## A review of the combined effects of climate change and other local human stressors on the marine environment

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## Appendix

**Table A.1.** Keywords used for the systematic literature review on cumulative effect assessments and climate change, in line with Hoegh-Guldberg and Bruno (2010).

| Group | Keywords |
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| Combined effects | "Cumulative impact*" OR "Cumulative analy*" OR "Cumulative environmental analy*" OR "Cumulative human impact*" OR "Cumulative effect*" OR "Combined impact*" OR "synerg* effect" OR "combined effect*" OR "additive effect*"OR"multiple stressor*" |
| Marine or coastal environments | "marine" OR "sea" OR "ocean" OR "coast*" |
| Climate change | "climate change" OR "ocean acidification" OR "global warming" OR "global change" OR "ocean warming" OR "warming" OR "sea level rise" |

**Table A.2.** Database of the 107 eligible studies that addressed the combined effects of climate change and human stressors. References were separated accordingly to the levels of biological diversity (ecological foci) targeted in the study.

| Year | Authors | Title | DOI |
|---|---|---|---|
| | *At species level* | | |
| 2020 | Otto SA, Niiranen S, Blenckner T et al. | Life Cycle Dynamics of a Key Marine Species Under Multiple Stressors | 10.3389/fmars.2020.00296 |
| 2019 | Voss R, Quaas MF, Stiasny MH et al. | Ecological-economic sustainability of the Baltic cod fisheries under ocean warming and acidification | 10.1016/j.jenvman.2019.02.105 |
| 2019 | Morrongiello JR, Sweetman PC, Thresher RE | Fishing constrains phenotypic responses of marine fish to climate variability | 10.1111/1365-2656.12999 |
| 2019 | Montero-Serra I, Garrabou J, Doak DF et al. | Marine protected areas enhance structural complexity but do not buffer the consequences of ocean warming for an overexploited precious coral | 10.1111/1365-2664.13321 |
| 2019 | Baumann JH, Ries JB, Rippe JP et al. | Nearshore coral growth declining on the Mesoamerican Barrier Reef System | 10.1111/gcb.14784 |
| 2018 | Sguotti C, Otto SA, Frelat R et al. | Catastrophic dynamics limit Atlantic cod recovery | 10.1098/rspb.2018.2877 |
| 2018 | Sarà G, Porporato EMD, Mangano MC et al. | Multiple stressors facilitate the spread of a non-indigenous bivalve in the Mediterranean Sea | 10.1111/jbi.13184 |
| 2018 | Pickett E, Chan M., Cheng W et al | Cryptic and cumulative impacts on the wintering habitat of the endangered black-faced spoonbill (*Platalea minor*) risk its long-term viability | 10.1017/S0376892917000340 |
| 2018 | Le Bris A, Mills KE, Wahle et al. | Climate vulnerability and resilience in the most valuable North American fishery | 10.1073/pnas.1711122115 |
| 2018 | Grech, Hanert E, McKenzie et al. | Predicting the cumulative effect of multiple disturbances on seagrass connectivity | 10.1111/gcb.14127 |
| 2018 | Bårdsen BJ, Hanssen SA, Bustnes JO | Multiple stressors: modeling the effect of pollution, climate, and predation on viability of a sub-arctic marine bird | 10.1002/ecs2.2342 |
| 2017 | Pardo D, Forcada J, Wood AG et al. | Additive effects of climate and fisheries drive ongoing declines in multiple albatross species | 10.1073/pnas.1618819114 |

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| 2016 | Lunn NJ, Servanty S, Regehr EV et al. | Demography of an apex predator at the edge of its range: Impacts of changing sea ice on polar bears in Hudson Bay | 10.1890/15-1256. |
| 2016 | Munroe D, Narváez Hennen D et al. | Fishing and bottom water temperature as drivers of change in maximum shell length in Atlantic surf clams (*Spisula solidissima*) | 10.1016/j.ecss.2016.01.009 |
| 2015 | Fuller E, Brush R, Pinsky ML | The persistence of populations facing climate shifts and harvest | 10.1890/ES14-00533.1 |
| 2015 | Pinsky ML, Byler D | Fishing, fast growth and climate variability increase the risk of collapse | 10.1098/rspb.2015.1053 |
| 2014 | Burthe S, Wanless S, Newell MA et al. | Assessing the vulnerability of the marine bird community in the western North Sea to climate change and other anthropogenic impacts | 10.3354/meps10849 |
| 2014 | Bartolino V, Margonski P, Lindegren M et al. | Forecasting fish stock dynamics under climate change: Baltic herring (*Clupea harengus*) as a case study | doi:10.1111/fog.12060 |
| 2014 | Wang HY, Botsford LW, White JW et al. | Effects of temperature on life history set the sensitivity to fishing in Atlantic cod *Gadus morhua* | 10.3354/meps10943 |
| 2013 | Maxwell SM, Hazen EL, Bograd SJ et al. | Cumulative human impacts on marine predators | 10.1038/ncomms3688 |
| 2011 | Hidalgo M, Rouyer T, Molinero JC et al. | Synergistic effects of fishing-induced demographic changes and climate variation on fish population dynamics | 10.3354/meps09077 |
| 2011 | Eero MH, MacKenzie BR, Köster FW et al. | Multi-decadal responses of a cod (*Gadus morhua*) population to human-induced trophic changes, fishing, and climate | 10.1890/09-1879.1 |
| 2010 | Field I, Meekan MG, Buckworth RC et al. | Susceptibility of sharks, rays and chimaeras to global extinction | 10.1016/S0065-2881(09)56004-X |
| 2010 | Regular PM, Robertson GJ, Montevecchi WA et al. | Relative importance of human activities and climate driving common murre population trends in the Northwest Atlantic | 10.1007/s00300-010-0811-2 |
| 2010 | Linares C, Doak DF | Forecasting the combined effects of disparate disturbances on the persistence of long-lived gorgonians: A case study of *Paramuricea clavata* | 10.3354/meps08437 |
| 2010 | Rivalan P, Barbraud C, Inchausti P et al. | Combined impacts of longline fisheries and climate on the persistence of the Amsterdam Albatross *Diomedia amsterdamensis* | 10.1111/j.1474-919X.2009.00977.x |
| 2008 | Rolland V, Barbraud C, Weimerskirch H | Combined effects of fisheries and climate on a migratory long-lived marine predator | 10.1111/j.1365-2664.2007.01360.x |
| Total = 27 studies at species level | | | |
| *At trophic groups level* | | | |
| 2020 | Reum JCP, Blanchard JL, Holsman KK et al. | Ensemble Projections of Future Climate Change Impacts on the Eastern Bering Sea Food Web Using a Multispecies Size Spectrum Model | 10.3389/fmars.2020.00124 |
| 2019 | Griffith GP, Strutton PG, Semmens JM et al. | Identifying important species that amplify or mitigate the interactive effects of human impacts on marine food webs | 10.1111/cobi.13202 |
| 2019 | Ehrnsten ES, Bauer B, Gustafsson BG | Combined effects of environmental drivers on marine trophic groups - A systematic model comparison | 10.3389/fmars.2019.00492 |
| 2018 | Coll M, Albo-Puigserver M, Navarro J et al. | Who is to blame? Plausible pressures on small pelagic fish population changes in the northwestern Mediterranean Sea | 10.3354/meps12591 |
| 2018 | Ortega-Cisneros K, Cochrane KL, Fulton EA et al. | Evaluating the effects of climate change in the southern Benguela upwelling system using the Atlantis modelling framework | 10.1111/fog.12268 |
| 2018 | Raoux A, Dambacher JM, Pezy J-P et al. | Assessing cumulative socio-ecological impacts of offshore wind farm development in the Bay of Seine (English Channel) | 10.1016/j.marpol.2017.12.007 |
| 2017 | Serpetti N, Heymans J, Burrows R. et al. | Impact of ocean warming on sustainable fisheries management informs the Ecosystem Approach to Fisheries | 10.1038/s41598-017-13220-7 |
| 2017 | Coralles X, Coll M, Ofir E et al. | Hindcasting the dynamics of an Eastern Mediterranean marine ecosystem under the impacts of multiple stressors | 10.3354/meps12271 |
| 2016 | Ortiz I, Aydin K, Hermann AJ et al. | Climate to fish: Synthesizing field work, data and models in a 39-year retrospective analysis of seasonal processes on the eastern Bering Sea shelf and slope | 10.1016/j.dsr2.2016.07.009 |
| 2016 | Chew LL, Chong VC | Response of marine copepods to a changing tropical environment: Winners, losers and implications | 10.7717/peerj.2052 |
| 2015 | Giakoumi S, Halpern BS, Loıc NM et al. | Towards a framework for assessment and management of cumulative human impacts on marine food webs | 10.1111/cobi.12468 |
| 2014 | Travers-Trolet M, Shin Y., Shannon LJ et al. | Combined fishing and climate forcing in the southern Benguela upwelling ecosystem: An end-to-end modelling approach reveals dampened effects | 10.1371/journal.pone.0094286 |

