp.	2016	2004.5	24	29	1	-26.66
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Pseuodopleuronectes americanus*	2014	1990.5	48	35	1	NA
(Schroeder et al., 2009)	AR5	CCAL	37.70	-123.00	Seabirds	*Ptychoramphus aleuticus*	2006	1991.666	19	2	0	4
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Pygocelis adeliae*	2004	1977	55	9	0	0.51
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Pyramimonas* spp.	2016	2004.5	24	29	1	-15.81
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Rhizosolenia hebetata*	2009	1983.5	45	49	1	-0.89
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Rhizosolenia imbricata*	2011	1985.166	45	49	1	-8.59
(Scharfe and Wiltshire, 2019)	Current	NECS	54.18	7.90	Phytoplankton	*Rhizosolenia setigera*	2015	1988.5	54	8	1	-10.22
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Rhizosolenia styliformis*	2016	1987	59	12	1	-2.31
(Volkov and Pozdnyakov, 2021)	Current	BPLR	73.00	125.00	Seabirds	*Rhodostethia rosea*	2013	1997.5	32	1	1	NA
(Byrd et al., 2008)	AR5	BERS	57.00	-169.00	Seabirds	*Rissa brevirostris*	2005	1990	31	4	1	-8.35
(Descamps et al., 2019)	Current	PSAW	52.35	-176.93	Seabirds	*Rissa brevirostris*	2015	2000	31	16	1	-0.44
(Descamps et al., 2019)	Current	ALSK	58.92	-152.17	Seabirds	*Rissa tridactyla*	2016	1999	35	16	0	0.04
(Byrd et al., 2008)	AR5	BERS	57.00	-169.00	Seabirds	*Rissa tridactyla*	2005	1990	31	4	1	-6.1
(Moe et al., 2009)	AR5	BPLR	78.90	12.22	Seabirds	*Rissa tridactyla*	2008	1989	39	2	0	1.3
(Frederiksen et al., 2004)	AR5	NECS	56.18	-2.55	Seabirds	*Rissa tridactyla*	2005	1990.75	22	3	0	4.81
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Sagitta* spp.	1994	1984	21	25	1	NA
(Otero et al., 2014)	Current	ARCT	65.75	-14.90	Fish	*Salmo salar*	2008	1998.5	20	3	1	NA
(Otero et al., 2014)	Current	BPLR	53.56	-56.35	Fish	*Salmo salar*	2008	1989	39	3	1	NA
(Kennedy and Crozier, 2010)	AR5	NECS	55.20	-6.53	Fish	*Salmo salar*	2007.611	1992.416	31	1	1	3.31
(Juanes et al., 2004)	AR5	NWCS	41.25	-72.35	Fish	*Salmo salar*	2000.162	1986.135	23	1	1	-7.9
(Otero et al., 2014)	Current	SARC	70.03	22.96	Fish	*Salmo salar*	2009	1998.5	23	3	1	NA

(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Salmo trutta*	2013	1986.5	54	30	0	NA
(Kovach et al., 2013)	Current	ALSK	58.38	-134.65	Fish	*Salvelinus malma*	2010	1995	31	2	1	-0.68
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Sardina pilchardus*	2013	1986.5	54	30	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Sardinops sagax*	2008	1979.5	58	43	1	-11.1
(Fitchett et al., 2019)	Current	EAFR	-29.85	31.02	Fish	*Sardinops sagax*	2012	1979.5	66	1	0	1.3
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Scomber japonicus*	2008	1979.5	58	43	1	-1
(Kanamori et al., 2019)	Current	KURO	35.00	141.00	Fish	*Scomber japonicus*	2017	1997.5	40	1	0	4.24
(Jansen and Gislason, 2011)	Current	NECS	56.95	11.30	Fish	*Scomber scombrus*	2010.5	1992	22	1	1	-23.4
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Scomber scombrus*	2014	1990.5	48	35	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Scophthalmus maximus*	2013	1986.5	54	30	0	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Scophthalmus rhombus*	2013	1986.5	54	30	0	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Scopthalmus aquosus*	2014	1990.5	48	35	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Sebastes aurora*	2008	1979.5	58	43	1	-5.4
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Sebastes diploproa*	2008	1979.5	58	43	1	-12.3
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Sebastes fasciatus*	2014	1990.5	48	35	1	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Sebastes goodei*	2008	1979.5	58	43	0	6.7
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Sebastes jordani*	2008	1979.5	58	43	1	-2.8
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Sebastes paucispinis*	2008	1979.5	58	43	0	1.6
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	Siphonophores	2012	2000	25	24	1	-2.4
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Skeletonema costatum*	2012	1986	45	49	0	-2.19
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Skeletonema marinoi*	2016	2004.5	24	29	1	-52.51
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	Small *Peridinium* spp.	2012	2000	25	24	1	-12.8
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Snowella* spp.	2016	2004.5	24	29	0	6.32
(Fincham et al., 2013)	Current	NECS	51.00	-4.75	Fish	*Solea solea*	2008.875	1992.125	27	1	1	-7.45
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Somateria mollissima*	2006	1988.5	36	7	1	0.19

(D'Alba et al., 2010)	AR5	SARC	64.02	-22.71	Seabirds	*Somateria mollissima*	2006	1991.5	30	1	1	-2.8
(Chambers et al., 2014)	Current	SANT	-44.04	65.22	Seabirds	*Spheniscus magellanicus*	2006	1994.5	24	4	0	NA
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Spioniden metatrocha*	1994	1984	21	25	0	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Sprattus sprattus*	2013	1986.5	54	30	0	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Squalus acanthias*	2014	1990.5	48	35	0	NA
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Stenobrachius leucopsarus*	2008	1979.5	58	43	1	-1.7
(Langan et al., 2021)	Current	NWCS	41.50	-71.40	Fish	*Stenotomus chrysops*	2016	1987.5	58	5	1	-2.1
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Sterna hirundo*	2006	1988.5	36	7	1	-0.45
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Sterna paradisaea*	2002	1976	36	7	1	-2.26
(Wanless et al., 2009)	AR5	NECS	56.18	-2.56	Seabirds	*Sterna sandvicensis*	2006	1988.5	36	7	1	-0.18
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Stomias atriventer*	2008	1979.5	58	43	0	1.2
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Phytoplankton	*Strombidium* spp.	2012	2000	25	24	1	-3.2
(Atkinson et al., 2015)	Current	NECS	50.25	-4.21	Holozooplankton	*Subeucalanus* spp.	2012	2000	25	24	0	2
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Symbolophorus californiensis*	2008	1979.5	58	43	1	-6.15
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Syngnathus acus*	2013	1986.5	54	30	1	NA
(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Synthliboramphus antiquus*	2015	2006	19	16	1	-0.21
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Tarletonbeania crenularis*	2008	1979.5	58	43	1	1.65
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Teleaulax* spp.	2016	2004.5	24	29	1	-45.2
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Holozooplankton	*Telonema subtile*	2016	2004.5	24	29	1	-35.06
(Greve et al., 1996)	Current	NECS	54.19	7.90	Holozooplankton	*Temora longicaudata*	1994	1984	21	25	1	NA
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Temora longicornis*	2006.666	1991.5	45	49	0	-3.17
(Appelqvist and Havenhand, 2016)	Current	NECS	58.25	11.35	Invertebrates	*Teredo navalis*	2006	1988.5	36	1	1	3.92
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Tetragonurus cuvieri*	2008	1979.5	58	43	0	3.5
(Wiltshire et al., 2010)	AR5	NECS	54.18	7.90	Phytoplankton	*Thalassionema nitzschoides*	2006	1984	45	1	1	NA
(Chivers et al., 2020)	Current	NECS	55.00	5.00	Phytoplankton	*Thalassionema nitzscioides*	2015.5	1987.75	59	12	1	1.33

(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Thalassiosira baltica*	2016	2004.5	24	29	1	-21.41
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Thalassiosira* spp.	2012	1986	45	49	0	-3.36
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Phytoplankton	*Thalassiothrix longissima*	2009	1983.5	45	49	1	-1.94
(Barbraud and Weimerskirch, 2006)	AR5	APLR	-66.66	140.00	Seabirds	*Thalassoica antarctica*	2004	1992	25	9	0	12.64
(Dufour et al., 2010)	AR5	NADR	46.00	-13.00	Fish	*Thunnus alalunga*	2009	1990.333	39	2	1	-2.77
(Dufour et al., 2010)	AR5	NADR	46.00	-13.00	Fish	*Thunnus thynnus*	2005	1993.833	25	2	1	-10
(Edwards and Richardson, 2004)	AR5	NECS	55.00	5.00	Holozooplankton	*Tomopteris* spp.	2002	1980	45	49	1	-4.19
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Trachurus symmetricus*	2008	1979.5	58	43	1	-6.7
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Triphoturus mexicanus*	2008	1979.5	58	43	1	-6.2
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Trisopterus luscus*	2013	1986.5	54	30	1	NA
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Trisopterus minutus*	2013	1986.5	54	30	1	NA
(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Uria aalge*	2015	1998.5	34	16	0	0.07
(Byrd et al., 2008)	AR5	BERS	57.00	-169.00	Seabirds	*Uria aalge*	2005	1990	31	4	0	1.3
(Schroeder et al., 2009)	AR5	CCAL	37.70	-123.00	Seabirds	*Uria aalge*	2006.666	1992.333	19	2	1	-2.4
(Frederiksen et al., 2004)	AR5	NECS	56.18	-2.55	Seabirds	*Uria aalge*	2005.6	1990.8	21	3	0	0.82
(Descamps et al., 2019)	Current	ALSK	54.18	-164.83	Seabirds	*Uria lomvia*	2016	1999	35	16	1	-0.31
(Byrd et al., 2008)	AR5	BERS	57.00	-169.00	Seabirds	*Uria lomvia*	2005	1990	31	4	0	2.36
(Gaston et al., 2005)	AR5	BPLR	74.04	-90.03	Seabirds	*Uria lomvia*	2003.5	1992.5	26	1	1	-2.5
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Urophycis chuss*	2014.666	1989.5	48	35	0	8.86
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Urophycis regia*	2014	1990.5	48	35	1	NA
(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Urophycis tenuis*	2014	1990.5	48	35	1	NA
(Cherry et al., 2013)	Current	BPLR	59.71	-85.25	Mammals	*Ursus maritimus*	2013.714	2001.285	19	1	1	-1.46
(Asch, 2015)	Current	CCAL	34.00	-122.00	Meroplankton	*Vinciguerria lucetia*	2008	1979.5	58	43	1	-5.6
(Forsblom et al., 2019)	Current	NECS	59.70	24.50	Phytoplankton	*Woronichinia* spp.	2016	2004.5	24	29	1	-13.92

(Henderson et al., 2017)	Current	NWCS	40.00	-71.00	Fish	*Zoarces americanus*	2015	1989	48	35	1	9.78
(van Walraven et al., 2017)	Current	NECS	53.57	6.94	Fish	*Zoarces viviparus*	2013	1986.5	54	30	1	NA

SM3.4 Section 3.5

Table SM3.2: Climate-sensitive human pathogens associated with an aquatic-system infection route. Mode, type of evidence and strength assessment of climate influence are based on Nichols et al. (2018). Acronyms: CA Cost analysis; CEO Circumstantial evidence only; CSS Cross sectional survey; EACI Ecological association between climate and infections; EACO Ecological association between climate and outbreaks; FTA Fault Tree Analysis; GAMTS Generalised additive model time series; GDSE Gastrointestinal and dermatological symptoms and exposure; HSM Hindsight suitability model; LR Literature review; MLM Multi-level modelling; MM Mathematical modelling; MMF Microbiological monitoring of flooding; MMO Microbiological monitoring of outbreaks; MMST Microbiological monitoring with salinity and temperature; NBM Negative binomial model; OI Outbreak investigation; PMCC pairwise-matched case-control study; PORA Post outbreak rainfall analysis; POTA Post outbreak temperature analysis; POWE Post outbreak water examination; RAI Review of animal infections; RCS Retrospective cohort study; RILO Rodent investigation linked to outbreak; RRM Rainfall runoff model; RSA Rainy season association; RSE Recreational swimming exposure; SA Spatial analysis; SCS Sporadic case series; SFA Seasonal factor analysis; TSAT Time series analysis of temperature; QMRA Quantitative microbial risk assessment; WMR Water microbiology and rainfall.

Pathogen	How Climate Might Affect Disease Occurrence	Strength of Evidence for Water-Related Infections	Type of Infection Route	Type of Study Linking Climate and Infection
Acanthamoeba	*A. polyphaga* linked to contact lens washing and hygiene is important. Infections linked to flooding (presumed contamination of potable water). Water contamination links.	Freshwater/Seawater – Strong	Waterborne	PMCC; LR
Adenovirus	Subgroups A–E cause upper respiratory infections, conjunctivitis, febrile illness, sore throat and swollen glands. The enteric subgroup F adenoviruses Ad40 and Ad41 cause gastroenteritis in children. Contamination of groundwater used as a drinking water source and from faecal or respiratory contamination of untreated recreational waters. Swimming pool outbreaks.	Freshwater/Seawater – Moderate	Waterborne	POWE; OI
Astrovirus	Astroviruses cause diarrhoea in children under five years old. Viruses are excreted in faeces, and they will be present in sewage. Contact with contaminated recreational waters may be a risk factor. Outbreaks are often mixed. Outbreak linked to flood water contamination of shellfish with several viruses.	Freshwater/Seawater – Weak	Waterborne	POWE

Campylobacter spp.	The commonest bacterial cause of diarrhoea. Most infections are sporadic, but waterborne outbreaks linked to camp sites, travelling abroad, hospitals and large communities. Infection is commonly derived from contaminated poultry and water for the chicken flocks may be one source of contamination. Campylobacter spp. are spiral/curved organisms when isolated from patients and change to a more resistant coccal stage when present in water. Most human infections are caused by *C. jejuni, C. coli* and *C. lari. Campylobacter fetus* subsp. fetus can cause human infections, with septicaemia and gall bladder infection being more common than with the other species. *C. upsaliensis, C. hyointestinalis* subsp. *lawsonii* and *C. hyointestinalis* subsp. *hyointestinalis* are occasionally isolated from diarrheal patients. Infection through contaminated drinking water—heavy rainfall.	Freshwater/Seawater – Strong, outbreaks represent a small percentage of cases	Waterborne	PORA; EACI
Cryptosporidium	Cause diarrhea in young mammals and in humans but cannot grow in the environment. Large waterborne outbreaks have been reported throughout the world. Oocysts are excreted in faeces and sewage. Many species (*C. hominis, C. parvum, C. meleagridis, C. cuniculus, C. ubiquitum, C. viatorum, C. canis, C. felis, C. suis, C. scrofarum, C. bovis*, and *C. muris*) and genotypes of *C. parvum*) can cause human disease. Rainfall can contribute to drinking water contamination from both human and animal faeces.	Freshwater/seawater – Strong	Waterborne	SA; SFA; OI; POWE; FTA; RSA
Cyanobacteria spp.	Grow as blooms or mats, mostly within freshwater bodies. There are a large variety of species, many producing potent toxins that can cause acute and chronic disease in mammals, including man. The toxins include microcystins, nodularins, anatoxins, Saxitoxins, aplysiatoxins, cylindrospremopsins, beta-methyl-amino-L-alanine (BMAA) and lipopolysaccharides. Algal blooms are more commonly found in eutrophic (eutrophic waters have a high concentration of nutrients) inland waters. Human health risks arise if the water is consumed untreated, if people bathe or participate in water contact sports in waters with a scum or heavy bloom and if contaminated water is used in renal dialysis. There have been some notable outbreaks associated with cyanobacterial toxins with a high mortality rate in dialysis patients. There are also associations between exposure to cyanobacterial toxins and long-term health risks including cancer. The risks from BMAA linked to neurological disease are unclear. Climate influence on algal blooms. Human recreational and drinking water exposures.	Freshwater/seawater – Strong for outbreaks linked to peritoneal dialysis	Water toxicosis	CEO

