Competence Centre for Climate Change

# ICCA Study Report

## Annexes 1 – 4

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

CIFOR

# CONTENTS

# ANNEX 1

# ICCA GLOBAL LITERATURE REVIEW METHODS & SEARCH RESULTS

### Initial selection of references

Initial export:
- Total of 9,500 references extracted to EndNote
- Total of 6,749 references after removal of duplicates by EndNote
- Final total of 5,868 references after removal of further duplicates by Excel

First stage selection based on title and abstract (for inclusion/exclusion criteria see end of document):
- 543 articles in the category "INCLUDED"
- 102 articles in the category "MAYBE"

The full text of the articles in the "MAYBE" category was checked for relevant keywords in order to decide for inclusion or exclusion. Of the 102 articles, a total of 43 were added in the category "INCLUDED".
- Final number of included articles: 586.

The 586 included articles were categorized according to the following (based on their abstracts):
- Main ecosystem subject or boundary (mangroves, coral reefs, fauna related to mangroves/coral reefs, ridge-to-reef etc.)
- Type of study (biophysical, social, both)
- Main stressor (e.g. acidification, sea-level rise, storms etc.)
- Country/Region

The database of all 586 articles encompassing the references and their categorization will be delivered by the end of the project.

For the full text review, the total number of articles in different categories of ecosystem-stressor that encompass a comparatively large number of references will be reduced according to the scope and time frame of the study. For example, the category of biophysical studies looking at the impacts of ocean warming on coral reefs encompasses a large number of papers (>45). From this category, a sample of no less than 10–15 articles will be selected. This is based on the assumption that the same conclusions regarding stressor impacts are repeated in more than one article.

All impact chains described here are illustrated in the full study report and can be found on ci:grasp under the following links:
- Ocean acidification
- Ocean warming
- Changes in precipitation
- Sea-level rise
- Tropical storms

This annex as well as the full study can be downloaded from AdaptationCommunity.net.