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| 2013 | Salihoglu B, Sevinc N | Quantification of the synergistic effects of eutrophication, apex predator pressure, and internal processes on the Black Sea ecosystem | 10.4194/1303-2712-v13_4_03 |
| 2013 | Niiranen S, Yletyinen J, Tomczak MT et al. | Combined effects of global climate change and regional ecosystem drivers on an exploited marine food web | 10.1111/gcb.12309 |
| 2013 | Nye JA, Gamble RJ, Link JS | The relative impact of warming and removing top predators on the Northeast US large marine biotic community | 10.1016/j.ecolmodel.2012.08.019 |
| 2013a | Hoover C, Pitcher T, Christensen V | Effects of hunting, fishing and climate change on the Hudson Bay marine ecosystem: II. Ecosystem model future projections | 10.1016/j.ecolmodel.2013.01.010 |
| 2013b | Hoover C, Pitcher T, Christensen V | Effects of hunting, fishing and climate change on the Hudson Bay marine ecosystem: I. Re-creating past changes 1970-2009 | 10.1016/j.ecolmodel.2013.02.005 |
| 2013 | Quetglas A, Ordines F, Hidalgo M et al. | Synchronous combined effects of fishing and climate within a demersal community | 10.1093/icesjms/fss181 |
| 2013 | Busch MPS., Greene CM, Good TP | Estimating Effects of Tidal Power Projects and Climate Change on Threatened and Endangered Marine Species and Their Food Web | 10.1111/cobi.12164 |
| 2012 | Griffith GP, Fulton EA, Gorton R et al. | Predicting Interactions among Fishing, Ocean Warming, and Ocean Acidification in a Marine System with Whole-Ecosystem Models | 10.1111/j.1523-1739.2012.01937.x |
| 2012 | Araújo JN, Bundy A | Effects of environmental change, fisheries and trophodynamics on the ecosystem of the western Scotian Shelf, Canada | 10.3354/meps09792 |
| 2011 | Griffith MJP., Fulton A, Richardson AJ | Effects of fishing and acidification-related benthic mortality on the southeast Australian marine ecosystem | 10.1111/j.1365-2486.2011.02453.x |
| 2010 | Kaplan IC, Levin PS, Burden M et al. | Fishing catch shares in the face of global change: A framework for integrating cumulative impacts and single species management | 10.1139/F10-118 |
| 2010 | Lindegren M, Möllmann C, Nielsen A et al. | Ecological forecasting under climate change: the case of Baltic cod | 10.1098/rspb.2010.0353 |
| 2010 | Shears NT, Ross PM | Toxic cascades: Multiple anthropogenic stressors have complex and unanticipated interactive effects on temperate reefs | 10.1111/j.1461-0248.2010.01512.x |
| 2009 | Kotta J, Kotta I, Simm M et al. | Separate and interactive effects of eutrophication and climate variables on the ecosystem elements of the Gulf of Riga | 10.1016/j.ecss.2009.07.014 |
| 2009 | Kirby RR, Beaugrand G, Lindley JA | Synergistic Effects of Climate and Fishing in a Marine Ecosystem | 10.1007/s10021-009-9241-9 |
| Total = 27 studies at trophic groups level | | | |
| *At habitat level* | | | |
| 2020 | Wåhlström I, Höglund A, Almroth-Rosell E et al. | Combined climate change and nutrient load impacts on future habitats and eutrophication indicators in a eutrophic coastal sea | 10.1002/lno.11446 |
| 2020 | Tulloch VJD, Turschwell MP, Giffin AL et al. | Linking threat maps with management to guide conservation investment | 10.1016/j.biocon.2020.108527 |
| 2020 | Furlan E, Slanzi D, Torresan S et al. | Multi-scenario analysis in the Adriatic Sea: A GIS-based Bayesian network to support maritime spatial planning | 10.1016/j.scitotenv.2019.134972 |
| 2020 | Evans RD, Wilson SK, Fisher R et al. | Early recovery dynamics of turbid coral reefs after recurring bleaching events | 10.1016/j.jenvman.2020.110666 |
| 2020 | Andersen JH, Al-Hamdani Z, Harvey ET et al. | Relative impacts of multiple human stressors in estuaries and coastal waters in the North Sea–Baltic Sea transition zone | 10.1016/j.scitotenv.2019.135316 |
| 2019 | Halpern BS, Frazier M, Afflerbach J et al. | Recent pace of change in human impact on the world's ocean | 10.1038/s41598-019-47201-9 |
| 2019 | Furlan E, Torresan S, Critto A et al. | Cumulative Impact Index for the Adriatic Sea: Accounting for interactions among climate and anthropogenic pressures | 10.1016/j.scitotenv.2019.03.021 |
| 2018 | Ortiz J-C, Wolff NH, Anthony KRN et al. | Impaired recovery of the great barrier reef under cumulative stress | 10.1126/sciadv.aar6127 |
| 2018 | Magris R, Grech E, Presse et al. | Cumulative human impacts on coral reefs: Assessing risk and management implications for brazilian coral reefs | 10.3390/d10020026 |
| 2018 | Jones AR, Doubleday ZA, Prowse TAA et al. | Capturing expert uncertainty in spatial cumulative impact assessments | 10.1038/s41598-018-19354-6 |
| 2017 | Wyatt KH, Griffin R, Guerry AD et al. | Habitat risk assessment for regional ocean planning in the U.S. Northeast and Mid-Atlantic | 10.1371/journal.pone.0188776 |
| 2017 | Mach ME, Wedding LM, Reiter SM et al. | Assessment and management of cumulative impacts in California's network of marine protected areas | 10.1016/j.ocecoaman.2016.11.028 |
| 2015 | Halpern B, Frazier KE, Potapenko J et al. | Spatial and temporal changes in cumulative human impacts on the world's ocean | 10.1038/ncomms8615 |
| 2015 | Clarke Murray C, Agbayani S, Ban NC | Cumulative effects of planned industrial development and climate change on marine ecosystems | 10.1016/j.gecco.2015.06.003 |