Cyanobacteria—Microcystis spp.	*M. aeruginosa* is a common cyanobacteria found in eutrophic waters. It can cause hepatic failure and diarrhoea in man and other animals. An association was found between drinking water from a reservoir contaminated with *M. aeruginosa* and raised liver enzymes in a population in New South Wales, Australia. Other toxic species include *M. viridis* and *M. botrys*.	Freshwater – Strong	Water toxicosis	GDSE
Dinoflagellates and diatoms	These are protozoan organisms that can produce a range of potent toxins. They occur predominantly in saltwater and, under the right conditions, can produce blooms that cause 'red tides' that can cause toxic effects in fish and other sea-life. The toxins can accumulate within shellfish, causing paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), Amnesic Shellfish Poisoning (ASP). Some of the toxins can also accumulate through passing up the food chain to give carnivorous fish that are toxic (ciguatera toxin). Coastal blooms causing respiratory symptoms, ciguatera and shellfish poisoning. Blooms of dinoflagellates are linked to weather and nutrients.	Freshwater/seawater – Strong	Toxin contamination of marine foods	CEO
Dracunculus medinensis	*Dracunculus medinensis* life cycle involves the water flea Cyclops. It is the cause of dracontiasis. Human infection results from the consumption of water contaminated with infected water fleas. The adult worm emerges on the foot or leg, and rhabditoid larvae are released into the water where they re-infect water fleas. There is a WHO-led worldwide programme to eradicate Guinea Worm. Rainfall contamination of source waters. Infection is associated with water scarcity and the start of the rainy season.	Freshwater – Strong	Waterborne	RSA
Enteroviruses	Gross contamination of drinking water leading to enterovirus outbreaks.	Freshwater/Seawater – Moderate	Waterborne	OI; QMRA
Escherichia coli—Shiga cytotoxigenic	Infection through contaminated drinking water—heavy rainfall.	Freshwater/Seawater – Strong	Waterborne	CA; OI
Fasciola hepatica	A liver fluke (helminth) that is common in herbivores that graze in wet pasture. The parasite requires a snail as an intermediate host, and man is occasionally infected through the consumption of aquatic plants, particularly watercress, contaminated with the metacercaria.	Freshwater – Strong	Water based	RAI

Giardia spp.	Grows attached to the small intestinal lining and causes malabsorption in people. The parasite can be isolated from the faeces of wild and domestic animals, and waterborne outbreaks are usually associated with recreational water use. The parasite cyst, which is found in faeces, is moderately resistant to chlorine. The modes of transmission remain unclear. Giardia can be transmitted through recreational and drinking water, although hygiene is also important.	Freshwater/Seawater – Strong	Waterborne	CSS
Hepatitis A	Hepatitis A virus causes hepatitis and can be acquired person-to-person, through contaminated water, shellfish, and foods eaten raw or washed in contaminated water and waterborne routes. Infection resulting from sewage contamination of source waters and shellfish. Some rainfall associations.	Freshwater/Seawater – Strong	Waterborne	PORA; SFA
Hepatitis E	Hepatitis E virus has a genome of single stranded RNA. Epidemiological evidence suggests that the disease can be transmitted by drinking water contaminated with faeces or contact with an environment contaminated with faeces. Pigs may be an important reservoir of infection. Infections in the UK are associated with overseas travel. Large waterborne outbreaks.	Freshwater/Seawater – Strong	Waterborne	OI
Leptospira spp.	Tightly coiled spiral bacteria that cause Weil's Disease (jaundice) in people. Infection is from rodents and agricultural and domestic animals, usually through exposure to contaminated water or urine. Drinking or exposing wounds or mucous membranes to contaminated water can result in infection. Infection through natural water contaminated by rodent urine and occasionally through non chlorinated drinking water. Outbreaks follow heavy rainfall and flooding and occasionally abnormally low rainfall.	Freshwater – Strong	Waterborne	OI; RILO; SA; RCS; NBM; CSS
Microsporidia	*Enterocytozoon bieneusi* infection is linked to transmission through food and water. Encephalitozoon hellem keratoconjunctivitis possibly related to water or mud. Link to rainy season in Singapore.	Freshwater/Seawater – Weak	Waterborne	RSA
Naegleria fowleri	Colonises thermally polluted waters. Infections in the Southern US are seasonal, with more in the summer. Infections in cattle are also seasonal. Infections may increase in some countries with warmer temperatures. Runoff from heavy rains introduces this organism into lakes, ponds, and surface waters.	Freshwater – Strong, links to water contamination	Waterborne	SCS
Norovirus	Is mostly transmitted person-to-person. Transmission has also been indicated via contaminated ice, stored water on cruise ships, borehole water and contaminated recreational bathing waters. Municipal drinking water supplies have been implicated in outbreaks of gastroenteritis, usually following contamination by	Freshwater/Seawater – Strong	Waterborne	OI

	sewage. Strongly seasonal. Link to shellfish contaminated from infected faeces. Coastal water contamination linked to rainfall.			
Rotavirus	Rotavirus. Rotaviruses are part of the Reovirus family and have a double stranded RNA genome. Exposure is by contact with infected individuals or contaminated water or other materials. Group C rotaviruses have been identified throughout the world. Group B rotaviruses have caused large outbreaks of diarrheal illness in mainland China. The virus entered the population as a result of faecal contamination of water supplies drawn from rivers, and then spread through the population by person-to-person contact. Waterborne outbreaks in developing countries.	Freshwater/Seawater – Weak	Waterborne	
Sapovirus	A calicivirus, formerly called “Sapporo-like virus” (SLV), is a classic or typical calicivirus and is associated with relatively mild gastroenteritis in children. Outbreak linked to flood water contamination of shellfish with several viruses.	Freshwater – Weak	Unknown	POWE
Schistosoma spp.	These are flukes (helminth) which are transmitted through the contamination of water with faeces containing the ova. Cases linked to flooding and land surface temperature.	Freshwater – Strong	Water based	OI; SA; RRM; MM; MLM
Schistosoma japonicum	Infection is found in Eastern Asia including Japan and Korea. Links to rainfall and temperature.	Freshwater – Strong	Water based	CSS
Schistosoma mansoni	The life cycle involves the ova hatching and infecting specific snail species, and the cercaria infect people occupationally or recreationally exposed to contaminated water through the skin.	Freshwater – Strong	Water based	OI; SA
Toxoplasma gondii	A protozoan parasite which occurs in a wide range of warm-blooded animals. The only definitive host in which the full sexual cycle has been observed is members of the cat family (Felidae), which excrete the oocysts which contaminate the environment and source waters. People can be infected from consuming food or water that is contaminated with oocysts or the consumption of undercooked meat which contains tissue cysts. Infection can be a particular problem for pregnant women and immunocompromised patients. Some evidence that heavy rainfall can precede outbreaks.	Freshwater/Seawater – Strong	Waterborne	OI; SA
Vibrio cholerae	Causes cholera, a disease that is characterised by acute and life-threatening diarrhoea and dehydration usually in epidemic outbreaks. Cholera is transmitted through drinking water, shellfish and contaminated food. The disease is usually restricted to less developed countries where drinking water and waste disposal are poor, and to migrant populations associated with drought, flood, famine and war. Evidence of links to rainfall over the last century.	Freshwater/Seawater – Strong	Waterborne	GAMTS; EACO; POWE

Vibrio parahaemolyticus	Inhabits estuarine and marine environments. It can cause food-poisoning through the contamination of seafood. *V. parahaemolyticus* associated with raised water temperature.	Seawater – Moderate	Foodborne through seafood	RSE
Vibrio vulnificus	*Vibrio vulnificus* can cause severe, soft tissue infections, septicaemia, and deaths. Infection is through the consumption of contaminated seafood (particularly raw oysters). *V. vulnificus* infection increased following hurricane Katrina.	Seawater – Strong	Waterborne; Foodborne through seafood	MMF; HSM; MMST; OI
Vibrio spp. (other than V. cholerae)	A variety of *Vibrio* spp. can cause human disease, including the halophilic *V. parahaemolyticus, V. fluvialis, V. hollisae* and the non-halophilic vibrios non-O1 *V. cholerae* and *V. mimicus*. Cholera is a classical waterborne disease, and the water route is still important in developing countries. There is no evidence that vibrios are able to cause human disease by growing within water distribution systems. *Vibrio* spp. are part of normal marine flora and can be found in marine, estuarine and river water. These organisms proliferate during the summer months. People are infected through the consumption of raw or undercooked contaminated shellfish, other foods and faecally contaminated water. A large infective dose is required to initiate infection and person-to-person transmission does not occur. Infections in the United Kingdom tend to be in travellers returning from developing countries. Non-cholera *V. cholera* in warmer Baltic waters.	Freshwater (*V. cholerae*)/Seawater (*Vibrio spp.* including *V. cholerae*) – Strong	Waterborne	MMO; OI; TSAT; WMR; POTA

SM3.5 Section 3.6

SM3.5.1 Assessment of the Potential of Marine and Coastal Adaptation Solutions

The below text supports Figure 3.23 and Tables 3.28, 3.29 and 3.30 in Section 3.6.2.

SM3.5.1.1 Socio-Institutional Adaptation

Knowledge diversity. There is *high agreement* that successful ocean and coastal adaptation needs to incorporate the diversity of knowledge systems, moving beyond technical and scientific knowledge to also incorporate Indigenous Knowledge (IK) and Local Knowledge (LK) (Norström et al., 2020; Petzold et al., 2020; Gianelli et al., 2021; Schlingmann et al., 2021). Knowledge diversity guarantees an enriching understanding of ecological, technical, and political aspects of adaptation (Norström et al., 2020) while conciliating nature world views (Coscieme et al., 2020). Considering IK and LK systems is more beneficial for the communities (*high confidence*) (Nalau et al., 2018; Sultana et al., 2019; Owen, 2020; Gianelli et al., 2021), increases their resilience (*robust evidence*) (Ford et al., 2020), and is relevant and transferable beyond the local scale (*medium evidence*) (Schlingmann et al., 2021). Implementing knowledge diversity in marine and coastal systems adaptation ranges from ecotourism (Section 3.6.3.1.3) to conservation (Section 3.6.3.2.1) and from small island developing states (SIDS) to the Arctic (Section 3.6.3.4.1).

Socially inclusive policies. Socially inclusive policies that promote participation of all groups are able to address existing vulnerabilities in coastal communities, and promote adaptation and transformational change (*high agreement, low evidence*) (Brodie Rudolph et al., 2020; Ford et al., 2020; Friedman et al., 2020). Examples are described in Sections 3.6.3.4.1 and 3.6.3.4.2.

Participation. Participation in decision making and adaptation processes is recommended across a range of different hazards and contexts (Brodie Rudolph et al., 2020; Claudet et al., 2020; Sumaila et al., 2021), and has the potential to improve adaptation outcomes (*medium confidence*) (Hügel and Davies, 2020). Section 3.6.3 shows some examples of participation for fisheries and mariculture (Section 3.6.3.1.2), and in Indigenous communities (Section 3.6.3.4.1).

Livelihood diversification. Diversification of livelihoods is a common response strategy in coastal communities exposed to climate impacts such as coastal flooding, ocean extreme events, and changes in abundance and diversity of marine resources for food or income (*high confidence*) (Mohamed Shaffril et al., 2020; Owen, 2020; Biswas and Mallick, 2021). Livelihood diversification entails a transformative change (Barnes et al., 2020; Biswas and Mallick, 2021), where dependence on marine systems is alleviated by engaging in additional sources of income, formally or informally, temporarily or permanently. Evidence shows that livelihood diversification in marine and coastal systems dependent communities reduces climate risks (Mohamed Shaffril et al., 2020; Owen, 2020; Pinsky, 2021), and confers flexibility to individuals which is key for adaptive capacity (*medium evidence*) (Blanchard et al., 2017; Cinner and Barnes, 2019; Taylor et al., 2021). However, diversification depends on the agency of the individuals and existing vulnerabilities and inequities can cause diversification to result in maladaptation outcomes (high agreement) (Cinner and Barnes, 2019; Ford et al., 2020; Ojea et al., 2020). Therefore we assess with *medium confidence* the ability of livelihood diversification alone to address the impacts of climate change in coastal communities. Livelihood diversification as a response to climate change is further assessed in fisheries and mariculture (Section 3.6.3.1.2), coastal communities (Cross-Chapter Box SLR in Chapter 3), and tourism (Section 3.6.3.1.3).

Mobility. Mobility of coastal livelihoods is a common practice in many regions of the world, such as the Pacific Islands (Chapter 15), that has been reported as a response to climate change impacts such as coastal flooding and extreme events. When individuals are given the choice about mobility, they use this response in order to minimise climate risks and benefit their livelihoods (*medium evidence*) (Barnett and McMichael, 2018). An example of mobility includes fishing (Section 3.6.3.1.2).

Migration. Coastal livelihoods facing severe climate change impacts often respond with migration, as a critical livelihood diversification strategy (Maharjan et al., 2020; Biswas and Mallick, 2021; Zickgraf, 2021). Migration often involves different spatiotemporal scales than mobility (Barnett and McMichael, 2018), and it could be considered an adaptation solution for some coastal and island populations in the cases of extreme events, but also as a response to more gradual changes (e.g., coastal erosion from SLR, Zickgraf, 2021). There is *low confidence* that migration alone can be a resilient response to climate change impacts in ocean and coastal systems (Section 3.6.3.1.1). The maladaptive outcomes of mobility and migration (and relocation, Section 3.6.3.1.1) are influenced by the mobility of vulnerable groups, the regions where the displacement occurs and the capacities that these individuals possess (Dandy et al., 2019; Maharjan et al., 2020). Examples of migration include island dwellers (Section 3.6.3.1.1).

Finance and market mechanisms. Financial mechanisms and credit provision for marine-dependent livelihoods are effective for overcoming impacts from SLR (Hinkel et al., 2018; Moser et al., 2019; Woodruff et al., 2020) and extreme events (*medium evidence*) (Shaffril et al., 2017; Dunstan et al., 2018; Sainz et al., 2019). Market mechanisms include payment for ecosystem services that can directly or indirectly, through mitigation, contribute to adaptation outcomes in marine and coastal systems (Cross-Chapter Box NATURAL in Chapter 2, Himes-Cornell et al., 2018; Brathwaite et al., 2021). There is *high confidence* in the potential of improved financial and market mechanisms for ocean adaptation, as they are key for transitioning into future ocean sustainability (Chapter 18, Sumaila et al., 2021). Examples of implementation of finance and economic mechanisms are further assessed in Section 3.6.3.4.2.