## 1.1 Search terms

**SUBJECT:**
coastal OR reef OR reefs OR mangrove OR mangroves

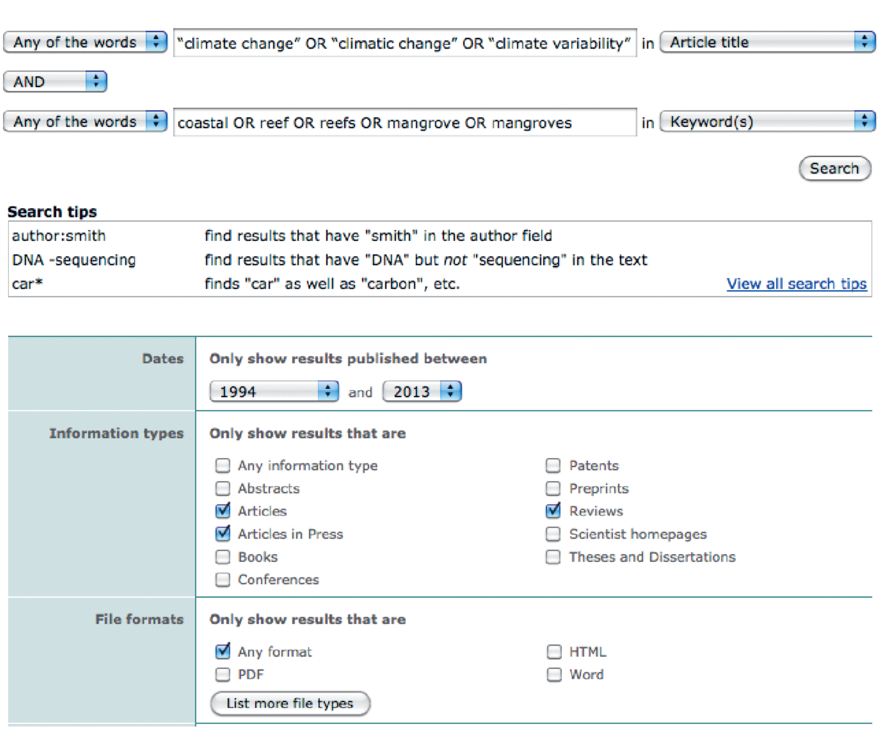
**AND**

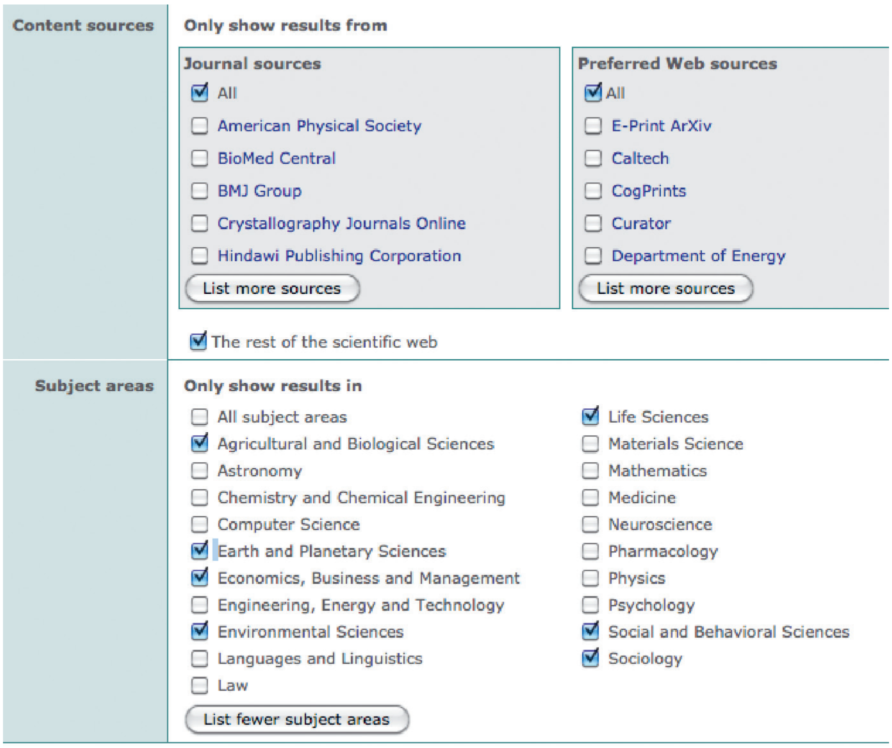
**EXPOSURE:**
"climate change" OR "climatic change" OR "climate variability" OR "climate variation" OR "climate variations" OR "climate extreme" OR "climate extremes" OR "coastal hazard" OR "coastal hazards" OR "natural disaster" OR "natural disasters" OR "climate disaster" OR "climate disasters" OR flood* OR storm* OR drought* OR wind* OR "sea level rise" OR "ocean acidification" OR typhoon* or cyclone* OR warming OR "temperature rise" OR "El Niño" OR "ENSO" or hurricane* OR erosion OR sedimentation OR deforestation OR "ecosystem degradation" OR "mangrove degradation" OR "reef degradation" OR "unsustainable harvesting" OR "land use change" OR conversion OR pollution OR "coral mining" OR "blast fishing" OR logging OR tsunami

# 1.2 Databases and search process

## 1.21 Scirus

Exposure terms in title and subject terms in keywords with the following restrictions below.






## 1.22 Scopus

Exposure terms in title and subject terms in title-abstract-keywords with the following restrictions:

- AND DOCTYPE(ar OR re) AND SUBJAREA(mult OR agri OR mult OR eart OR envi OR mult OR deci OR econ OR psyc OR soci) AND PUBYEAR > 1994 AND (LIMIT-TO(LANGUAGE, "English")). Source type limited to "Journals".
- Excluding irrelevant countries presenting more than 10 papers (Nordic countries, developed countries where no significant mangroves/corals are found or existed in the past, etc.). Countries cross-checked with FAO database www.fao.org/docrep/007/j1533e/J1533E00.htm and also World Map of Mangrove distribution http://en.wikipedia.org/wiki/File:World_map_mangrove_distribution.png

## 1.23 Web of Science

Subject terms in Topic and exposure terms in Title with the following restrictions:

**Current Limits:** (To save these permanently, sign in or register.)

**Timespan**

- ○ All Years (updated 2012-12-14)
- ● Date Range
  From: 1994-01-01 to: 2012-12-18
  - ☐ Use Processing Date instead of Publication Date

**Citation Databases**

- ☑ Science Citation Index Expanded (SCI-EXPANDED) --1900-present
- ☑ Social Sciences Citation Index (SSCI) --1900-present
- ☐ Arts & Humanities Citation Index (A&HCI) --1975-present
- ☐ Conference Proceedings Citation Index- Science (CPCI-S) --1991-present
- ☐ Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) --1991-present
- ☐ Book Citation Index– Science (BKCI-S) --2005-present
- ☐ Book Citation Index– Social Sciences & Humanities (BKCI-SSH) --2005-present

**Chemical Databases**

- ☐ Current Chemical Reactions (CCR-EXPANDED) --1985-present
  *(Includes Institut National de la Propriete Industrielle structure data back to 1840)*
- ☐ Index Chemicus (IC) --1993-present

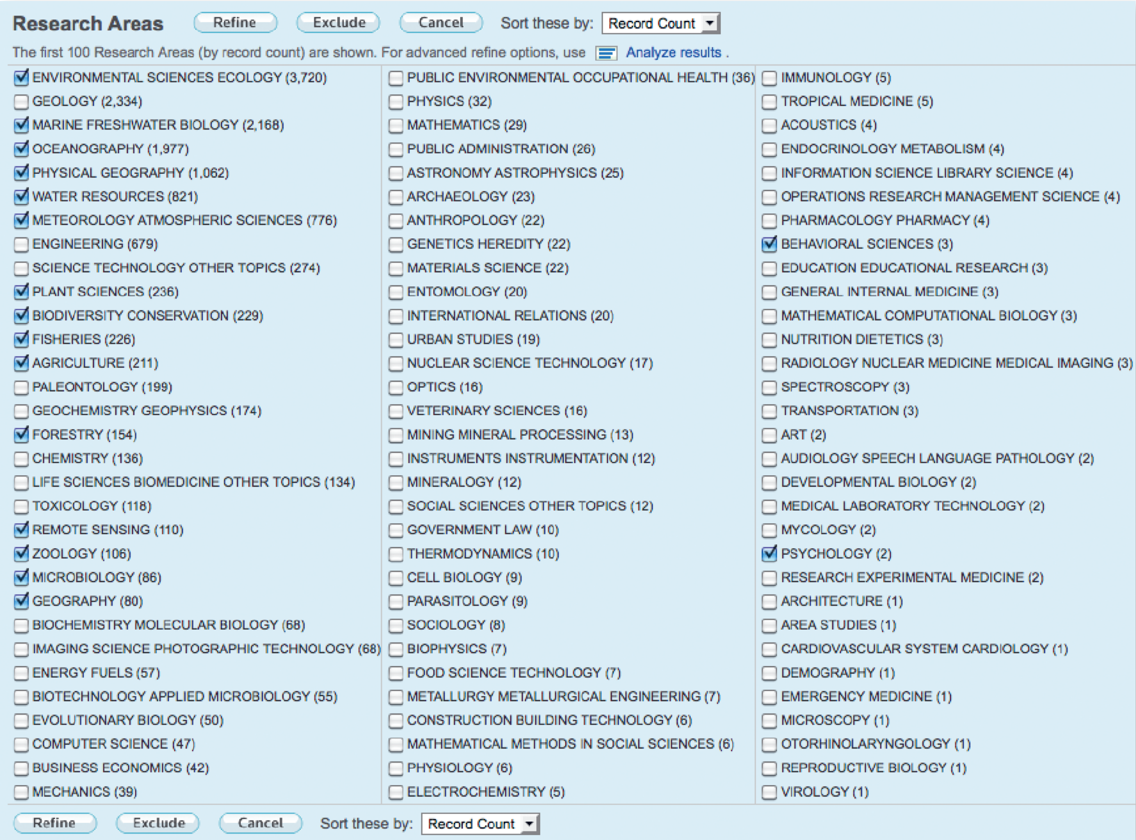
**Adjust your search settings**

Note: Spelling variations (such as US and UK spelling differences) in topic and title search terms are found aut feature, enter quotation marks around terms (for example, "colour").