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| 2015 | Okey T, Alidina HM, Agbayani S | Mapping ecological vulnerability to recent climate change in Canada's Pacific marine ecosystems | 10.1016/j.ocecoaman.2015.01.009 |
| 2015 | Rodríguez-Rodríguez M, Sánchez-Espinosa A, Schröder C et al. | Cumulative pressures and low protection: a concerning blend for Mediterranean MPAs | 10.1016/j.marpolbul.2015.09.039 |
| 2014 | McManus E, Jenni K, Clancy M et al. | The 2014 Puget Sound Pressures Assessment. Puget Sound Partnership. | - |
| 2014 | Ban S, Pressey RL, Graham NAJ | Assessing interactions of multiple stressors when data are limited: A Bayesian belief network applied to coral reefs | 10.1016/j.gloenvcha.2014.04.018 |
| 2013 | Walbridge S Walbridge. et al. | Cumulative Human Impacts on Mediterranean and Black Sea Marine Ecosystems: Assessing Current Pressures and Opportunities. | 10.1371/journal.pone.0079889 |
| 2012 | Kappel CV, Halpern BS | Mapping cumulative impacts of human activities on marine ecosystems | 10.31230/osf.io/6exng |
| 2010 | Teck SJ, Halpern BS, Kappel CV et al. | Using expert judgment to estimate marine ecosystem vulnerability in the California Current | 10.1890/09-1173.1 |
| 2009 | Selkoe KA, Halpern BS, Ebert CM et al. | A map of human impacts to a "pristine" coral reef ecosystem, the Papahānaumokuākea Marine National Monument | 10.1007/s00338-009-0490-z |
| 2009 | Halpern BS, Kappel CV, Selkoe KA et al. | Mapping cumulative human impacts to California Current marine ecosystems | https://doi.org/10.1111/j.1755-263X.2009.00058.x |
| 2008 | Halpern BS, Walbridge S, Selkoe KA et al. | A global map of human impact on marine ecosystems | 10.1126/science.1149345 |
| Total = 24 studies at habitat level | | | |
| *At ecosystem level* | | | |
| 2020 | Singh GG, Eddy IMS, Halpern, BS et al. | Mapping cumulative impacts to coastal ecosystem services in British Columbia | 10.1371/journal.pone.0220092 |
| 2020 | Negri AP, Smith RA, King O et al. | Adjusting Tropical Marine Water Quality Guideline Values for Elevated Ocean Temperatures | 10.1021/acs.est.9b05961 |
| 2020 | Ehrnsten E, Norkko A, Müller-Karulis B et al. | The meagre future of benthic fauna in a coastal sea—Benthic responses to recovery from eutrophication in a changing climate | 10.1111/gcb.15014 |
| 2019 | Ocaña FA, Pech D, Simões N et al. | Spatial assessment of the vulnerability of benthic communities to multiple stressors in the Yucatan Continental Shelf, Gulf of Mexico | 10.1016/j.ocecoaman.2019.104900 |
| 2019 | Mellin C, Matthews S, Anthony KRN et al. | Spatial resilience of the Great Barrier Reef under cumulative disturbance impacts | 10.1111/gcb.14625 |
| 2019 | Fisher R, Bessell-Browne P, Jones R | Synergistic and antagonistic impacts of suspended sediments and thermal stress on corals | 10.1038/s41467-019-10288-9 |
| 2019 | Ellis JI, Jamil T, Anlauf H et al. | Multiple stressor effects on coral reef ecosystems | 10.1111/gcb.14819 |
| 2019 | Armstrong CW, Vondolia GK, Foley NS et al. | Expert assessment of risks posed by climate change and anthropogenic activities to ecosystem services in the deep North Atlantic | 10.3389/fmars.2019.00158 |
| 2018 | Weijerman M, Veazey L, Yee S et al. | Managing local stressors for coral reef condition and ecosystem services delivery under climate scenarios | 10.3389/fmars.2018.00425 |
| 2018 | Stock A, Haupt AJ, Mach ME et al | Mapping ecological indicators of human impact with statistical and machine learning methods: Tests on the California coast | 10.1016/j.ecoinf.2018.07.007 |
| 2018 | Ramírez F, Coll M, Navarro J et al. | Spatial congruence between multiple stressors in the Mediterranean Sea may reduce its resilience to climate impacts | 10.1038/s41598-018-33237-w |
| 2018 | Montefalcone M, De Falco G, Nepote E et al. | Thirty year ecosystem trajectories in a submerged marine cave under changing pressure regime | 10.1016/j.marenvres.2018.02.022 |
| 2018 | Lercari ME, Defeo O, Ortega L et al | Long-term structural and functional changes driven by climate variability and fishery regimes in a sandy beach ecosystem | 10.1016/j.ecolmodel.2017.11.007 |
| 2018 | Corrales X, Coll M, Ofir E et al. | Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming | 10.1038/s41598-018-32666-x |
| 2017 | Singh G, Sinner A, Ellis J. et al. | Mechanisms and risk of cumulative impacts to coastal ecosystem services: An expert elicitation approach | 10.1016/j.jenvman.2017.05.032 |
| 2017 | Andersen JH, Berzaghi F, Christensen T et al | Potential for cumulative effects of human stressors on fish, sea birds and marine mammals in Arctic waters | 10.1016/j.ecss.2016.10.047 |
| 2016 | Clarke Murray C, Mach ME, Martone RG et al. | Supporting Risk Assessment: Accounting for Indirect Risk to Ecosystem Components | 10.1371/journal.pone.0162932 |