Disaster response programs. In the occurrence of coastal and ocean extreme events, coastal communities and marine dependent livelihoods can respond following existing disaster response programs, which confer resilience to communities and contribute to adaptation when designed to be inclusive, participatory and adaptive (*high confidence*) (Nurhidayah and McIlgorm, 2019). Disaster response programs need adequate finance that combines viable economic investments and risk financing instruments (Jongman, 2018). Recent evidence suggests that the analysis and understanding of communications data during disaster responses is key to avoid maladaptation outcomes (*high agreement*) (Nichols et al., 2019). Disaster response programs can be implemented with climate services (Section 3.6.3.4.3), and examples include the tourism cruise ship sector (Section 3.6.3.1.3).

Multi-level ocean governance. The multi-scale nature of ocean and coastal climate change risk demands adaptation solutions at multiple levels of governance (*high confidence*) (Miller et al., 2018; Gilfillan, 2019; Holsman et al., 2019; Obura et al., 2021), which consider the objectives and perceptions of all stakeholders to support local implementation of broad strategies (Miller et al., 2018). However, current ocean governance is complex and fragmented (Scobie, 2019b; Haas et al., 2021), and faces challenges that intersect with climate adaptation. Therefore, there is *high agreement* in the need to transition into multi-level governance to respond to the challenges of climate change in the oceans (Chapter 18, Haas et al., 2021).

Institutional transboundary agreements. At the international level, institutional agreements for the management of transboundary marine resources are key for a sustainable future given current impacts on marine species distribution due to climate change (*high agreement*) (Mason et al., 2020; Melbourne-Thomas et al., 2021). Existing climate adaptive transboundary agreements are scarce (Melbourne-Thomas et al., 2021; Sumby et al., 2021) and need to be re-designed in order to address the challenges of climate-induced marine species distributional changes (*medium confidence*) (Engler, 2020; Oremus et al., 2020). Despite the need for new instruments, adhering to existing ocean conservation and resource management international agreements contributes to sustainable ocean futures and climate change adaptation (Haas et al., 2021). Examples are implemented in fisheries (Section 3.6.3.1.2, Cross-Chapter Box MOVING SPECIES in Chapter 5).

SM3.5.1.2 Built Infrastructure and Technology

Accommodation and relocation. Asset accommodation and relocation in the marine and coastal environment is amongst the most commonly discussed adaptations to climate hazards such as SLR and coastal extreme events (Hanson and Nicholls, 2020; Monios and Wilmsmeier, 2020). Planned relocation is a response to extreme events and SLR in coastal regions and it has the advantage of maintaining community and social structures (Zickgraf, 2021), but can lead to maladaptation in cases where individuals are not included in decision making and where no monitoring exists (Zickgraf, 2021). While there is *high confidence* that relocation reduces coastal risk, there are important social and economic costs linked to such interventions (Cross-Chapter Box SLR in Chapter 3) and they require transformative changes in the longer run (Magnan et al., 2020).

Protection and beach and shore nourishment. As an alternative to hard structures, a common response to beach erosion around the world is beach nourishment (Barbier, 2014; Oppenheimer et al., 2019; Pinto et al., 2020; Toimil et al., 2020; Elko et al., 2021). This practice involves supplementing existing beach sediments with sediment sourced from adjacent ecosystems. Part of the appeal of beach nourishment is that it provides relatively rapid results, but it invariably also entails poorly quantified trade-offs between efficacy, long-term cost, utility to beach users and ecological damage (de Schipper et al., 2021). Protection with seawalls and beach and shore nourishment constrains the development of ecosystem-based adaptation and the associated co-benefits, and can have negative consequences on coastal ecosystems (Sections 3.4.2.4 –3.4.2.6, Cross-Chapter Box SLR in Chapter 3). However, protection may be a feasible alternative for densely populated and urbanized coastal areas (Barnard et al., 2021; Neijnens et al., 2021). Therefore, there is *medium confidence* on the ability of protection with beach and shore nourishment to reduce climate change impacts in coastal systems. Combined solutions, including soft or nature-based infrastructure (Section 3.6.2.3) and socio-institutional approaches (Section 3.6.2.2) achieve better outcomes when implemented together (Cross-Chapter Box SLR in Chapter 3, Gattuso et al., 2018; Foti et al., 2020; Reguero et al., 2020; Seddon et al., 2020). Examples of implementation of these solutions are further assessed in Section 3.6.3.1.1.

Early-warning systems. AR5 and SROCC mention that early-warning systems can support decision-making, decrease economic losses from extreme events, and aid in the enterprises and development of adaptive management systems for coastal systems and fisheries (Hoegh-Guldberg et al., 2014; Bindoff et al., 2019; Collins et al., 2019). Such systems have potential risks in the form of erroneous forecasts, resulting in unintended consequences (e.g., forecast leading to increased exploitation of a resource or, decrease in tourism) and exacerbation of inequality due to geographical unevenness of development and access (Section 3.6.3.2.4, Soares et al., 2018). Early-warning systems may also be at risk of disruption by non-climate events, as demonstrated by the recent interruptions of maintenance and monitoring of ocean and coastal observing systems owing to COVID-19 (Northrop et al., 2020).

Seasonal and dynamic forecasts. Rapid expansion of hindcast data, remote-sensing data, and computational power have led to the proliferation of real-time and seasonal forecasts of temperature extremes, MHWs and their impacts (Liu et al., 2018; Holbrook et al., 2020; Spillman and Smith, 2021), storm surges and wave-driven flooding (Fernández-Montblanc et al., 2019; Winter et al., 2020), water quality and HABs (Bever et al., 2021; Davidson et al., 2021), and the distribution of living marine resources (Payne et al., 2017; Tommasi et al., 2017; Hazen et al., 2018). These tools have the capacity to contribute to monitoring, early warning systems, adaptive management and ecosystem-based management, as improvements in the spatial scale for management are being reached (*high confidence*) (Tommasi et al., 2017). There is *high confidence* that capacity-building and broad engagement of stakeholders from communities, governments and industries is critical to creating early-warning systems with forecasts that can be properly interpreted by users and be effectively incorporated into monitoring, management and decision-making (Section 3.6.3.2.4).

Monitoring. Monitoring systems that address both climate change hazards, ecosystem impacts and social vulnerabilities in marine social-ecological systems, are a key priority for adaptation to climate hazards in coastal areas (*high agreement*) (Nichols et al., 2019; Claudet et al., 2020; Wilson et al., 2020). For ocean extreme events, specific event-based monitoring can help managers and stakeholders in decision making in real time (Holbrook et al., 2020). Monitoring and detection of marine species range shifts is key to adaptation (Melbourne-Thomas et al., 2021). However, monitoring efforts and costs differ across regions, where the most remote ocean systems regularly lack such actions (Claudet et al., 2020), and where there is a lack of standardized methods and open access information in global terms (Rilov et al., 2020; A. Maureaud et al., 2021; Melbourne-Thomas et al., 2021), therefore, there is *medium confidence* on the potential of monitoring systems alone in supporting adaptation in marine and ocean systems. Examples of implemented monitoring systems are shown for MPAs (Section 3.6.3.2.1), climate services (Section 3.6.3.2.4) and fisheries (Section 3.6.3.1.2).

Ecological interventions: habitat development, active restoration, and assisted evolution. The near-term nature of climate risk to coastal systems has led to increased research and investment in technological interventions to support and enhance species' and ecosystems' capacity to adapt to climate change (Jones et al., 2018; Boström-Einarsson et al., 2020; Kleypas et al., 2021). Unlike traditional marine conservation ('passive') approaches (Section 3.6.2.3), which aim to allow ecosystems to naturally recover from disturbance, ecological interventions and engineering approaches aim to accelerate recovery of damaged systems and promote ecological or biological adaptation to future climate change (Jones et al., 2018; Kleypas et al., 2021). Artificial habitat development, for example, has the potential to stabilize shorelines and increase fisheries productivity in rocky reef systems (Gilby et al., 2018). Active restoration involves reintroducing species or augments existing populations, for example, propagating and transplanting heat-tolerant coral species (Boström-Einarsson et al., 2020; Rinkevich, 2021). More controversial interventions like assisted evolution, in which genes are manipulated to accelerate natural selection, has been investigated for corals (National Academies of Sciences, 2019), kelp (Morris et al., 2020) and other habitat-forming species (Bulleri et al., 2018). The effectiveness and feasibility of these solutions are further assessed for existing restoration efforts in Section 3.6.3.2.2.

SM3.5.1.3 Marine and Coastal Nature-Based Solutions

Habitat restoration. Marine habitat restoration increases biodiversity (*high confidence*) (McLeod et al., 2019), and protects shorelines and coastal livelihoods from climate oceanic hazards in the near term (*high confidence*) (Colls et al., 2009; Arkema et al., 2017; Espeland and Kettenring, 2018; McLeod et al., 2019). To date, restoration efforts have predominantly focused on typically productive coastal habitats, including coral reefs, seagrasses, mangroves, saltmarshes, oyster reefs and kelp forests (Bayraktarov et al., 2016; Espeland and Kettenring, 2018; Gilby et al., 2018; Reguero et al., 2018; McLeod et al., 2019; Duarte et al., 2020a) that provide critical nursery or foraging habitats for commercially or culturally important species. Although habitat restoration can enhance fish-stock production (Ermgassen et al., 2016; McLeod et al., 2019), bring socio-cultural benefits by promoting stewardship and community involvement (Hein et al., 2019), and benefit recreational use and tourism (Section 3.6.3.2, Weatherdon et al., 2016; Hoegh-Guldberg et al., 2018; Agyeman, 2019), there is *limited evidence* that it can safeguard fish-stock production in future climate conditions (McLeod et al., 2019) or restore coastal habitats after conversion to alternate states (Sections 3.4.2.1, 3.4.2.3, 3.6.2.3, Hein et al., 2017; Fox et al., 2019; Hein et al., 2021). There is also substantial evidence that simply restoring habitats to mid-20th century states will not enable them to persist in the medium term, without substantial emissions reductions (*medium to high confidence*) (Sections 3.4.2.1, 3.4.2.3, 3.4.2.5, 3.4.2.6), because benefits are challenging to quantify and include time-delayed responses associated with the rebuilding of biological communities (McLeod et al., 2019). Finally, habitat restoration can limit loss of ecosystem services related to recreational use and traditional tourism (*medium confidence*) (Weatherdon et al., 2016; Hoegh-Guldberg et al., 2018) while benefiting ecotourism (Agyeman, 2019). See an assessment of implemented restoration efforts in marine systems in Section 3.6.3.2.2.

Marine protected areas and OECMs. Marine Protected Areas (MPAs) are the most widely implemented approach to conserving marine biodiversity and have long provided the foundation for initiatives at local to international scales (Rilov et al., 2020; Arafeh-Dalmau et al., 2021). MPAs and networks of MPAs that are well designed and enforced provide well-known conservation and socio-cultural benefits to people, because they protect biodiversity and ecosystem functioning that support delivery of important ecosystem services including food supply, recreation, scenic beauty and water regulation (Section 3.5, Edgar et al., 2014; Gill et al., 2017; Wilson et al., 2020; Ovando et al., 2021; Sala et al., 2021). However, the effectiveness of current MPA networks to assist in climate-change adaptation is equivocal (Tittensor et al., 2019; Wilson et al., 2020), as climate change impacts are rarely incorporated in management (*high confidence*) (Section 3.6.3.2.1, Rilov et al., 2020; Arafeh-Dalmau et al., 2021). If carefully designed to address climate change, strategically placed and well enforced, they hold great potential to deliver better adaptation outcomes (*high confidence*) (e.g., Queirós et al., 2016; Roberts et al., 2017; Maxwell et al., 2020a; Arafeh-Dalmau et al., 2021; Sala et al., 2021). An additional spatial conservation instrument that contributes to ocean protection and adaptation of coastal livelihoods are the Other Effective area-based Conservation Measures (OECMs) (Gurney et al., 2021). These are areas managed by ocean-dependent communities that are recognized for the contribution of such management and interaction to marine conservation (Maxwell et al., 2020b; Gurney et al., 2021). Recognizing these areas can benefit adaptation through the increased ecological and social resilience that such management regimes confer (Section 3.6.3.2.1).

Conservation of climate refugia. Marine regions that retain climate and biodiversity conditions for longer periods of time under climate change impacts are considered climate refugia (Wilson et al., 2020; Arafeh-Dalmau et al., 2021). There is *low evidence* but *high agreement* (*medium confidence*) that protecting these areas can increase the resilience of marine ecosystems in the face of ocean warming and MHW, (Rilov et al., 2020; Arafeh-Dalmau et al., 2021), facilitate marine species shifts (Cross-Chapter Box MOVING SPECIES in Chapter 5, Wilson et al., 2020) and help avoid species extinctions and extirpations. But it is not recommended as the only climate adaptation solution for marine conservation (Tittensor et al., 2019; Wilson et al., 2020). Recent evidence points that the selection of marine climate refugia areas needs to be guided by both socioeconomic criteria and broadly applicable climate-change metrics such as climate velocity (Brito-Morales et al., 2018; Arafeh-Dalmau et al., 2021).

Transboundary MSP and ICZM. Marine spatial Planning (MSP) is an often participatory process to allocate spatial and temporal distribution of human uses in the ocean, with the aim to reduce conflicts and reach sustainability (Gissi et al., 2019; Frazão Santos et al., 2020). After several decades of development of MSP initiatives and MSP processes in more than half of EEZs, 25 countries have already implemented or have government approved plans, most of them in economically developed nations (Frazão Santos et al., 2020). The potential of MSP to incorporate adaptation goals is important but limited so far by the lack of consideration of climate change in the plans (*robust evidence*) (Gissi et al., 2019; Frazão Santos et al., 2020), and the lack of consideration of socio-cultural goals (Pennino et al., 2021). MSP that incorporates climate change impacts and adaptation in the design can contribute to support climate adaptation from a multi-sector perspective and through existing policy frameworks (*low evidence*) (Tittensor et al., 2019; Frazão Santos et al., 2020; Rilov et al., 2020). However, climate resilient MSP would require a transformation in current policy systems, as plans would need to be dynamic and incorporate new jurisdictions, climatic predictions and novel expertise (Frazão Santos et al., 2020; Pennino et al., 2021). In this context, Transboundary Marine Spatial Planning (TMSP), a process of international cooperation in the marine space to resolve conflicts across nations (Li and Jay, 2020) holds promise to adapt to the shifting nature of climate change impacts in the oceans, ad make MSP robust to climate change impacts (Pinsky et al., 2021). Integrated Coastal Zone Management (ICZM or ICM) differs from MSP in that it focuses on the land-sea interface (Frazão Santos et al., 2020). Recent evidence supports the need to integrate disaster response programs and adaptation goals in ICZM (*low evidence*) (Rosendo et al., 2018), and to overcome the existing implementation challenges for governments to be able to use ICZM for climate change adaptation (Rosendo et al., 2018). Examples of MSP and ICZM implementation are further assessed in Section 3.6.3.1.3 (tourism) and Section 3.6.3.2.1 (conservation).

Sustainable Harvesting. Harvesting marine resources at rates that are ecologically sustainable increases the resilience of marine systems to climate change, while providing important ecosystem services to marine dependent communities (Chapter 5). Sustainable harvesting is recognized as a nature-based solution that contributes to adaptation by safeguarding the provision of marine food services (Section 3.5.3), related cultural services (Section 3.5.6) and food security, while reducing marine systems ecological vulnerability (*high confidence*) (Gattuso et al., 2018; Burden and Fujita, 2019; Duarte et al., 2020a). Further assessment is performed for fisheries and mariculture practices (Section 3.6.3.1.2).