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| 2016 | Marzloff MR, Little LR, Johnson CR | Building Resilience Against Climate-Driven Shifts in a Temperate Reef System: Staying Away from Context-Dependent Ecological Thresholds | 10.1007/s10021-015-9913-6 |
| 2015 | Weijerman ME, Fulton EA, Kaplan IC et al. | An integrated coral reef ecosystem model to support resource management under a changing climate | 10.1371/journal.pone.0144165 |
| 2015 | Wakelin S, Artioli Y, Butenschön M et al. | Modelling the combined impacts of climate change and direct anthropogenic drivers on the ecosystem of the northwest European continental shelf | 10.1016/j.jmarsys.2015.07.006 |
| 2015 | Cornwall CE, Eddy TD | Effects of near-future ocean acidification, fishing, and marine protection on a temperate coastal ecosystem | 10.1111/cobi.12394 |
| 2015 | Ban SS, Pressey RL, Graham NAJ | Assessing the effectiveness of local management of coral reefs using expert opinion and spatial Bayesian modeling | 10.1371/journal.pone.0135465 |
| 2014 | Cook GS, Fletcher PJ, Kelble CR | Towards marine ecosystem based management in South Florida: Investigating the connections among ecosystem pressures, states, and services in a complex coastal system | 10.1016/j.ecolind.2013.10.026 |
| 2012 | Neumann T, Eilola K, Gustafsson B et al. | Extremes of Temperature, Oxygen and Blooms in the Baltic Sea in a Changing Climate | 10.1007/s13280-012-0321-2 |
| 2012 | Meier HM, Müller-Karulis B, Andersson HC et al. | Impact of Climate Change on Ecological Quality Indicators and Biogeochemical Fluxes in the Baltic Sea: A Multi-Model Ensemble Study | 10.1007/s13280-012-0320-3 |
| 2012 | Coll M, Piroddi C, Albouy C et al. | The Mediterranean Sea under siege: spatial overlap between marine biodiversity, cumulative threats and marine reserves | 10.1111/j.1466-8238.2011.00697.x |
| 2011 | Cai W, Hu KE, Huang W et al. | Acidification of subsurface coastal waters enhanced by eutrophication | 10.1038/ngeo1297 |
| 2011 | Meier HE, Eilola K, Almroth E | Climate-related changes in marine ecosystems simulated with a 3-dimensional coupled physical-biogeochemical model of the Baltic Sea | 10.3354/cr00968 |
| 2010 | Darling ES., Mcclanahan TR, Côté IM | Combined effects of two stressors on Kenyan coral reefs are additive or antagonistic, not synergistic | 10.1111/j.1755-263X.2009.00089.x |
| Total = 29 studies at ecosystem level | | | |

**Table A.3**. Classification of methods considered by the review of Stelzenmüller et al. (2018).

| Methods | Definition | References |
|---|---|---|
| Integrative assessment | Methods that include multiple ecosystem components (e.g., biological, chemical, physical, social, economic), numerous biodiversity elements (e.g., from microbes to cetaceans), different assessment scales, some criteria to define spatial scales and some guidance on integrating information. Borja et al. (2014) identified a number of different approaches of integrative assessment that combined a number of variables (which could be metrics, indicators, or criteria) into an overall assessment. Any integration and aggregation principle used for different indicators or descriptors should be ecologically relevant, transparent and well documented (Borja et al., 2016). Integrative assessment methods were proposed for determining environmental status and assessing marine ecosystems health. In those cases, methods currently available are applied to synthesize the ecosystem complexity, by aggregating and integrating information when assessing the ecosystem status. | Borja et al., 2016, 2014 |
| Quantitative food web modelling | Methods that include the analysis through food web modelling with quantitative analysis of trophic level interactions. | Pauly et al., 2000 |
| Statistical modelling - linear & non-linear models | Methods that applies linear or non-linear models, such as Generalized Linear Models (GLM) or Generalized Additive Models (GAM) | |
| Mechanistic modelling | Methods to demonstrate a causality of input–output relationships, seeking to establish a mechanistic relationship between inputs and outputs. A mechanistic model should be able to provide an explanation for the patterns, which should (at least in principle) provide a platform for extrapolation beyond the test conditions (e.g., from constant to time-varying exposure, and from ad libitum to limiting food availability). | Baker et al., 2018; Jager, 2016 |

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| Expert judgement | Methods that adopt expert interpretation and synthesis on specific subjects to make existing research directly useful to management, because of the lack of comprehensive empirical information (e.g., expert knowledge on ecosystem vulnerability because of the lack on ecosystem–stressor interactions comprehensive information). Expert judgement is used when data are scarce and uncertainty exists These gaps are overcome by using the best available scientific judgments. | Teck et al., 2010 |
| Qualitative food web modelling | Methods that include the analysis through food web modelling without quantitative analysis of trophic level interactions in quantitative terms | |
| Spatial analysis – GIS tools | Methods that assess the cumulative effects assessment by applying a spatial analysis, usually with GIS tools | Halpern et al., 2015, 2008 |
| Species distribution models (SDMs) | Species distribution models (SDMs) are numerical tools that combine observations of species occurrence or abundance with environmental estimates. | Elith and Leathwick 2009 |
| Other | Other types of methods | |

**Table A.4**. Classification of the categories and classes by which local stressors (LS) were grouped, and the frequency at which LS were combined with climate change (CC) effects at different biological levels and in total. The categories are meant to represent the relevance of the different LS in relation to the management and planning of the different coastal and maritime activities. The types of LS are represented as D = driver, and P = pressure according to Stelzenmüller et al. (2018).

| | | | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Category | Description | No. | Human stressors | Type | Species | Trophic groups | Habitats | Ecosystems | No. | % |
| 1 | Industrial fisheries | This category includes the LS deriving from industrial fisheries | 1.1 | Industrial fisheries | D | 19 | 20 | 19 | 20 | 78 | 72.9 |
| 2 | Other fishery- and aquaculture-related LS | This category includes all the other fishery- and aquaculture related LS that are not included under the category "industrial fisheries" | 2.1 | Artisanal fishery | D | 3 | 3 | 11 | 4 | 21 | 19.6 |
| | | | 2.2 | Aquaculture | D | 1 | 1 | 12 | 3 | 17 | 15.9 |
| | | | 2.3 | Recreational fishing | D | 1 | 1 | 5 | 5 | 12 | 11.2 |
| | | | 2.4 | Harvesting | D | 3 | 2 | 1 | 1 | 7 | 6.5 |
| | | | 2.5 | Hunting | D | 1 | | | | 1 | 0.9 |
| 3 | Pollution-related LS | This category includes the LS that are pollution-related pressures in the ocean, classified as addressed in each study | 3.1 | Organic pollutants | P | 1 | 1 | 14 | 10 | 26 | 24.3 |
| | | | 3.2 | Ocean-based pollution* | P | 3 | | 13 | 6 | 22 | 20.6 |
| | | | 3.3 | Marine litter | P | 2 | | 7 | 3 | 12 | 11.2 |
| | | | 3.4 | Inorganic pollutants | P | 1 | | 7 | 3 | 11 | 10,3 |
| | | | 3.5 | Oil pollution | P | 2 | | 6 | 2 | 10 | 9.3 |
| | | | 3.6 | Eutrophication | P | 3 | 5 | 1 | 1 | 10 | 9.3 |
| | | | 3.7 | Light pollution | P | 1 | | 6 | | 7 | 6.5 |
| | | | 3.8 | Thermal stress | P | | 1 | 2 | | 3 | 2.8 |
| | | | 3.9 | Atmospheric deposition | P | | | 3 | | 3 | 2.8 |
| | | | 3.10 | Human-induced diseases | P | | | 2 | 1 | 3 | 2.8 |
| | | | 3.11 | Deteriorating water quality due to discharges | P | | 1 | 1 | | 2 | 1.9 |
| | | | 3.12 | Hypoxia | P | | | 1 | | 1 | 0.9 |
| | | | 3.13 | Other contaminants | P | 1 | | | | 1 | 0.9 |
| 4 | | This category includes the LS that represent drivers at sea. | 4.1 | Shipping | D | 1 | 1 | 19 | 6 | 27 | 25.2 |
| | | | 4.2 | Coastal engineering | D | 2 | 1 | 10 | 4 | 17 | 15.9 |

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| | LS from maritime activities | divided according to the different maritime activities addressed in each study[**] | 4.3 | Oil platforms and oil rigs | D | | | 9 | 2 | 11 | 10.3 |
| | | | 4.4 | Renewable energies | D | 1 | 2 | 3 | | 6 | 5.6 |
| | | | 4.5 | Ocean mining | D | | | 5 | 2 | 7 | 6.5 |
| | | | 4.6 | Marinas | D | | | 6 | 2 | 8 | 7.5 |
| | | | 4.7 | Dredging | D | | | 6 | 4 | 10 | 9.3 |
| | | | 4.8 | Power plants | D | 1 | | 2 | | 3 | 2.8 |
| | | | 4.9 | Pipelines | D | | | 3 | | 3 | 2.8 |
| | | | 4.10 | Military areas | D | | | 2 | | 2 | 1.9 |
| | | | 4.11 | Ship wrecks | D | | | 2 | | 2 | 1.9 |
| 5 | Terrestrial-based LS | This category includes the LS that represent land-based drivers and pressures, classified as addressed in each study | 5.1 | Land use/land cover change | D | 4 | 2 | 9 | 2 | 17 | 15.9 |
| | | | 5.2 | Land-based pollution* | P | 2 | 1 | 7 | 4 | 14 | 13.1 |
| | | | 5.3 | Land-based activities (e.g.. infrastructure, agriculture) | D | | 1 | 8 | 3 | 12 | 11.2 |
| | | | 5.4 | Change in sediment load | P | 3 | | 3 | 3 | 9 | 8.4 |
| | | | 5.5 | Forestry | D | | 1 | 3 | 1 | 5 | 4.7 |
| | | | 5.6 | Change in population density | D | | | 5 | | 5 | 4.7 |
| | | | 5.7 | Freshwater delivery | P | | | 1 | 2 | 3 | 2.8 |
| | | | 5.8 | Coastal-based impacts* | P | | | 1 | 1 | 2 | 1.9 |
| | | | 5.9 | Dams | D | | | 2 | 1 | 3 | 2.8 |
| | | | 5.10 | Mining (onshore) | D | | | 1 | 1 | 2 | 1.9 |
| 6 | Tourism-based LS | This category includes the LS that are driven by tourism and recreational activities at sea | 6.1 | Pleasure boating | D | 1 | | 3 | 3 | 7 | 6.5 |
| | | | 6.2 | Recreational activities | D | | | 2 | 2 | 4 | 3.7 |
| | | | 6.3 | Beach tourism | D | 3 | | | 1 | 4 | 3.7 |
| | | | 6.4 | Whale watching | D | | | 2 | | 2 | 1.9 |
| | | | 6.5 | Diving | D | 1 | | 2 | 2 | 5 | 4.7 |
| 7 | Other LS | This category includes the LS that represent miscellaneous human-related drivers and pressures at sea not included in previous categories and generally less frequently mentioned than the other six categories. | 7.1 | Alien species (human-induced) | P | | 2 | 11 | 3 | 16 | 15.0 |
| | | | 7.2 | Change in predator density (human-induced) | P | 4 | 3 | 1 | | 8 | 7.5 |
| | | | 7.3 | Human Trampling | P | | | 4 | 2 | 6 | 5.6 |
| | | | 7.4 | Desalinization | D | | 1 | 1 | | 2 | 1.9 |
| | | | 7.5 | Temporal change in primary production | P | | 1 | | 1 | 2 | 1.9 |
| | | | 7.6 | Research activities | D | | | 1 | | 1 | 0.9 |
| | | | 7.7 | Lack of social license[§] | D | | | | 1 | 1 | 0.9 |

* These LS are treated as generic input layers for which the authors of the studies included in this review did not provide any further detail, for instance, on the type of pollution or on the type of impacts.

[**] LS from maritime activities excluding fisheries, aquaculture and tourism that are already addressed under categories 1, 2 & 6 (respectively).

[§] Singh et al. (2017) considered the combined effect of the lack of social license with other LS and CC through expert elicitation; the lack of social license is intended as the growing indifference for biodiversity, which can lead to fewer protections for biodiversity and/or less resistance to developments and policy that threaten biodiversity. With respect to aquaculture, the lack of social license stems from public wariness around aquaculture that contributes to permitting restrictions.

**Table A.5**. Classification of the categories and classes by which climate change (CC) effects were grouped, and frequency of the CC effects with which they have been studied in combination to local human stressors at different levels of biological diversity in the 107 studies.

| | | | | | | | | | **Total** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Category** | **No.** | **Class** | **Description of aggregated effects mentioned in the studies (if any)** | **Species** | **Trophic groups** | **Habitats** | **Ecosystems** | **no.** | **%** |
| 1 | UV radiation | - | UV radiation | UV radiation anomalies, UV change, irradiance, solar radiation | 1 | 1 | 12 | 6 | 20 | 18.7 |
| 2 | Ocean acidification | - | Ocean acidification | - | 3 | 6 | 13 | 14 | 36 | 33.6 |
| 3 | Sea level rise | - | Sea level rise | - | | 1 | 8 | 3 | 12 | 11.2 |
| 4 | Change in salinity | - | Change in salinity | - | 3 | 5 | 2 | 4 | 14 | 13.1 |
| 5 | Change in temperature | - | Change in temperature | Ocean warming, ocean temperature (generic), temperature variability, change in sea surface temperature (SST), bottom temperatures, surface air temperature, depth integrated temperature produced by SSTs, climate velocity - shift of isotherms, heat change in freshwater temperature, thermal stress | 23 | 22 | 21 | 23 | 89 | 83.2 |
| 6 | Climatic mode of variability | - | Climatic mode of variability / Change in climate patterns | Three different annual measures of the Oceanic Niño Index, changes to El Niño–Southern Oscillation (ENSO), Southern Oscillation Index, Southern Annular Model (Antarctic Oscillation), Atlantic Multi-decadal Oscillation (AMO) index, Subtropical Indian Ocean Dipole index (SIOD)/Dipole mode index (DMI)/Indian Ocean Dipole (IOD), Winter North Atlantic Oscillation. | 4 | 2 | 1 | 2 | 9 | 8.4 |
| 7 | Other atmospheric and weather effects | 7.1 | Winds change | Meridional wind speed anomaly (MWSA), wind direction, wind changes | | 3 | | 1 | 4 | 3.7 |
| | | 7.2 | Increase in storm | Increase in storm frequency - cyclone frequency - rare storm events - Severe Tropical Cyclone | 1 | 1 | 2 | 3 | 7 | 6.5 |
| | | 7.3 | Extreme weather events | Extreme weather events, hot weather events, change in weather | | | 1 | 3 | 4 | 3.7 |
| | | 7.4 | Change to currents | Change to currents, currents | | 1 | | 2 | 3 | 2.8 |
| | | 7.5 | Change in precipitations | Change in precipitations amounts and patterns, extreme rainfall events, decreased annual rainfall, precipitation records | 1 | | 2 | | 3 | 2.8 |
| | | 7.6 | River inflow altered | River inflow, altered low and peak flows from climate change, change in freshwater hydrology | | 2 | 2 | 1 | 5 | 4.7 |
| | | 7.7 | Sea ice extent | Sea Ice Extent - sea ice decrease, sea ice concentration, loss of Artic sea ice | 2 | 3 | | | 5 | 4.7 |
| | | 7.8 | Climatic models scenarios | Changing/dynamic carrying capacity of the climate<br>change scenarios, regional climate models | 2 | 1 | | | 3 | 2.8 |
| | | 7.9 | Atm. Sea level pressure | Atmospheric sea level pressure | 1 | | | | 1 | 0.9 |
| | | 7.10 | Oxygen conditions | Hypoxic areas, oxygen conditions | 2 | 2 | 2 | | 6 | 5.6 |
| | | 7.11 | Change in upwellings | - | | | 1 | | 1 | 0.9 |
| | | 7.12 | Change in pCO2 | - | | | | 2 | 2 | 1.9 |
| | | 7.13 | Air-sea heat fluxes | Air-sea heat fluxes | | | | 1 | 1 | 0.9 |
| | | 7.14 | Evaporation | Evaporation | | | | 1 | 1 | 0.9 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | CC-induced biological drivers of change | 8.1 | Mass mortality effects | - | 2 | | | | 2 | 1.9 |
| | | 8.2 | Coral bleaching derived | Coral bleaching (derived from climate driven increase in temperatures). | | | 3 | 3 | 6 | 5.6 |
| | | 8.3 | CC driven alga blooms | Climate driven alga blooms - specific events | | 1 | | | 1 | 0.9 |
| | | 8.4 | Disease | Disease - Temperature anomalies relevant to disease | | | 1 | 2 | 3 | 2.8 |
| | | 8.5 | Invasive species | CC-induced invasive species increase | | | | 2 | 2 | 1.9 |
| | | 8.6 | Native species change | Native species changes in distribution and abundance induced by CC | | 1 | | | 1 | 0.9 |
| | | 8.7 | Q10 parameter | Magnitude of the Q10 parameter controlling temperature dependence | | 1 | | | 1 | 0.9 |

**Table A.6**. Frequencies of the combinations of local human stressors (LS) with climate change (CC) effects per ecological focus considered in the studies.

| | Species | | Trophic groups | | Habitats | | Ecosystems | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of LS combined with CC | no. | % | no. | % | no. | % | no. | % | no. | % |
| 1 | 14 | 51.9 | 18 | 66.7 | 2 | 8.3 | 12 | 41.4 | 46 | 43.0 |
| 2 | 8 | 29.6 | 5 | 18.5 | 1 | 4.2 | 8 | 27.6 | 22 | 20.6 |
| 3 | 2 | 7.4 | 3 | 11.1 | | | 1 | 3.4 | 6 | 5.6 |
| 4 | 1 | 3.7 | | | 1 | 4.2 | 1 | 3.4 | 3 | 2.8 |
| 5 | | | | | 3 | 12.5 | | | 3 | 2.8 |
| 6 | | | | | 2 | 8.3 | 1 | 3.4 | 3 | 2.8 |
| 7 | | | | | 2 | 8.3 | | | 2 | 1.9 |
| 8 | 1 | 3.7 | | | 1 | 4.2 | 1 | 3.4 | 3 | 2.8 |
| 9 | | | | | 2 | 8.3 | 2 | 6.9 | 4 | 3.7 |
| 10 | | | | | | | 1 | 3.4 | 1 | 0.9 |
| 11 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 12 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 13 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 14 | 1 | 3.7 | 1 | 3.7 | 1 | 4.2 | | | 3 | 2.8 |
| 15 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 16 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 17 | | | | | | | 1 | 3.4 | 1 | 0.9 |
| 18 | | | | | 1 | 4.2 | 1 | 3.4 | 2 | 1.9 |
| 22 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 24 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| 25 | | | | | 1 | 4.2 | | | 1 | 0.9 |
| Tot | 27 | 100.0 | 27 | 100.0 | 24 | 100.0 | 29 | 100.0 | 107 | 100.0 |