Climate adaptive management. Climate adaptive management of ocean and coastal resources allows to iteratively update management with climate knowledge and information available for the system, with observed and projected changes in the environment and with the experience of "learning by doing" (Rilov et al., 2020; Wilson et al., 2020). There is *high agreement* on the need to incorporate climate adaptive management in marine resources in order to adapt to the impacts of species distribution (Cross-Chapter Box MOVING SPECIES in Chapter 5, Wilson et al., 2020; Melbourne-Thomas et al., 2021) and other climate change multiple hazards (Rilov et al., 2019). There are examples of implementation of adaptive management in many contexts such as MPAs (Nickols et al., 2019), fisheries management, mangroves (Sections 3.6.3.1.2, 3.6.3.2.1, 3.6.3.2.2, Ellison et al., 2020).

Ecosystem-based management. Ecosystem-based management is an approach to manage ocean and coastal systems that focuses on the habitats and ecosystems as management units, where initiatives can follow a set of key principles (Long et al., 2015). It incorporates many of the above-mentioned tools and processes (Harvey et al., 2018), such as participatory processes; conservation tools, MSP and ICZM, adaptive management and sustainable harvesting, among others. By incorporating climate adaptive measures and focusing on the ecosystems, this approach benefits the adaptation of marine ecosystems and supports the provision of ecosystem services under climate change (*high confidence*) (Fernandino et al., 2018; Lowerre-Barbieri et al., 2019). When developing nature-based adaptation measures, there is an increase in the ecosystem resilience and a decrease socio-economic vulnerability to climate change (Miller et al., 2018;

Holsman et al., 2019; McLeod et al., 2019; Seddon et al., 2020). An increasing number of vulnerability and risk assessments of climate change and impacts of multiple stressors on species, habitats and natural communities (e.g., Holsman et al., 2017; Pinsky et al., 2019; Samhouri et al., 2019; Gissi et al., 2021), on ecosystem services (Kurniawan et al., 2016; Stewart-Sinclair et al., 2020a), and on associated vulnerabilities and risks to social systems (Gaichas et al., 2018; Thiault et al., 2019) support the development of NbS for adaptation.

EBA Hotspots. Mangroves and coral reefs have been identified as EbA hotspots (Figure 3.25) because they line shores that are highly vulnerable to tropical storms and SLR, and they protect at least 5.3 and 3.4 million people living within 2 km of the coast, respectively (Section 3.4.2.5, Cross-Chapter Box SLR in Chapter 3, Jones et al., 2020; Menéndez et al., 2020; Van Coppenolle and Temmerman, 2020). At least 38% of mangroves that intersect with EbA hotspots are under some level of protection (Jones et al., 2020), which is especially important considering recent analyses, which show global yearly emissions of 23.5–38.7 Tg yr^{-1} due to losses of mangroves (Ouyang and Lee, 2020). Greater levels of protection would improve the potential of these EbA, especially in countries with low adaptive capacity (Friess et al., 2019), and this potential could be further enhanced by incorporating mangrove restoration (Jones et al., 2020; Menéndez et al., 2020).

Table SM3.3: Background materials and data for Figure 3.23 and 3.24. Includes levels of feasibility and effectiveness in Figures 3.23 and 3.24. Includes the full Feasibility assessment in Figure 3.24.

Adaptation Solution	Technical & Economic Feasibility	Supporting references Technical & Economic	Institutional and Geophysical Feasibility	Supporting references Institutional and Geophysical	Socio-Ecological Feasibility	Supporting references Socio-Ecological Feasibility	Feasibility (general)	Effectiveness	Supporting references Effectiveness
Knowledge diversity	High - Incorporation of various knowledge systems is at the early stages of implementation but is transversal to other systems and sectors (i.e. Agriculture, biodiversity conservation, etc.). it is in the phase of adaptation planning and early implementation. There are no high associated economic costs, unknown productivity, low technical requirements.	(Pasquini and Cowling, 2015; Dawson et al., 2020)	Medium – IK and LK are transferable across regions. Institutions are not currently designed to incorporate knowledge diversity, and act as a barrier, so do laws and regulations in many places of the world. Global institutions greatly support knowledge diversity, also the SDGs.	(Stephenson et al., 2016; Schlingmann et al., 2021)	High - Environmental feasibility is high as knowledge diversity is related to higher ecological resilience. Socially, diversity of knowledge systems is also increasing social-ecological resilience and supporting ecosystem services related to culture and identity.	(FAO, 2015a; Ross et al., 2019; Terra Stori et al., 2019; Ford et al., 2020)	High	Low – needs combination with other solutions. Facilitates the implementation and success of adaptation tools such as EbA,	(Nalau et al., 2018; Peñaherrera-Palma et al., 2018; Raymond-Yakoubian and Daniel, 2018; Coscieme et al., 2020 ; Owen, 2020)
Socially inclusive policies	High - Technical readiness is medium based on an adaptation planning and early implementation stage, however socially inclusive policies are transversal to systems and sectors and their implementation is well known. Economic feasibility is high as no high costs are expected.	(Archer et al., 2014)	Medium - Not applicable geophysical. Institutions can support at all levels social inclusion and applications differ across countries, while supported by the SDGs. However current governance system may limit inclusive policies.	(Devereux, 2016; Bennett, 2018)	High - Ecological feasibility is high as there are no known trade-offs between inclusive processes and biodiversity ecosystem services, and there is a win-win situation. Social feasibility is high as social aspects, including equity in access to resources and recognition and inclusion of all stakeholders within policy planning and implementation, are key to success.	(Anderson, 2015; Basel et al., 2020; McNamara et al., 2020; Ogier et al., 2020; Williams et al., 2020)	High	Low – needs combination with other solutions. Facilitates finance and market mechanisms, monitoring systems, among others, for adaptation.	(Tommasi et al., 2017; Claudet et al., 2020; A. Maureaud et al., 2021; Sumaila et al., 2021)
Participation	High - broadly implemented approaches, trans-sectorial, with low economic and technological constraints. New successful approaches to co-generate adaptation solutions.	(van der Voorn et al., 2017; Flood et al., 2018; Johnson et al., 2020)	Low - Unequal opportunities for co-management and participation across institutions, low co-management in industrial fisheries, tourism or marine conservation and restoration. Not largely implemented in existing governance across sectors. Geophysical not applicable.	(Nursey-Bray et al., 2018; Brodie Rudolph et al., 2020)	High - Increases environmental resilience and reduces inequities due to secure access to resources. Allows for co-management systems for marine resources. Improves education.	(Ojea et al., 2017; Koenigstein et al., 2020; Voorberg and Van der Veer, 2020; Gianelli et al., 2021)	Medium	High – potential to improve adaptation outcomes and identify impacts and adaptation needs.	(Rumore et al., 2016; Hügel and Davies, 2020)

Livelihood diversification	Medium - Implementation expanding, low technical constraints however economic constraints given the available income deriving alternatives in place, which will require public and private investments (i.e., Aquaculture, tourism, blue energy, etc.).	(Deb and Haque, 2016; Gephart et al., 2020; Mohamed Shaffril et al., 2020; Owen, 2020; Biswas and Mallick, 2021; Sumaila et al., 2021)	Low - Rigid institutions and systems to allow livelihood diversification, unknown political acceptability, existing legal and regulatory actions (i.e., licenses). Requires transformational change.	(Peck and Pinnegar, 2018; Ojea et al., 2020; Biswas and Mallick, 2021)	Low - Environmentally has the potential of increasing pressure in the marine environment with other uses (if conducted non sustainable). Socially it is constrained by the learning capacity of people and it has the risks of resource detachment, loss of cultural identity and professional pride.	(Hossain et al., 2018; Cinner and Barnes, 2019; Fabinyi, 2020; Pham, 2020)	Low	Medium –-reduces climate risks and provides adaptive capacity, but does not necessarily engage all individuals due to agency.	(Cinner and Barnes, 2019; Ford et al., 2020; Mohamed Shaffril et al., 2020; Ojea et al., 2020; Owen, 2020; Pinsky, 2021; Taylor et al., 2021)
Mobility	Medium - Early planning stage and little implementation. Mobility is a tradition for livelihoods in some specific regions. In fisheries, industrial fleets are able to move but economic costs are often subsidized. Small-scale fleet do not have much mobility options, or they come at high costs.	(Jarre et al., 2013; Pinsky et al., 2018; Fulton et al., 2019b; Frazão Santos et al., 2020)	Medium – Mixed regulations and governance to favor mobility of livelihoods or within industries. Current regulations allow for high fish mobility in high-capacity fishing countries, but management regulations often do not match shifting fishing grounds.	(Cross-Chapter Box MOVING SPECIES in Chapter 5, Young et al., 2019; Bell et al., 2021)	Low - Environmental feasibility is low as it can diminish resource availability elsewhere. Social feasibility is low as conflicts can arise between communities, countries, industries and increase vulnerabilities of specific groups (women, indigenous peoples, migrants). This is particularly problematic where the communities have long cultural associations with fisheries, and/or where few other employment opportunities exist.	(Jarre et al., 2013; Ojea et al., 2020; Gonzalez-Mon et al., 2021)	Medium	Medium – given the choice and under specific circumstances livelihoods engage in mobility to reduce risk.	(Barnett and McMichael, 2018)
Migration	Medium - Adaptation planning and early implementation; technical feasibility is moderate but economic feasibility is low due to high costs of re-location, building new infrastructures, loss infrastructure spaces, etc. However, in some specific settings, migration (planned relocation) may be a lower cost solution than protection.	(Birk and Rasmussen, 2014; Islam et al., 2014; Khan et al., 2018b; Stephens et al., 2018; Siders et al., 2019)	Low - Not always physically feasible due to borders and international regulations. Institutions globally and at the national or regional level are not ready for trans-boundary re-location and migration, can interfere with international agreements on human rights. Few countries have currently included migration in national climate change commitments.	(Wilkinson et al., 2016; Scobie, 2019a)	Low - Although migration can alleviate risks (i.e. sea-level rise for human populations), it has substantial political, social and economic costs, and sometimes it is simply impractical, as in the case of coastal megacities.	(Gibbs, 2015; Bordner et al., 2020)	Low	Medium – is a common response for incremental impacts and hazards, but often results in maladaptation outcomes.	(Biswas and Mallick, 2021; Zickgraf, 2021)
Finance & market mechanisms	High - Known technical feasibility from adaptation planning and early implementation. High economic feasibility from cost effective market mechanisms. Finance mechanisms require private/public investment and innovative solutions	(Bott and Braun, 2019; Ware and Banhalmi-Zakar, 2020; Sumaila et al., 2021)	Medium – Multi-scale reach. Political acceptability varies across countries, existing regulations support mechanisms that are already functioning in other sectors and can be ready to transfer to the marine realm; varying transparency of processes.	(Lowe et al., 2019)	Medium - Environmental feasibility is medium as these mechanisms can promote one ecosystem service and detriment others, although they can be designed for win-win solutions (i.e., Carbon and biodiversity), it is not always possible. Socially, these instruments usually do not recognize traditional livelihoods,	(Donner and Webber, 2014; Hinkel et al., 2018; Klöck and Nunn, 2019; Claudet et al., 2020; Ojea et al., 2020; Tompkins et	Medium	High – effective for reducing impacts of SLR and extreme events.	(Shaffril et al., 2017; Dunstan et al., 2018; Hinkel et al., 2018; Moser et al., 2019; Sainz et al., 2019; Woodruff et al., 2020)

	that have been already tested.				minorities without land tenure and other social facets, and can exacerbate existing inequalities. Design in the mechanisms and equitable access can increase their feasibility, but more development of the instruments is needed. Barriers are greater in low to mid-income countries.	al., 2020; Sumaila et al., 2021)				
Disaster response programs	High - Technical feasibility is high given the widespread implementation. Economic costs and investments can be significant, but benefits are high. It requires viable economic investments and risk financing instruments.	(Stewart et al., 2015; Dawson et al., 2016; Jongman, 2018; Quinn et al., 2019)	High – Scales of risk can match the scales of responses. Institutions allow the implementation and maintenance of DRP and are common in every nation and in international treaties.	(Rosendo et al., 2018)	High - high social and environmental feasibility as they address impacts in livelihoods, and they could also benefit ecosystem services provision. When inclusive, participatory and adaptive, they confer resilience to communities.	(Cvitanovic et al., 2016; Nurhidayah and McIlgorm, 2019)	High		Low – solution reduces impacts however it depends on design and innovations, needs coordination with climate adaptation and generally has a science policy gap.	(Izumi et al., 2019; Busayo and Kalumba, 2021)
Multi-level ocean governance	High - allowing for multiple bodies and a polycentric governance system in the oceans is not necessarily constrained by economic costs and benefits of technology.	(Armitage, 2007)	High - Broad scalability, existing instruments and institutions; feasible in most countries where high governance and transparent decision making is present. Globally high feasibility. Required for land-sea interactions.	(Mahon and Fanning, 2019; Schlüter et al., 2020)	Medium - Social feasibility is medium as an asymmetric distribution of power to make decisions for resource control or uses has impeded interagency collaboration. This is not necessarily always the case. Environmental feasibility is high as it is recognized to increase socio-ecological resilience.	(Ho et al., 2012; Ojea et al., 2017; Miller et al., 2018)	High		High – allows for integration of policy making across levels for sectors such as fisheries. Polycentric governance is effective in adaptation.	(Brodie Rudolph et al., 2020; Partelow et al., 2020; Schlüter et al., 2020)
Institutional transboundary agreements	Medium - They are on early planning and little implementation. Transboundary agreements can be constrained by economic negotiations over quotas and or compensations. Technologically, they may require adaptive management or other systems that require a degree of technical capacity	(Pinsky et al., 2018; Melbourne-Thomas et al., 2021; Sumby et al., 2021)	Low - Lack of an international regulatory framework or convention for climate induced transboundary agreements. Existing regional fisheries management platforms that are transboundary but countries have a strong role. Existing fishing agreements and policies are not considering climate change impacts and may need to be re-designed.	(Gaines et al., 2018; Engler, 2020; Oremus et al., 2020)	High - High feasibility in environmental and social terms as trade-offs are not expected if agreements address sustainability and equity issues. Risk of denying access to resources to communities, and of shifting pressure to other regions.	(Mason et al., 2020; Palacios-Abrantes et al., 2020; Melbourne-Thomas et al., 2021)	Medium		High – institutional agreements and cooperation in sectors such as fisheries contributes to adaptation and offsetting climate change impacts.	(Oremus et al., 2020; Haas et al., 2021)