**Table A.7**: Frequency of the combination of effects of climate change (CC) per ecological focus at the 107 studies.

| CC factors | Species | | Trophic groups | | Habitats | | Ecosystems | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Combinations | no. | % | no. | % | no. | % | no. | % | no. | % |
| 1 | 16 | 59.2 | 15 | 55.6 | 5 | 20.8 | 9 | 31.0 | 45 | 42.0 |
| 2 | 6 | 22.2 | 7 | 25.9 | 2 | 8.3 | 9 | 31.0 | 24 | 22.4 |
| 3 | 5 | 18.5 | 1 | 3.7 | 10 | 41.7 | 7 | 24.1 | 23 | 21.5 |
| 4 | | | 1 | 3.7 | 4 | 16.7 | 1 | 3.4 | 6 | 5.6 |
| 5 | | | 2 | 7.4 | 2 | 8.3 | | | 4 | 3.7 |
| 6 | | | | | 1 | 4.2 | 2 | 6.9 | 3 | 2.8 |
| 7 | | | 1 | 3.7 | | | 1 | 3.4 | 2 | 1.8 |
| tot | 27 | 100.0 | 27 | 100.0 | 24 | 100.0 | 29 | 100.0 | 107 | 100.0 |

**Table A.8**: Number (no.) of studies at the different level of biological diversity that performed a scenario analysis per ecological focus.

| Is climate change included through scenario analysis as an indirect potential driver of impacts (e.g., redistribution of species)? | Species | | Trophic groups | | Habitats | | Ecosystems | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | no. | % | no. | % | no. | % | no. | % | no. | % |
| No | 14 | 51.9 | 6 | 22.2 | 20 | 83.3 | 16 | 55.2 | 56 | 52.4 |
| Yes | 13 | 48.1 | 21 | 77.8 | 4 | 16.7 | 13 | 44.8 | 51 | 47.6 |
| total | 27 | 100.0 | 27 | 100.0 | 24 | 100.0 | 29 | 100.0 | 107 | 100 |

**Table A.9:** Number (no.) of studies at the different level of biological diversity that projected scenarios at short, medium, and long-term; the percentages are referred to the total number of studies (107).

| | Species | | Trophic groups | | Habitats | | Ecosystems | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | no. | % | no. | % | no. | % | no. | % | no. | % |
| long term (from 20 to 100 years) | 9 | 8.4 | 14 | 13.1 | 2 | 1.9 | 11 | 10.3 | 36 | 33.6 |
| medium term (i.e. 1 to 20 years) | 3 | 2.8 | 4 | 3.7 | 2 | 1.9 | 2 | 1.9 | 11 | 10.3 |
| short term (i.e. seasons within a year) | 1 | 0.9 | 3 | 2.8 | 0 | 0.0 | 0 | 0.0 | 4 | 3.7 |
| Total | 13 | 12.1 | 21 | 19.6 | 4 | 3.7 | 13 | 12.1 | 51 | 47.6 |

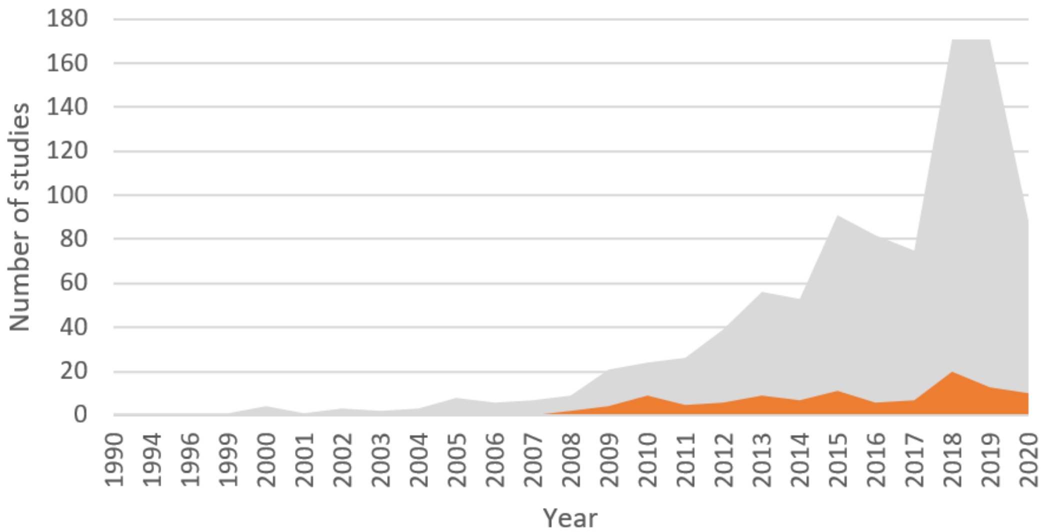


**Figure A.1.** Number of publications dealing with the effects of climate change individually or combined with other CC stressors (in grey), and with the combined effects of CC and at least another local human stressor in natural conditions (in orange).

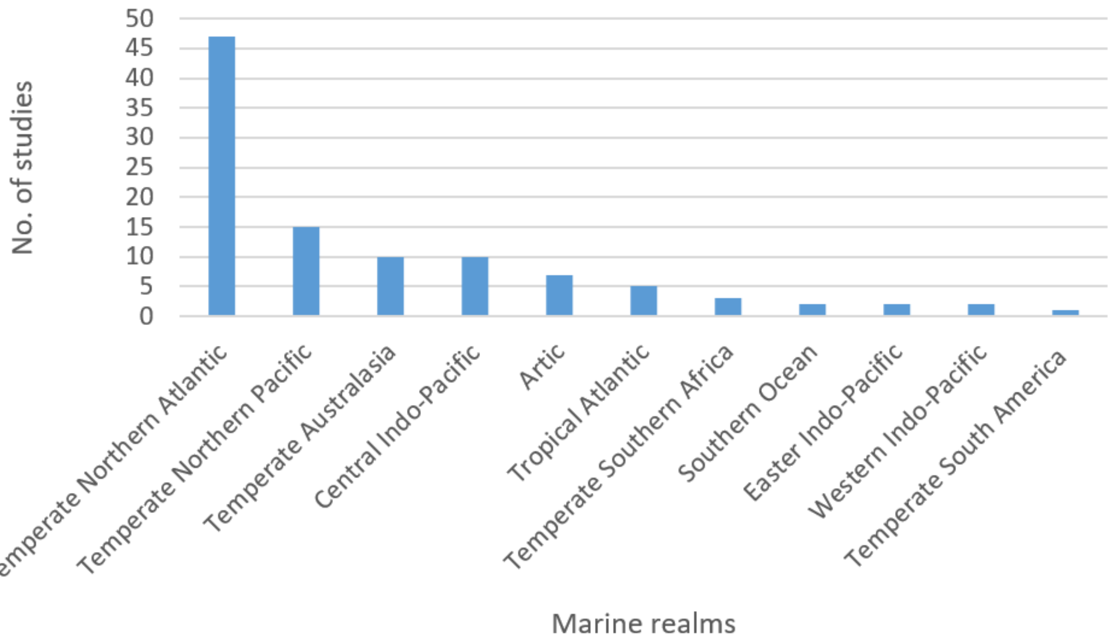


**Figure A.2.** Number of studies (No.) per marine biogeographic realms *sensu* Spalding et al. (2007).

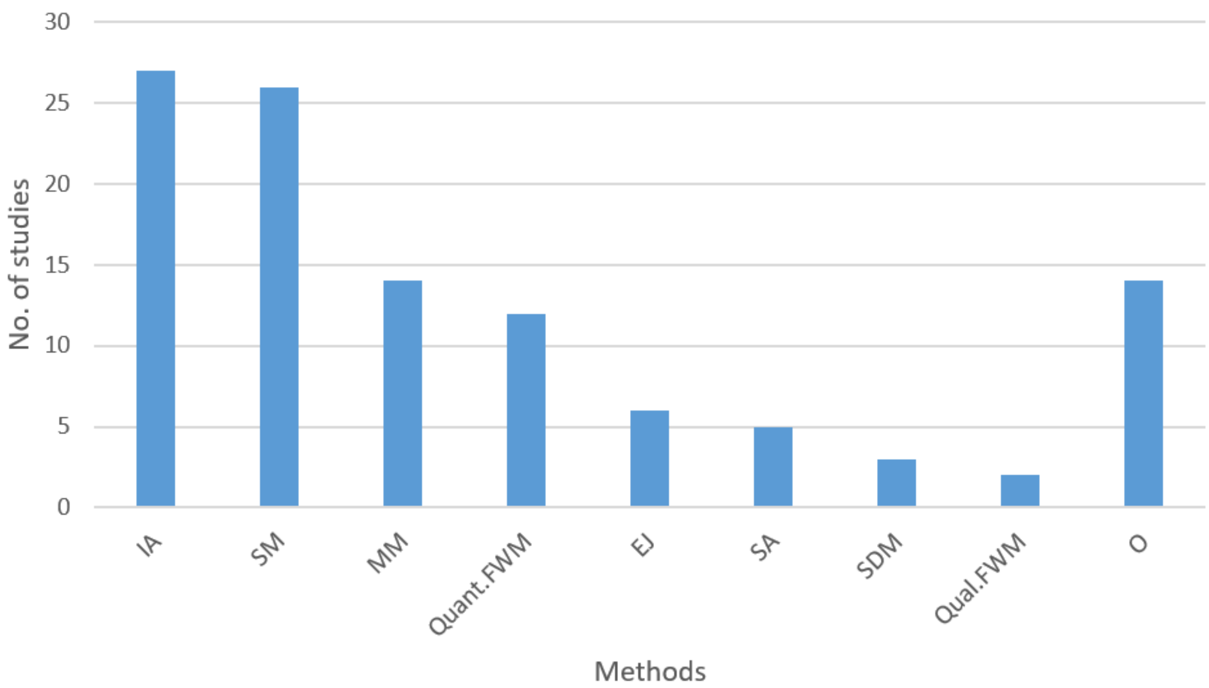


**Figure A.3**: Methods applied in the analysis of multiple effects of combined climate change and human stressors; EJ=Expert judgement, IA=Integrative assessments, MM=Mechanistic modelling, O=Other, Qual.FWM=Qualitative food-web modelling, Quant.FWM=Quantitative food-web modelling, SA=Spatial analysis with GIS tools, SDM=Species distribution models, SM=Statistical modelling – linear and non-linear models.

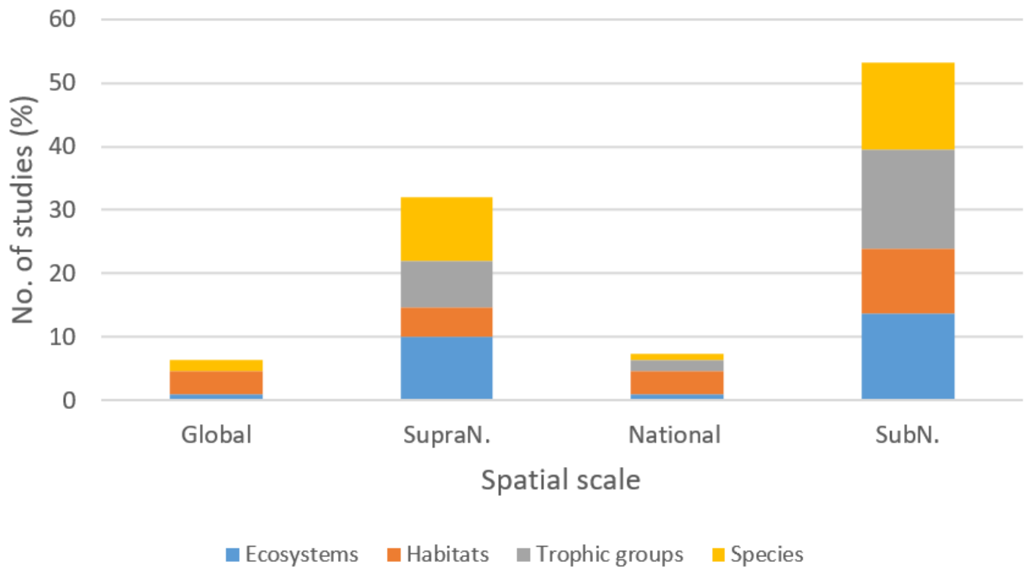


**Figure A.4.** Spatial scales at which the combined effects of climate change and human stressors have been studied across levels of biological diversity; SubN.=Subnational, SupraN.=Supranational.

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