Accommodation and re-location	Low - At the stage of adaptation planning and early implementation; technology is advanced but economic costs are high.	(Masria et al., 2015; Hanson and Nicholls, 2020; Monios and Wilmsmeier, 2020)	Medium - Diverse political support for this option; shift in international institutions towards nature-based solutions. Geophysically constrained by the environment and urbanization of coastlines.	(Vikolainen et al., 2017)	Low - Low environmental feasibility due to irreversible environmental change. Medium social feasibility as sometimes these are socially accepted but other times can cause conflicts. Effects to communities outside of the immediate community need to be considered as well as local impacts. It is important that stakeholders be involved in decision-making to ensure that impacts are understood and agreed upon.	(Shelton, 2014; Zickgraf, 2021)	Low	High – relocation can be planned with participatory processes to achieve higher effectiveness, and may be required in the long run.	(Cross-Chapter Box SLR in Chapter 3, Magnan et al., 2020; Zickgraf, 2021)
Protection & beach and shore nourishment	Medium - At the stage of adaptation planning and early implementation, high economic returns and technological ready, includes however large economic costs.	(Bayraktarov et al., 2016; Samora-Arvela et al., 2017; Pinto et al., 2018)	High - High political support at the international level and increasing support nationally. Geophysical possible although limited by row materials and footprint	(Nicholls, 2018)	Medium - Low environmental feasibility as it can involve interventions that transform the natural habitats, although with the objective of maintaining ecosystem, services. Medium social feasibility as these measures are generally accepted although if not well-designed, they can disbenefit certain groups. Protection may be a feasible option for highly populated coastal areas.	(Gattuso et al., 2018; Barnard et al., 2021; de Schipper et al., 2021; Neijnens et al., 2021)	Medium	Medium – protection and soft infrastructure is effective in the short term and required under highly developed coastlines. But is ineffective in the longer term as it is a barrier to NbS.	(Gattuso et al., 2018; Bevacqua et al., 2020; Kirezci et al., 2020; de Schipper et al., 2021)
Early warning systems	High - Technology is mature and widespread use. Economic barriers linked to access to technology and information. Implementation continues to expand.	(Dembele et al., 2019)	High - High political acceptability and supporting institutions.	(Leal Filho et al., 2018)	Medium - early-warning systems can aid decision making, diversification of enterprises and development of adaptable management systems for coastal systems and fisheries. However it has implementation risks as increasing inequalities due to access.	(Soares et al., 2018; Bindoff et al., 2019)	high	High	(Hoegh-Guldberg et al., 2014; Bindoff et al., 2019; Collins et al., 2019)
Seasonal and dynamic forecasts	Medium - Implementation is widespread, technologically ready however technology requires high capacity and economic costs are significant. Combining seasonal forecasting and climate projections in dynamic model forecasts might provide a pragmatic option for marine industries, including fisheries, aquaculture, and	(Recha et al., 2015; Payne et al., 2017; Tommasi et al., 2017; Hobday et al., 2018)	High - High political acceptability and supporting institutions. Need to share information and data across jurisdictions.	(Hobday et al., 2016; A. Maureaud et al., 2021)	High - Rapid expansion of remote-sensing data, computational ability and ocean modelling have led to the proliferation of real-time and seasonal forecasts of marine heatwaves and associated impacts as well as the abundance and distribution of living marine resources (Payne et al., 2017).	(Payne et al., 2017; Hobday et al., 2018)	high	High – improved technologies match management scales and can be incorporated into many adaptation solutions, for different hazards and sectors.	(Tommasi et al., 2017; Winter et al., 2020; Davidson et al., 2021; Spillman and Smith, 2021)

	tourism to adapt to future climate risk by changing practices or relocating.								
Monitoring systems	Medium - Technology is widely implemented and currently available and used. Economic quotas vary across regions where there is large gaps in ocean and coastal monitoring across the oceans.	(Kurekin et al., 2019; Claudet et al., 2020)	Medium - Diverse political acceptability: institutions differ at the national and local level on the engagement on these technologies and investing in climate change monitoring. There is uneven access and lack of shared information and open data in general.	(Rilov et al., 2020; A. Maureaud et al., 2021; Melbourne-Thomas et al., 2021)	Medium – high feasibility for environmental monitoring in protected areas and management agencies. Medium social acceptance for social monitoring in sectors such as fishing. Benefits of monitoring vessel activity to avoid illegal harvesting.	(Bell et al., 2013; Lubchenco and Grorud-Colvert, 2015; Cabral et al., 2018; Kurekin et al., 2019)	Medium	Medium – monitoring is effective for climate adaptive management however there has many barriers towards implementation.	(Rilov et al., 2020; A. Maureaud et al., 2021; Melbourne-Thomas et al., 2021)
Habitat development	Low - Low stage of implementation with vulnerability assessment and early planning. High economic costs related to technology, which is at the earlier stages.	(Gilby et al., 2018)	Medium - Geographical feasibility may be moderately limited by marine spatial planning and uses; institutional feasibility has the regulations and support for these actions	(Boerema and Meire, 2017; von Haaren et al., 2019)	Medium - Medium ecological and social feasibility as it has the potential to alleviate some of the risks posed by climate change. Possible risks in implementing assisted migration: invasive species, mortality and investment loss if the species. Restoration activities may be ineffective or may lead to undesirable social impacts with endangered species or impacts from increased recreational use of restored habitat.	(Buckley and Crone, 2008; Bindoff et al., 2019)	Medium	Medium – high has the potential to stabilize shorelines and increase fisheries productivity in rocky reef systems but little evidence on effectiveness.	(Gilby et al., 2018)
Active restoration	High - This restoration is expanding over marine systems, needs high investments but it's economically productive. Technology is accessible and feasible as of today.	(Bayraktarov et al., 2016; Basconi et al., 2020; Duarte et al., 2020a)	High - The geographical feasibility is high, it does not require extensive areas limiting other uses, and it may reduce hazards. Regulations and policies are in place to regulate stressors and allow for restoration and conservation of ecosystems broadly.	(Larkin et al., 2019)	Medium - High feasibility to recover ecosystem services provision that benefits livelihoods and their resilience. There can be conflicting uses, but these can be addressed with inclusive processes, and the benefits are supposed to outweigh losses in most cases.	(Fadli et al., 2012; Gattuso et al., 2018; Boström-Einarsson et al., 2020; Hafezi et al., 2021)	high	High – achieves species recovery and reintroduction.	(Boström-Einarsson et al., 2020; Rinkevich, 2021)

Assisted evolution	Medium - Implementation is widespread however technical capacity can be a barrier and at the early stages. Moderate to high cost.	(van Oppen et al., 2015)	Medium - No significant barriers in geophysical feasibility, as these interventions are small scale. Institutional feasibility is medium due to political acceptability and the lack of an existing regulatory and legal framework	(Thiele, 2020)	Medium - Medium ecological and social feasibility as it has the potential to alleviate some of the risks posed by climate change. Translocated plants and animals may carry pathogens or parasites affecting the health of native populations, be maladapted to other non-climate related changes, or may cause a change in genetic composition or population structure of native organisms, a loss of genetic diversity, or a breakdown of coadapted gene complexes. A counter argument here may be that with climate change and severe declines on the horizon, the spread and dominance of selected keystone species might be a better outcome than total loss.	(Laikre et al., 2010; van Oppen et al., 2015; Anthony et al., 2017; Gattuso et al., 2018)	medium	Medium -potential to conserve species and habitats from future change.	(Bulleri et al., 2018; National Academies of Sciences, 2019; Boström-Einarsson et al., 2020; Fredriksen et al., 2020; Morris et al., 2020; Kleypas et al., 2021)
Habitat restoration	Medium - adaptation planning and early to mid-implementation, high costs.	(Williams et al., 2015; Bayraktarov et al., 2016; Pinto et al., 2018; Duarte et al., 2020a)	Medium - Medium scope; not economies of scale, scalability limited and depends on habitats (i.e. Mangroves more scalable than seagrasses); helps hazard risk reduction (mitigation).	(Duarte et al., 2020a; Bertolini and da Mosto, 2021; Braun de Torrez et al., 2021)	High - Supports ecosystem services and biodiversity reducing their vulnerability to climate change, provides ecological resilience, social co-benefits. May have varying social acceptability given other habitat uses (fishing, infrastructure, etc.)	(Shelton, 2014; Gattuso et al., 2018)	Medium	High – has proven effective from local to regional to global scales. Has associated co-benefits from mitigation to ecosystem services to coastal livelihoods.	(Silver et al., 2019; Duarte et al., 2020a; Gordon et al., 2020; Braun de Torrez et al., 2021)
Marine protected areas (MPAs) & OECMs	High - MPAs already in place, widely implemented. There are additional costs of increasing enforcement, spill over economic effects. OECMs have high technical feasibility as they only require recognition of an existing management system.	(Takasaki, 2016; Maxwell et al., 2020b; Rilov et al., 2020; Arafeh-Dalmau et al., 2021; Gurney et al., 2021)	High - High geophysical feasibility given the current network of MPAs and OECMs potential initiatives already in place, high institutional readiness given the regulatory framework of marine protection	(Roberts et al., 2018; Tittensor et al., 2019)	High – Support ecosystem services and biodiversity although these can be impacted by climate change significantly. Provide ecological resilience. Some MPAs have associated social conflicts and acceptability issues, but these are already existing. This can be minimized if inclusiveness and participatory processes are incorporated	(Edgar et al., 2014; Gill et al., 2017; Wilson et al., 2020; Ovando et al., 2021; Sala et al., 2021)	High	Medium – as current MPAs are not expected to be effective against climate change impacts in the mid-term, where adaptive management, dynamic conservation and/or conservation of climate refugia may be needed.	(Tittensor et al., 2019; Wilson et al., 2020)

Conservation of Climate refugia	Low - adaptation planning stage, no implementation yet, extent of new MPAs unknown.	(Roberts et al., 2017; Rilov et al., 2020; Arafeh-Dalmau et al., 2021)	Low - Physically feasible and in a large-scale application but probably dynamic over time. Institutional bodies and agreements are not prepared for these dynamic conservation tools. Climate change not yet incorporated in conservation planning.	(Tittensor et al., 2019; Rilov et al., 2020; Arafeh-Dalmau et al., 2021)	High - Supports ecosystem services under climate change more efficiently and increases ecological and social resilience in the longer term. Limits social acceptability as access rights and marine uses can be limited. Loss of access to natural resources may result in burdens on communities and livelihood shifts, and may result in inequitable distribution of benefits. Design and implementation should be inclusive and participatory, combining participation with climate change metrics.	(Brito-Morales et al., 2018; Wilson et al., 2020; Arafeh-Dalmau et al., 2021)	Medium	High – models and experiments show potential effectiveness of conserving climate refugia.	(Rilov et al., 2020; Wilson et al., 2020; Arafeh-Dalmau et al., 2021)
Transboundary MSP and ICZM	High- - large implementation processes of MSP and ICZM in most countries in the world. Potential for transboundary MSP.	(Frazão Santos et al., 2020; Li and Jay, 2020)	Medium - Coastal use change and planning is feasible and broad in scope, but institutional needs for transboundary integrated coastal and ocean spatial management are at the infancy (i.e. ABNJ treaty). Additionally, existing MSP and ICZM lack considerations of climate change adaptation.	(Gissi et al., 2019; Frazão Santos et al., 2020)	High - Well-designed ICZM and MSP across jurisdictions can guarantee access rights and sustainable resource use, that generates social and ecological co-benefits.	(Free et al., 2020)	High	High - MSP that incorporates climate change impacts and adaptation in the design can contribute to support climate adaptation from a multi-sector perspective and through existing policy frameworks. Little evidence exists for transboundary MSP and ICZM.	(Tittensor et al., 2019; Frazão Santos et al., 2020; Rilov et al., 2020)
Sustainable harvesting	Medium - 30% stocks not managed sustainably, problems of enforcement, access to assets, capacity shortfalls and perverse subsidies. High potential for sustainable mariculture. Tools known and implemented broadly, requires fleet adjustments in some cases and ending illegal fishing. Sustainable fisheries and mariculture stabilize income and create opportunities for value-addition.	(International Council for Science, 2017; Khan et al., 2018a; Costello et al., 2020b)	High - Global institutions are ready and advocating for sustainable fisheries management, including RFMOs, SDGs. National institutions vary in readiness, but overall global feasibility is high.	(Miller et al., 2010; Burden and Fujita, 2019; Duarte et al., 2020a)	High - Increases provisioning ecosystem services in different systems and allows for social co-benefits if access is guaranteed and regulations are inclusive. Reduces the number of species at risk from climate change. Supports intergenerational equity and inclusive and participatory policies (i.e. co-management).	(International Council for Science, 2017; Le Blanc et al., 2017; Cheung et al., 2018) (Allison, 2011)	High	Medium- sustainable harvesting effectively reduced the impacts of climate change, however it may not be sufficient for specific systems (i.e. tropical coral reefs) and or regions that expect large maximum catch potential losses.	(Gaines et al., 2018; Free et al., 2020; Lam et al., 2020; Sumaila and Tai, 2020)

Climate adaptive management	Low - requires data rich assessments and ecological and climate monitoring. Adaptive management is effective but high costs for countries with scientific shortfalls. Very limited implementation so far.	(Huntington et al., 2017; Paulus et al., 2019; Holsman et al., 2020)	High - Scope yet is small but institutions existing can incorporate adaptive fisheries management without broad transformations; it is physically feasible and helps hazard risk reduction	(Pentz et al., 2018)	High - there are no significant environmental barriers, as it increases ecosystem services (food provisioning), SDG2. It can have social co-benefits or differ in acceptability, in order to increase acceptability, design should be inclusive and distribution across the globe	(Pinsky et al., 2018)	Medium	High – scarce examples of implementation but models and evidence shows high effectiveness to reduce risks and foster adaptation in fisheries and conservation.	(Asch, 2015; Levin and Möllmann, 2015; Fulton et al., 2019a; Nickols et al., 2019)
Ecosystem-based management	Medium - Implementation is expanding, requires economic resources but less than adaptive fisheries management, data poor management is possible. Increasing implementation in fisheries management.	(Wamsler et al., 2016; Bryndum-Buchholz et al., 2021)	Medium - Scope so far is small but can be scaled up to regional management. Institutions are not ready, but it may not require important transformations. It contributes to risk reduction and resilience.	(Alexander et al., 2019)	High - High ecological feasibility due to the co-benefits and the support to biodiversity and ecosystem services. High acceptability, supports intergenerational equity, allows for participation, co-management and inclusive processes.	(Leslie and McLeod, 2007; Fernandino et al., 2018; Lowerre-Barbieri et al., 2019)	Medium	High- Ecosystem-based management can incorporate many adaptation solutions, can reduce climate impacts in fisheries in the near-term, and under low emission scenarios.	(Harvey et al., 2018; Karp et al., 2019; Holsman et al., 2020)

SM3.5.2 Fisheries Adaptation to Climate Change

Adaptation to climate impacts in fisheries and mariculture most commonly begins with harvesters moving. Mobility allows fishing fleets and fishers to adapt to shifting marine species distributions (*high agreement*) (Section 3.5.3, 3.4.3.1, Peck and Pinnegar, 2018; Pinsky et al., 2018; Frazão Santos et al., 2020). Following preferred species is challenging: well-developed, regionally coordinated fisheries can fail to match climate-driven range shifts of target species (Pinsky and Fogarty, 2012); in some cases, target species may vacate designated fishing grounds (Bell et al., 2021). An alternative is diversifying fishing locations, as occurred when the squid fishery in Baja California Sur (Mexico) faced drastic decreases in catches before collapsing (Gonzalez-Mon et al., 2021). However, fishery relocation can disrupt cultural associations, or worsen scarce employment opportunities (e.g., Jarre et al., 2013). Even mobile oceanic fisheries, like the industrial tuna fleet, face falling revenues from tracking shifting target species (Bell et al., 2021). Overall, there is *limited evidence* on the positive or maladaptive implications of relocation (Magnan et al., 2020; Islam et al., 2021).

Diversification of harvests, tactics, and livelihoods is a common adaptation strategy that can help address climate impacts to fisheries and mariculture (*high confidence*) (Galappaththi et al., 2017; Blair and Momtaz, 2018; Miller et al., 2018; Peck and Pinnegar, 2018; Robinson et al., 2020; Gonzalez-Mon et al., 2021). Harvest diversification increases yields and livelihood stability in commercial and small-scale fisheries (*high confidence*) (Cline et al., 2017; Young et al., 2019; Barnes et al., 2020; Robinson et al., 2020). Tactics may include changing fishing gear or vessel power, or combining different income-generating activities within the fishing and mariculture sectors (Ojea et al., 2020). Livelihood diversification includes transitioning from wild fisheries to mariculture (Gephart et al., 2020; Ojea et al., 2020), or to other marine sectors like ecotourism, or leaving marine sectors entirely. Coastal and offshore mariculture is expected to continue growing to meet increasing seafood demand (Costello et al., 2020a) despite constraints from climate change (Froehlich et al., 2018a; Froehlich et al., 2020) and sustainability (Corten et al., 2017; Theuerkauf et al., 2019; Costello et al., 2020a), and it requires its own set of adaptations including technological (Froehlich et al., 2018b; Cottrell et al., 2020) and socio-institutional changes (Galappaththi et al., 2020). (A full assessment of mariculture and fisheries within food systems is found in Chapter 5.) Increasing tourism is a commonly reported diversification strategy for fishers (Wood et al., 2013; Cinner, 2014), but this action has a limited ability to improve or maintain the well-being of fishing communities (*high confidence*) (Lasso and Dahles, 2018; Fabinyi, 2020; Pham, 2020) as they become dependent on tourism flows and seasonality. Social capital and land tenure can support successful transitions among sectors (*low evidence*) (Diedrich et al., 2019; Fabinyi, 2020) and livelihoods also benefit from participating in co-management systems to confront the impacts of climate change (*medium evidence*) (Voorberg and Van der Veer, 2020; Gianelli et al., 2021).

Technology and infrastructure adaptations can improve marine harvest efficiency, reduce risk, and support resource management goals (Friedman et al., 2020; Bell et al., 2021; Melbourne-Thomas et al., 2021), but their ability to overcome climate-change impacts remains uncertain (Bell et al., 2020). For example, the tropical tuna industry use aggregation devices to increase efficiency, but the ability of these devices to offset climatic impacts is uncertain (Rubio et al., 2020). Technologies like satellite-tracked vessel-monitoring systems facilitate enforcement of marine reserves (Bradley et al., 2019; White et al., 2020) and identify illegal, unreported and unregulated fishing activity (Lubchenco and Grorud-Colvert, 2015; Cabral et al., 2018; Kurekin et al., 2019), thereby helping alleviate overfishing, a major detrimental interacting driver (Section 3.5.3). However, the degree to which these technologies can overcome expected climate-change impacts (Bell et al., 2013; Erauskin-Extramiana et al., 2019) is unquantified, as are any associated ecological consequences.

Improving capacity to predict anomalous conditions in coastal and marine ecosystems (Jacox et al., 2019; Holbrook et al., 2020; Jacox et al., 2020), storm-driven flooding in reef-lined coasts (Scott et al., 2020; Winter et al., 2020) and fisheries stock recruitment (Payne et al., 2017; Tommasi et al., 2017; Muhling et al., 2018) can improve forecasts of coastal and marine resources. These can enhance sustainability of wild-capture fisheries (*high confidence*) (Blanchard et al., 2017; Tommasi et al., 2017) and inform fisheries and mariculture decision-making at management-relevant time scales (Payne et al., 2017; Tommasi et al., 2017; Hobday et al., 2018). Combining seasonal and multi-year climate projections in dynamic model forecasts helps marine industries consider longer-term adaptations such as changing practices or relocating (*medium confidence*) (Tommasi et al., 2017; Hobday et al., 2018; Merryfield et al., 2020). These tools will be most effective when they are accessible to decision makers and local communities (see Section 3.6.3.3) (Tommasi et al., 2017; A. Maureaud et al., 2021).

At the global level, eliminating overexploitation *very likely* benefits fisheries adaptation to climate change (Burden and Fujita, 2019; Free et al., 2019; Sumaila and Tai, 2020). Regulating landing sizes is a simple strategy that addresses both climate change and overexploitation impacts (Queirós et al., 2018; Thompson et al., 2020). Controlling overfishing may also decrease methylmercury bioaccumulation in pelagic Atlantic finfish (Schartup et al., 2019). But more sophisticated approaches like adaptive management, which anticipates and responds to changes in both fishery productivity and distribution, can not only reduce fisheries impacts but also improve fisheries yields and profits (*high confidence*) (Costello et al., 2016; Gaines et al., 2018; Pinsky et al., 2018; IPBES, 2019; Karp et al., 2019). Management that adjusts the timing of fishery closures and uses timed stock assessment surveys or hatchery releases might also effectively address climate-driven changes in phenology (Section 3.4.3.2) that alter the seasonality of harvests (*low evidence*) (Asch, 2015) and decrease the dependability of seasonal employment and cultural activities (Section 3.5.6). Achieving sustainable fishing practices together with strong mitigation (RCP2.6) is projected to reduce the number of fisheries target species at risk in 2100 by 63% (Cheung et al., 2018), but the implementation of climate-adaptive management in global fisheries remains limited (Holsman et al., 2020).

Ecosystem-based fisheries management is widely legislated (Bryndum-Buchholz et al., 2021), and can reduce climate impacts in fisheries in the near-term, especially under low-emission scenarios (Karp et al., 2019; Holsman et al., 2020). Multi-species ecosystem-based management outperforms single-species management (Fulton et al., 2019a) and has been proposed as an effective tool for addressing regime shifts (Section 3.4.3.3.3, Levin and Möllmann, 2015). Ecosystem-based management, however, poses substantial challenges for nations that lack the necessary resources or information (Fernandino et al., 2018). Awareness and integration of social-ecological contexts in policy and management promotes equitable strategies for sustainable fisheries and mariculture and for reducing risks of unintended negative social impacts on regions or sectors (Cochrane, 2021).

Transboundary agreements on shifting fisheries will reduce the risk of overharvesting and depletion of resources at the trailing edges of their distributions (*high agreement, medium confidence*) (Gaines et al., 2018). Permits tradable across political boundaries could also address this challenge, but *limited evidence* is available regarding their efficacy (Pinsky et al., 2018). One promising approach for migratory species is the 'Vessel Day Scheme', a cap-and-trade system (Aqorau et al., 2018) that allows allocated fishing days to be exchanged among countries as El Niño shifts the tropical Pacific skipjack tuna distribution while preserving license revenue for all participating countries. However, this approach is not expected to fully accommodate projected tuna distributional shifts, requiring additional management adjustment (Bell et al., 2021). Other proposed adaptation strategies incorporate fisheries management and climate-smart conservation under the negotiations on areas beyond national jurisdiction (Pinsky et al., 2018; Tittensor et al., 2019; Frazão Santos et al., 2020), and in the CBD areas designed as other effective area-based conservation measures (OECMs) (Tittensor et al., 2019).

Despite the potential for adaptive management to achieve sustainable fisheries, outcomes will *very likely* be inequitable (Gaines et al., 2018; Free et al., 2020; Lam et al., 2020). Many tropical and low-income countries will not be able to offset all climate change impacts on fisheries or mariculture with management and policy reforms (*high confidence*) (Frazão Santos et al., 2020; Free et al., 2020; Bell et al., 2021), owing to the unequal geographic distribution of climate impacts and hazards (*high confidence*). In addition, fisheries reforms and adaptive management are less developed in the most climate-vulnerable and fisheries-dependent nations (*high confidence*) (Thiault et al., 2019; Lam et al., 2020; Bell et al., 2021). Human adaptations that reduce climate-driven risks to food provision can have positive or negative effects on marine resource management and socioeconomic systems (*limited evidence, high agreement*) (see also Section 3.6, Chapter 5, and detailed in Barange et al., 2018). To overcome these limitations, community-level analyses that account for environmental and social conditions as well as policy history are required to support adaptation planning (*high confidence*) (Dubik et al., 2019; Rogers et al., 2019) so that climate risk of individual fishing communities and responses by local ecosystems and social systems can be considered in the context of neighbouring communities. Flexible and polycentric governance approaches have facilitated some short-term successes in achieving equitable, sustainable fisheries practices, but these may be challenging to implement where other governance systems, especially hierarchical systems, are well-established (Cvitanovic et al., 2018; Bell et al., 2020).

SM3.5.3 Multilateral Environmental Agreements and Climate Change

Several established global agreements and regional, sectoral, or scientific bodies do already address climate adaptation and resilience, including the UN Framework Convention on Climate Change (UNFCCC), the UN Convention on Biological Diversity (CBD), Sustainable Development Goal 14 (Section 3.6.4), Regional Seas Conventions and Action Plans, and the Convention on Wetlands (Ramsar). All of these except Ramsar also address reducing other stressors, and regional fisheries management organizations and agreements (RFMOs/RFMAs) and the International Seabed Authority (ISA) seek to reduce non-climate stressors also. UNFCCC and CBD also address finance mechanisms necessary for climate action (Conservation International and IUCN, 2021; Sumaila et al., 2021).

Reduction of non-climate stressors and adaptation to climate impacts has advanced slowly and unevenly under existing agreements and established bodies (*medium evidence, high agreement*). Parties to the UNFCCC's Paris Agreement have developed Nationally Determined Contributions (NDCs) and adaptation communications detailing their plans to reduce greenhouse gas emissions and adapt to climate change; in 2017, only 9% of coastal nations' NDCs lacked marine considerations (Gallo et al., 2017). By 2020, more than 50 nations presented blue carbon strategies (Duarte et al., 2020a) intended to contribute to both mitigation and adaptation, and 29% of Parties proposed restoring and protecting marine habitats for adaptation (Seddon et al., 2020). National adaptation communications include a diverse suite of products (Christiansen et al., 2020) whose ocean focus has not been assessed. Under the UN CBD, in 2011 nations pledged to protect 10% of the global ocean by 2020 (the Aichi targets) by achieving sustainable harvest and management of marine resources, alleviating other anthropogenic pressures on marine ecosystems, and expanding coverage and effectiveness of MPAs and OECMs (CBD, 2020; CBD Secretariat, 2020), but as of August 2021, these targets were not met as only 7.74% of marine areas are protected (UNEP-WCMC, 2021). The 18 Regional Seas Conventions under the UN Environmental Programme, encompassing 146 nations, have advanced regional action on common marine environmental concerns, such as marine pollution, biodiversity, area-based measures, monitoring, and climate change adaptation (Johnson et al., 2021), all of which influence, and are influenced by, climate impacts. Since 1971, the Ramsar Convention has advanced coordinated action to monitor and sustainably manage wetlands, contributing to greater resilience, but this work has not been explicitly coupled to climate considerations (Finlayson et al., 2017). RFMOs and other regional fisheries bodies facilitate international cooperation on high-seas fishing, but opinions vary on whether they have adequately prevented overfishing and marine ecosystem degradation (Lodge et al., 2007), two major drivers interacting with climate impacts on ocean and coastal systems (Sections 3.4–3.6). The ISA organizes and controls mineral resources-related activities in areas beyond national jurisdiction (International Seabed Authority, 2021); although mineral extraction has not begun, vigorous debate exists about the potential short-term climate mitigation advances from accessing critical minerals to support sustainable technology versus potential long-term mitigation and adaptation impacts from influencing marine biodiversity and other deep-sea ecosystem functions (Koschinsky et al., 2018; Niner et al., 2018; Weaver et al., 2018; Carver et al., 2020; Kung et al., 2021; Tilot et al., 2021).

Many opportunities exist for policies being implemented or developed now to support climate adaptation and mitigation opportunities as well as plan for probable climate impacts. Some exist in the growing implementation of national and international marine spatial planning (especially in South American and African coastal countries (Ehler and Fanny, 2009; Wright et al., 2019; Frazão Santos et al., 2020), and others are associated with the marine biological diversity beyond national jurisdictions (BBNJ) treaty being negotiated now by the UN, which will set targets for protection and sustainable use of the high seas (including the deep sea) and integrate planning, use, and environmental impact assessment of activities (Leary, 2019; Levin et al., 2020; Orejas et al., 2020). Opportunities also exist to update long-standing agreements, such as Regional Seas and RFMOs (Billé et al., 2017; Pentz et al., 2018; Johnson et al., 2021), and Ramsar (Hettiarachchi et al., 2015), with climate-informed targets and actions to achieve interacting objectives of climate mitigation and adaptation, reduction of non-climate impacts, and protection of biodiversity.

SM3.5.4 Data Supporting Figure 3.25

Table SM3.4: Background materials and data for Past Implementation of marine nature-based solutions in Figure 3.25a

Adaptation Solution	Final Indicators	Description	Years	Reference	Limitations	Units	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Habitat restoration	Number of restoration projects_Saltmarshes	Number of restoration projects over time, per habitat type	1972-2018	(Duarte et al., 2020b)	The global deployment of restoration projects for coastal ecosystems (kelps, coral reefs, mangroves, saltmarshes, seagrass meadows and oyster reefs) were compiled for existing resources, including the published literature and databases, from which location, year of initiation, latitude, and longitude of individual restoration sites were compiled. Where the year of initiation was not provided, it was estimated by subtracting 5 years from the year of publication, which was the mean time lag between project initiation and reporting	n	NA	NA	1	1	3	5	6	6	8	9	11	15	15	18	21	24	27	29	32	33	35	37	40	48	53	58	61	65	68	76	80	83	83	88	88	90	92	92	92	93	93	93	93	93	93	93	93	93	93	NA	NA
	Number of restoration projects_Seagrass_meadows	Number of restoration projects over time, per habitat type	1972-2018	(Duarte et al., 2020b)	The global deployment of restoration projects for coastal ecosystems (kelps, coral reefs,mangroves, saltmarshes, seagrass	n	NA	NA	9	12	13	14	15	17	18	19	22	24	27	28	32	34	36	46	52	58	66	72	73	81	93	102	109	116	120	132	138	149	156	173	186	201	206	216	221	224	232	234	239	243	247	247	251	251	251	NA	NA

				meadows and oyster reefs) were compiled for existing resources, including the published literature and databases, from which location, year of initiation, latitude, and longitude of individual restoration sites were compiled. Where the year of initiation was not provided, it was estimated by subtracting 5 years from the year of publication, which was the mean time lag between project initiation and reporting																																																		
Number of restoration projects Mangroves	Number of restoration projects over time, per habitat type	1972-2018	(Duarte et al., 2020b)	The global deployment of restoration projects for coastal ecosystems (kelps, coral reefs, mangroves, saltmarshes, seagrass meadows and oyster reefs) were compiled for existing resources, including the published literature and databases, from which location, year of initiation, latitude, and longitude of individual restoration sites	n	NA	NA	13	13	13	13	15	16	16	18	24	26	28	29	33	36	44	48	51	57	68	74	108	113	123	132	141	150	160	171	178	182	187	203	210	224	239	245	250	261	266	268	272	272	277	278	278	278	278	NA	NA

				were compiled. Where the year of initiation was not provided, it was estimated by subtracting 5 years from the year of publication, which was the mean time lag between project initiation and reporting																																																					
Number of restoration projects Oyster reef	Number of restoration projects over time, per habitat type	1972-2018	(Duarte et al., 2020b)	The global deployment of restoration projects for coastal ecosystems (kelps, coral reefs, mangroves, saltmarshes, seagrass meadows and oyster reefs) were compiled for existing resources, including the published literature and databases, from which location, year of initiation, latitude, and longitude of individual restoration sites were compiled. Where the year of initiation was not provided, it was estimated by subtracting 5 years from the year of publication, which was the mean time lag between project initiation and reporting	n	NA	NA	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	4	4	10	20	27	31	40	53	58	60	68	77	96	104	127	138	149	168	178	258	281	302	317	329	342	349	354	357	359	NA	NA

	Number of restoration projects Coral reef	Number of restoration projects over time, per habitat type	1972-2018	(Duarte et al., 2020b)	The global deployment of restoration projects for coastal ecosystems (kelps, coral reefs, mangroves, saltmarshes, seagrass meadows and oyster reefs) were compiled for existing resources, including the published literature and data bases, from which location, year of initiation, latitude, and longitude of individual restoration sites were compiled. Where the year of initiation was not provided, it was estimated by subtracting 5 years from the year of publication, which was the mean time lag between project initiation and reporting	n	NA	NA	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	3	3	3	3	5	6	6	7	8	9	12	14	15	25	35	35	38	41	42	58	62	69	72	79	87	93	98	106	115	119	131	133	NA	NA
Current MPAs	Coastal and Marine MPAs (km2)	MPA coverage in km2 over time, per type of MPA: Total and no take	1971-2020	Data on location, size and year of declaration of marine protected areas, from, UNEP-WCMC and IUCN (2020).	This dataset has been filtered to only include coastal and marine ecosystems	km^2	NA	224960.338	551639.784	663301.317	672626.794	683341.533	793865.791	1802607.41	1986538.67	1994272.78	2141194.34	2516441.45	2554939.12	2572375.06	2747849.85	2777075.94	2793954.65	2823355.9	2869392.06	2894654.26	2950838.73	3049267.55	3098559.03	3232395.17	3316235.58	3407207.66	3504398.92	3536424.74	3720222.58	3768613.68	3833709.88	4092326.83	4259361.34	4372585.67	4946979.25	5193530.39	8831002.89	10058857.5	10211372.6	10481463.6	12323692.5	12507191.7	14271905.6	14558401.2	16133822.7	16767758.9	18662803.6	21261620.3	25277834.4	26628998.2	26628998.9
	No Take MPAs	MPA coverage in km2 over time, per type of MPA:	1971-2020	Data on location, size and year of declaration of marine	This dataset has been filtered to only include coastal and marine	km^2	NA	636.911852	647.541472	686.337148	690.224648	722.747882	1359.39753	1410.67753	1542.13753	1914.67085	1919.61947	4556.83278	5307.07417	5573.23417	5575.53417	23070	5803.17723	5839.9455	5862.21423	5866.01055	13546.75	13547.2494	13627.8901	13695.9111	15123.0784	15436.4288	18180.7559	18891.5886	21092.8634	21473.1441	21772.6944	22540.5627	94138.492	99620.9797	232287.974	235007.305	237213.505	237703.083	249714.546	261001.09	1146074.19	1146768.52	1243254.09	1246654.55	1251641.56	185993	1551855.53	3643173.94	4427295.57	4428739.48	NA

		Total and no take		protected areas, from, UNEP-WCMC and IUCN (2020).	ecosystems																																																				
Transboundary MSP and ICM	High Seas MPA (km2)	High Sea MPAs. MPA coverage in km2 over time	2006-2018	(Data on location, size and year of declaration of high sea MPAs (ABNJ) from OSPAR Commission, 2019)	Older data not available in sources.	km^2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	22	22	22	94022	381093	381093	574909	574909	576166	576166	2126166	2126166	2126166	NA	NA
sustainable fisheries harvest	Rebuilt fish stocks (%)	Overexploited and collapsed fish stocks in the process of rebuilding	1971-2014	(Kleisner et al., 2013; Gattuso et al., 2018)	Relative to existing fisheries assessments and statistics.	%	NA	0.07	0.07	0.14	0.21	0.07	0.27	0.55	0.47	0.61	0.54	0.54	0.54	0.67	0.87	0.74	0.93	1.06	1.26	1.33	1.45	1.38	1.59	1.65	1.84	1.71	1.77	1.97	2.29	2.35	2.53	3.11	3.03	3.09	3.16	3.14	3.93	4.24	4.19	5.03	5.42	5.97	6.89	6.43	7.33	NA	NA	NA	NA	NA	NA

Table SM3.5: Background materials and data for coral reef adaptation pathways in Figure 3.25b. Based on assessment of effectiveness at maintaining >20% coral cover, with ongoing = likely (>66%), uncertain1= more likely than not to likely (50-66%), and uncertain2 = unlikely to more likely than not (33-50%). “Best management” practices = refers to reducing fishing pressure and elimination of non-climate stressors (e.g., removal of Crown-of-Thorns starfish); “Enhanced coral” = interventions like assisted would increase coral thermal tolerance (e.g., assisted evolution or assisted gene flow); Reef shading” = efforts to decrease incident radiation, “Change livelihoods” = reduces community reliance on coral reef services.

Coral Reefs	1°	1–1.5°	1.5-2°	2-2.5°	2.5-3°	3-4°	Confidence Level	Rationale	References
Best Management	starts	ongoing	uncertain2				very high	consensus of model results for reduction of grazing fish pressure (Caribbean) and crown-of-thorns starfish removal (Australia)	(Anthony et al., 2019; National Academies of Sciences Engineering and Medicine, 2019)
Coral restoration	starts	uncertain1	uncertain2				high	restoration without coral enhancement (e.g., assisted evolution, assisted gene flow) ineffective beyond 1.5C warming, following SR1.5, SROCC and Section 3.4.2.2	Section 3.4.2.1 (drawn from text on restoration)
(+) Enhanced coral		starts	ongoing	uncertain1	uncertain2		medium	consensus of model results combining best management and introduction of more heat-tolerant corals "outplanting warm-adapted coral juveniles" in Anthony et al. (2019).	(Anthony et al., 2019; National Academies of Sciences Engineering and Medicine, 2019)
(+) Reef Shading		starts	ongoing	uncertain1	uncertain2		medium	consensus of model results combining best management, introduction of more heat-tolerant corals, and artificial reef shading	(Anthony et al., 2019; National Academies of Sciences Engineering and Medicine, 2019)
Changing livelihoods		starts	ongoing	ongoing	ongoing	ongoing	very high	drawn from very high confidence in reef degradation with >1.5C warming and no management; supported consensus of the two model results with no management applied, and by other available projection studies which do not simulate management (see 3.4.2.1, no evolution case) (e.g., Logan et al., 2021)	(Section 3.4.2.1, Anthony et al., 2019; National Academies of Sciences Engineering and Medicine, 2019)

Table SM3.6: Background materials and data for Mangrove Adaptation Pathways in Figure 3.25c

Mangrove	1°	1-1.5°	1.5-2°	2-2.5°	2.5-3°	3-4°	Confidence Level	Rationale	References
Restoration/ revegetation	starts	ongoing	ongoing	ongoing	uncertain	uncertain	very high	mangroves are resistant to increase in temperature, though it is uncertain how much temperature may	(Duarte et al., 2020a; Friess et al., 2020)

								affect the recruitment of new plants and the availability of suitable space	
Conservation	starts	ongoing	ongoing	uncertain			high	without interventions that allow mangroves to migrate landward, mangroves will likely suffer significant losses by mid-century, even under SSP1-2.6; by the end of the century, the risk of severe mangrove losses resulting from SLR ranges from very likely under SSP1-2.6 to extremely likely under SSP5-8.5. will be not able to survive SLR projected at	(Section 3.4.2.5, Duarte et al., 2020a)
Payment for ecosystem services and C market		starts	ongoing	ongoing	ongoing	uncertain	high	the C market and PES strategies will depend on the success of other intervention to provide C stock at long term	(Macreadie et al., 2019)
Diversify livelihoods		starts	ongoing	ongoing	uncertain	uncertain	medium		(Duarte et al., 2020a; Stewart-Sinclair et al., 2020b)
migration & relocation (people)		starts	ongoing	ongoing	uncertain		low		(Duarte et al., 2020a; Lovelock and Reef, 2020)
hard infrastructure/retreat		starts	ongoing	ongoing	ongoing	uncertain	low		(Duarte et al., 2020a; Lovelock and Reef, 2020)

SM3.5.5 Data Supporting Figure 3.26

Table SM3.7: Background materials and data for Figure 3.26

Group	From	To	Interaction	Agreement	Author Scores					References
					1	2	3	4	5	
	SDG13	14.1-Reduce pollution	2	100	2	2	2	2	2	(International Council for Science, 2017; Le Blanc et al., 2017; Nilsson et al., 2018)
	SDG13	14.2-Protection	3	100	3	3	3	3	3	(Hoegh-Guldberg and Bruno, 2010; Le Blanc et al., 2017; Pecl et al., 2017)

		and restoration								
	SDG13	14.3-Reduce OA	3	100	3	3	3	3	3	(Le Blanc et al., 2017; Nilsson et al., 2018) (Hoegh-Guldberg and Bruno, 2010)
	SDG13	14.4-Sustainable fishing	2	80	3	2	2	2	2	(Le Blanc et al., 2017; Pecl et al., 2017)
	SDG13	14.5-Conservation	2	100	2	2	2	2	2	(Le Blanc et al., 2017)
	SDG13	14.6-No overfishing subsidies	0	80	0	1	0	0	0	(Sumaila et al., 2010; Pinsky et al., 2018)
	SDG13	14.7-Sustainable resources	3	100	3	3	3	3	3	(Nilsson et al., 2016; Nilsson et al., 2018; Wabnitz et al., 2018) (International Council for Science, 2017)
	SDG13	14.A-Knowledge	3	80	2	3	3	3	3	(International Council for Science, 2017) (Pecl et al., 2017)
	SDG13	14.B-SSF	1	60	1	1	1	0	2	(FAO, 2015b)
	SDG13	14.C-Sea law	3	100	3	3	3	3	3	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG1-No Poverty	2	80	2	1	2	2	2	(Shahidul Islam and Tanaka, 2004; International Council for Science, 2017; Le Blanc et al., 2017)
Society	14.2-Protect and Restore Ecosystems	SDG1-No Poverty	2	60	2	2	2	3	1	(International Council for Science, 2017; Le Blanc et al., 2017)
Society	14.3-Reduce Ocean Acidification	SDG1-No Poverty	2	60	1	3	1	2	1	(International Council for Science, 2017)
Society	14.4-Sustainable Fishing	SDG1-No Poverty	2	60	2	2	2	3	2	(Allison, 2011; International Council for Science, 2017; Le Blanc et al., 2017)
Society	14.5-Conserve Coastal and Marine Areas	SDG1-No Poverty	1	40	-1	1	1	3	2	(International Council for Science, 2017; Le Blanc et al., 2017; Singh et al., 2018)

Society	14.6- End Subsidies Contributing to Overfishing	SDG1-No Poverty	0	60	-1	-1	-1	2	2	(Allison, 2011; Le Blanc et al., 2017)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG1-No Poverty	3	60	3	2	2	3	2	(International Council for Science, 2017; Le Blanc et al., 2017; Singh et al., 2018)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG1-No Poverty	2	40	1	0	2	2	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.B- Support Small-scale Fisheries	SDG1-No Poverty	3	100	3	3	3	3	2	(Le Blanc et al., 2017)
Society	14.C-Implement and Enforce International Sea Law	SDG1-No Poverty	1	40	1	0	2	1	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG2-Zero Hunger	2	80	3	1	3	1	3	(Shahidul Islam and Tanaka, 2004)
Society	14.2-Protect and Restore Ecosystems	SDG2-Zero Hunger	2	60	2	2	2	2	2	(Kawarazuka and Béné, 2011; Béné et al., 2016; International Council for Science, 2017)
Society	14.3-Reduce Ocean Acidification	SDG2-Zero Hunger	2	60	1	1	2	3	1	(Hoegh-Guldberg et al., 2017; Le Blanc et al., 2017)
Society	14.4-Sustainable Fishing	SDG2-Zero Hunger	2	60	3	1	2	3	2	(Allison, 2011; International Council for Science, 2017; Le Blanc et al., 2017)
Society	14.5-Conserve Coastal and Marine Areas	SDG2-Zero Hunger	1	40	1	-1	1	2	1	(International Council for Science, 2017; Le Blanc et al., 2017; Singh et al., 2018)
Society	14.6- End Subsidies Contributing to Overfishing	SDG2-Zero Hunger	0	60	-1	-1	1	0	1	(Allison, 2011; Le Blanc et al., 2017)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG2-Zero Hunger	2	60	3	1	2	3	1	(Béné et al., 2016; FAO, 2016; Le Blanc et al., 2017)
Society	14.A-Increase Scientific Knowledge, Research	SDG2-Zero Hunger	2	40	1	2	2	2	1	(Le Blanc et al., 2017)

	and Technology for Ocean Health									
Society	14.B- Support Small-scale Fisheries	SDG2-Zero Hunger	3	100	2	3	3	3	2	(Le Blanc et al., 2017)
Society	14.C-Implement and Enforce International Sea Law	SDG2-Zero Hunger	1	40	1	0	2	1	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG3- Good Health and wellbeing	3	80	3	3	3	2	3	(Le Blanc et al., 2017)
Society	14.2-Protect and Restore Ecosystems	SDG3- Good Health and wellbeing	2	40	1	1	2	2	3	(HLPE, 2014; IPCC, 2014b; IPCC, 2014a; Béné et al., 2016)
Society	14.3-Reduce Ocean Acidification	SDG3- Good Health and wellbeing	1	80	1	1	2	1	1	(Vezzulli et al., 2012)
Society	14.4-Sustainable Fishing	SDG3- Good Health and wellbeing	2	40	1	2	2	3	3	(Le Blanc et al., 2017)
Society	14.5-Conserve Coastal and Marine Areas	SDG3- Good Health and wellbeing	1	40	0	0	1	2	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.6- End Subsidies Contributing to Overfishing	SDG3- Good Health and wellbeing	0	80	0	0	0	0	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG3- Good Health and wellbeing	2	60	1	1	2	3	1	(Perry, 2010)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG3- Good Health and wellbeing	2	60	1	2	1	2	2	(Calcabrini et al., 2017; Le Blanc et al., 2017)

Society	14.B- Support Small-scale Fisheries	SDG3- Good Health and wellbeing	2	40	1	1	2	2	3	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.C-Implement and Enforce International Sea Law	SDG3- Good Health and wellbeing	2	60	1	1	2	1	3	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG4- Quality Education	0	80	0	0	1	0	0	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.2-Protect and Restore Ecosystems	SDG4- Quality Education	0	60	0	0	1	0	1	(Vladimirova and Le Blanc, 2016)
Society	14.3-Reduce Ocean Acidification	SDG4- Quality Education	0	80	0	0	1	0	0	NA (authors discussion)
Society	14.4-Sustainable Fishing	SDG4- Quality Education	1	60	0	1	2	0	0	NA (authors discussion)
Society	14.5-Conserve Coastal and Marine Areas	SDG4- Quality Education	0	100	0	0	0	0	0	NA (authors discussion)
Society	14.6- End Subsidies Contributing to Overfishing	SDG4- Quality Education	0	80	0	1	0	0	0	NA (authors discussion)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG4- Quality Education	1	80	1	1	1	1	0	NA (authors discussion)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG4- Quality Education	1	80	1	1	1	1	0	NA (authors discussion)
Society	14.B- Support Small-scale Fisheries	SDG4- Quality Education	1	60	0	0	2	0	1	NA (authors discussion)

Society	14.C-Implement and Enforce International Sea Law	SDG4-Quality Education	0	60	0		1	0	0	NA (authors discussion)
Society	14.1-Reduce Marine Pollution	SDG5-Gender Equality	2	60	1	2	1	2	2	(Harper et al., 2013; Bellante et al., 2016)
Society	14.2-Protect and Restore Ecosystems	SDG5-Gender Equality	1	40	0	0	1	3	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.3-Reduce Ocean Acidification	SDG5-Gender Equality	1	40	1	0	1	3	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.4-Sustainable Fishing	SDG5-Gender Equality	1	60	1	0	1	3	1	(Allison, 2011)
Society	14.5-Conserve Coastal and Marine Areas	SDG5-Gender Equality	1	40	0	0	1	3	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018; Singh et al., 2018)
Society	14.6- End Subsidies Contributing to Overfishing	SDG5-Gender Equality	1	60	0	0	0	2	1	(Schuhbauer et al., 2017)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG5-Gender Equality	1	80	1	1	1	3	1	(Le Blanc et al., 2017)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG5-Gender Equality	2	60	1	1	1	3	2	(Le Blanc et al., 2017)
Society	14.B- Support Small-scale Fisheries	SDG5-Gender Equality	2	40	1	3	1	3	2	(Harper et al., 2013; Le Blanc et al., 2017)
Society	14.C-Implement and Enforce International Sea Law	SDG5-Gender Equality	1	40	1	0	1	3	1	(McLeod et al., 2018; Michalena et al., 2020)

Society	14.1-Reduce Marine Pollution	SDG6-Clean Water and Sanitation	3	80	3	3	3	3	2	(Ferrario et al., 2014)
Society	14.2-Protect and Restore Ecosystems	SDG6-Clean Water and Sanitation	2	60	2	2	2	3	1	(Luh et al., 2017; Pecl et al., 2017)
Society	14.3-Reduce Ocean Acidification	SDG6-Clean Water and Sanitation	1	40	1	0	1	2	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Society	14.4-Sustainable Fishing	SDG6-Clean Water and Sanitation	1	60	0	0	0	2	1	(Hassan et al., 2008)
Society	14.5-Conserve Coastal and Marine Areas	SDG6-Clean Water and Sanitation	2	60	1	2	2	2	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Society	14.6- End Subsidies Contributing to Overfishing	SDG6-Clean Water and Sanitation	0	80	0	0	0	0	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG6-Clean Water and Sanitation	1	60	1	-1	1	3	1	(Holding et al., 2016; UN, 2019)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG6-Clean Water and Sanitation	1	60	1	0	1	2	1	(Racault et al., 2019)
Society	14.B- Support Small-scale Fisheries	SDG6-Clean Water and Sanitation	1	60	0	0	1	1	1	(Rangel Soares et al., 2002; FAO, 2009)
Society	14.C-Implement and Enforce International Sea Law	SDG6-Clean Water and Sanitation	1	80	1	0	1	1	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG7-Affordable and clean energy	2	40	3	2	2	3	-1	(European Commission, 2012; Copping et al., 2014; Ellabban et al., 2014; Rilov et al., 2020)

Society	14.2-Protect and Restore Ecosystems	SDG7-Affordable and clean energy	0	40	0	-2	2	2	-1	(Wright, 2015; Fuso Nerini et al., 2018)
Society	14.3-Reduce Ocean Acidification	SDG7-Affordable and clean energy	0	80	0	0	1	0	0	NA (authors discussion)
Society	14.4-Sustainable Fishing	SDG7-Affordable and clean energy	-1	60	0	-2	0	0	-1	(Copping et al., 2014)
Society	14.5-Conserve Coastal and Marine Areas	SDG7-Affordable and clean energy	-1	40	0	-2	-1		-1	(Wright, 2015; Rilov et al., 2020)
Society	14.6- End Subsidies Contributing to Overfishing	SDG7-Affordable and clean energy	0	100	0	0	0	0	0	NA
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG7-Affordable and clean energy	2	60	1	2	2	2	1	(Blechinger et al., 2016)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG7-Affordable and clean energy	3	60	3	2	3	3	2	(Gegg and Wells, 2019)
Society	14.B- Support Small-scale Fisheries	SDG7-Affordable and clean energy	0	100	0	0	0	0	0	NA (authors discussion)
Society	14.C-Implement and Enforce International Sea Law	SDG7-Affordable and clean energy	1	60	2	1	1	2	1	(Wright, G., 2014)

Economy	14.1-Reduce Marine Pollution	SDG8-Decent Work and Economic Growth	1	40	1	-1	2	2	1	(International Council for Science, 2017) (Jang et al., 2014; Krelling et al., 2017)
Economy	14.2-Protect and Restore Ecosystems	SDG8-Decent Work and Economic Growth	1	40	-1	-1	3	1	1	(International Council for Science, 2017) (Gillett and Lightfoot, 2001; Allison, 2011; Béné et al., 2016)
Economy	14.3-Reduce Ocean Acidification	SDG8-Decent Work and Economic Growth	1	80	1	0	1	1	1	(International Council for Science, 2017) (Gillett and Lightfoot, 2001; Allison, 2011; Béné et al., 2016)
Economy	14.4-Sustainable Fishing	SDG8-Decent Work and Economic Growth	2	80	2	-1	2	2	2	(International Council for Science, 2017) (Allison, 2011; Le Blanc et al., 2017)
Economy	14.5-Conserve Coastal and Marine Areas	SDG8-Decent Work and Economic Growth	1	60	-1	1	1	2	1	(International Council for Science, 2017) (Russi et al., 2016; Le Blanc et al., 2017)
Economy	14.6- End Subsidies Contributing to Overfishing	SDG8-Decent Work and Economic Growth	0	40	-1	-1	0	0	1	(Le Blanc et al., 2017)
Economy	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG8-Decent Work and Economic Growth	3	60	3	2		3	3	(International Council for Science, 2017; Le Blanc et al., 2017)
Economy	14.A-Increase Scientific Knowledge, Research	SDG8-Decent Work	2	40	1	3	2	3	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)

	and Technology for Ocean Health	and Economic Growth								
Economy	14.B- Support Small-scale Fisheries	SDG8-Decent Work and Economic Growth	2	40	2	1	3	2	3	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Economy	14.C-Implement and Enforce International Sea Law	SDG8-Decent Work and Economic Growth	1	40	1	0	3	1	2	(Russi et al., 2016)
Economy	14.1-Reduce Marine Pollution	SDG9-Industry, Innovation and Infrastructure	0	40	0	-1	2	-1	1	(Anderson et al., 2017)
Economy	14.2-Protect and Restore Ecosystems	SDG9-Industry, Innovation and Infrastructure	0	60	0	0	2	-1	0	NA (authors discussion)
Economy	14.3-Reduce Ocean Acidification	SDG9-Industry, Innovation and Infrastructure	0	80	0	0	1	0	0	NA (authors discussion)
Economy	14.4-Sustainable Fishing	SDG9-Industry, Innovation and Infrastructure	1	60	0	1	2	0	0	NA (authors discussion)
Economy	14.5-Conserve Coastal and Marine Areas	SDG9-Industry, Innovation	0	60	0	0	1	-1	0	NA (authors discussion)

		and Infrastructure								
Economy	14.6- End Subsidies Contributing to Overfishing	SDG9- Industry, Innovation and Infrastructure	0	40	0	1	1	-1	0	NA (authors discussion)
Economy	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG9- Industry, Innovation and Infrastructure	1	60	0	0	2	0	1	(Blechinger et al., 2016)
Economy	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG9- Industry, Innovation and Infrastructure	2	60	0	2	2	3	2	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Economy	14.B- Support Small-scale Fisheries	SDG9- Industry, Innovation and Infrastructure	1	40	0	0	2	3	2	NA (authors discussion)
Economy	14.C-Implement and Enforce International Sea Law	SDG9- Industry, Innovation and Infrastructure	0	40	0	0	2	-1	1	NA (authors discussion)
Economy	14.1-Reduce Marine Pollution	SDG10- Reduced Inequalities	1	40	1	0	2	0	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.2-Protect and Restore Ecosystems	SDG10- Reduced Inequalities	1	60	1	0	2	1	1	(Beck et al., 2018; Naidoo et al., 2019)
Economy	14.3-Reduce Ocean Acidification	SDG10- Reduced Inequalities	1	80	1	1	1	0	1	(White et al., 2000)

Economy	14.4-Sustainable Fishing	SDG10-Reduced Inequalities	1	40	2	1	2	0	1	(Allison, 2011)
Economy	14.5-Conserve Coastal and Marine Areas	SDG10-Reduced Inequalities	0	60	-1	-1	1	-1	1	(Le Blanc et al., 2017; Singh et al., 2018)
Economy	14.6- End Subsidies Contributing to Overfishing	SDG10-Reduced Inequalities	1	60	1	2	1	2	1	(Le Blanc et al., 2017; Schuhbauer et al., 2017)
Economy	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG10-Reduced Inequalities	3	100	3	3	3	3	3	(Le Blanc et al., 2017)
Economy	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG10-Reduced Inequalities	1	80	1	1	2	1	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.B- Support Small-scale Fisheries	SDG10-Reduced Inequalities	2	60	2	2	3	2	3	(Le Blanc et al., 2017)
Economy	14.C-Implement and Enforce International Sea Law	SDG10-Reduced Inequalities	1	80	1	1	2	1	1	(Nilsson et al., 2016; International Council for Science, 2017; Nilsson et al., 2018) (Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG11-Sustainable Cities and Communities	2	60	1	3	2	2	2	(International Council for Science, 2017)
Society	14.2-Protect and Restore Ecosystems	SDG11-Sustainable Cities and Communities	2	40	1	1	2	3	2	(Marzeion and Levermann, 2014; International Council for Science, 2017; Reimann et al., 2018)
Society	14.3-Reduce Ocean Acidification	SDG11-Sustainable Cities and Communities	1	60	1	2	1	2	1	(International Council for Science, 2017) (Heron et al., 2017)

Society	14.4-Sustainable Fishing	SDG11-Sustainable Cities and Communities	1	60	1	1	2	1	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.5-Conserve Coastal and Marine Areas	SDG11-Sustainable Cities and Communities	1	60	1	2	1	2	1	(International Council for Science, 2017)
Society	14.6- End Subsidies Contributing to Overfishing	SDG11-Sustainable Cities and Communities	1	40	1	0	1	2	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG11-Sustainable Cities and Communities	1	40	1	0	1	3	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG11-Sustainable Cities and Communities	1	60	1	1	2	2	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.B- Support Small-scale Fisheries	SDG11-Sustainable Cities and Communities	1	60	1	0	1	1	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.C-Implement and Enforce International Sea Law	SDG11-Sustainable Cities and Communities	1	80	1	0	1	1	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.1-Reduce Marine Pollution	SDG12-Responsible Consumption and Production	2	60	3	1	3	3	1	(International Council for Science, 2017) (Grizzetti et al., 2013)
Economy	14.2-Protect and Restore Ecosystems	SDG12-Responsible Consumption	2	60	1	3	3	3	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)

		and Production								
Economy	14.3-Reduce Ocean Acidification	SDG12-Responsible Consumption and Production	1	80	1	1	1	2	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.4-Sustainable Fishing	SDG12-Responsible Consumption and Production	2	60	2	3	3	3	1	(International Council for Science, 2017)
Economy	14.5-Conserve Coastal and Marine Areas	SDG12-Responsible Consumption and Production	1	80	1	1	1	2	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.6- End Subsidies Contributing to Overfishing	SDG12-Responsible Consumption and Production	1	40	0	3	1	2	1	(Le Blanc et al., 2017)
Economy	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG12-Responsible Consumption and Production	2	60	1	2	1	3	1	(International Council for Science, 2017)
Economy	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG12-Responsible Consumption and Production	1	80	1	1	2	1	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.B- Support Small-scale Fisheries	SDG12-Responsible Consumption and Production	1	100	1	1	1	1	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)

Economy	14.C-Implement and Enforce International Sea Law	SDG12-Responsible Consumption and Production	1	60	1	1	2	2	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.1-Reduce Marine Pollution	SDG16-Peace and Justice	1	60	1	0	1	0	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.2-Protect and Restore Ecosystems	SDG16-Peace and Justice	1	60	1	0	2	1	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.3-Reduce Ocean Acidification	SDG16-Peace and Justice	1	60	1	0	1	0	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.4-Sustainable Fishing	SDG16-Peace and Justice	1	60	-1	2	2	1	2	(Brashares et al., 2014)
Society	14.5-Conserve Coastal and Marine Areas	SDG16-Peace and Justice	-1	60	-1	0	0	-1	-1	(Singh et al., 2018)
Society	14.6- End Subsidies Contributing to Overfishing	SDG16-Peace and Justice	0	60	0	1	0	0	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG16-Peace and Justice	1	60	1	0	1	1	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG16-Peace and Justice	1	60	1	0	1	1	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Society	14.B- Support Small-scale Fisheries	SDG16-Peace and Justice	1	60	1	1	1	2	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)

Society	14.C-Implement and Enforce International Sea Law	SDG16-Peace and Justice	1	60	1	2	1	1	2	(Pinsky et al., 2018)
Economy	14.1-Reduce Marine Pollution	SDG17-Partnerships for the Goals	0	60	1	0	1	-1	1	(Nilsson et al., 2018)
Economy	14.2-Protect and Restore Ecosystems	SDG17-Partnerships for the Goals	1	60	1	0	1	1	2	(Unger et al., 2016)
Economy	14.3-Reduce Ocean Acidification	SDG17-Partnerships for the Goals	1	60	1	0	1	0	1	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.4-Sustainable Fishing	SDG17-Partnerships for the Goals	1	40	1	0	1	-1	2	(Unger et al., 2016)
Economy	14.5-Conserve Coastal and Marine Areas	SDG17-Partnerships for the Goals	0	100	0	0	0	0	0	NA (authors discussion)
Economy	14.6- End Subsidies Contributing to Overfishing	SDG17-Partnerships for the Goals	1	60	0	1	0	0	2	NA (authors discussion)
Economy	14.7-Increase the Economic Benefits from Sustainable Use of Marine Resources	SDG17-Partnerships for the Goals	1	40	1	0	1	3	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.A-Increase Scientific Knowledge, Research and Technology for Ocean Health	SDG17-Partnerships for the Goals	1	60	1	1	1	2	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.B- Support Small-scale Fisheries	SDG17-Partnerships for the Goals	1	60	1	0	1	1	2	(Nilsson et al., 2016; Nilsson et al., 2018) (International Council for Science, 2017) (Singh et al., 2018)
Economy	14.C-Implement and Enforce International Sea Law	SDG17-Partnerships for the Goals	2	40	3	1	3	1	2	(Unger et al., 2016)

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