Lemmatization Off
(finds alternative forms of the search term, for example, tooth and teeth)

**Adjust your results settings**

**Refined** languages to: ENGLISH
**Refined** document types to: Articles & Reviews




Excluded irrelevant countries as in Scopus.

## 1.24 Wiley Online subscribed journals

Subject terms in abstract and Exposure terms in article title. Years 1994–2013.
Filtered results to journal articles only.

## 1.25 ProQuest Research Library

Subject terms in abstract and Exposure terms in document title with the following restrictions and filters:

- Limit to: Peer-reviewed
- Specific date range: 01.01.1994 – 01.01.2013
- Document type: article, literature review
- Language: English

Filtered results by excluding the following locations:

## 1.26 JSTOR

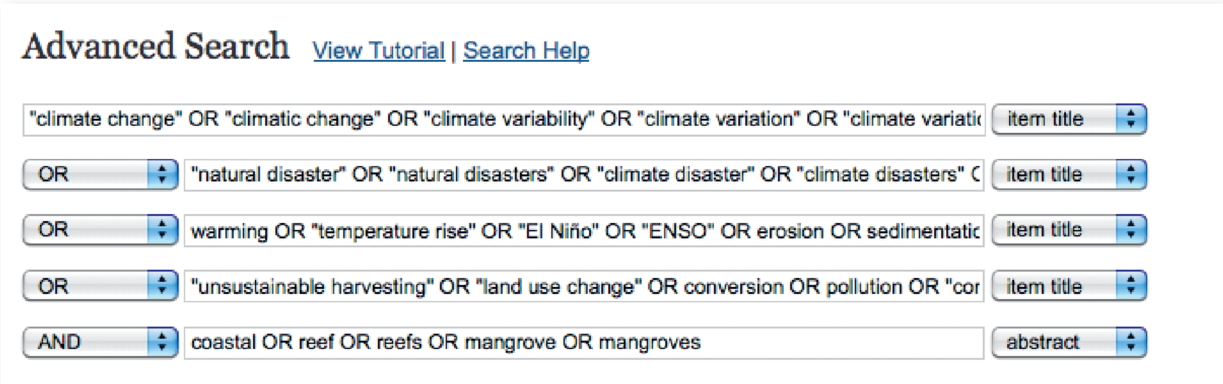
Due to restrictions in the use of wildcard terms, the search was performed as follows:

**FIRST SEARCH:**

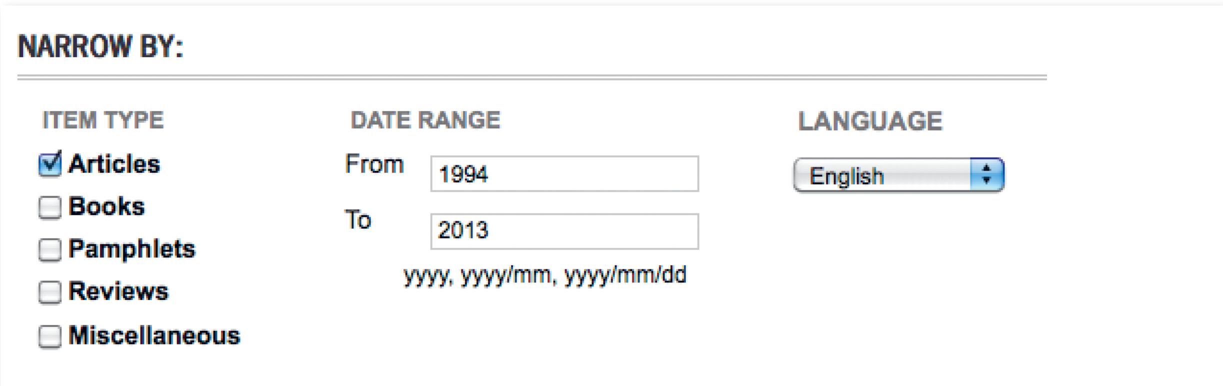
**Item title:**
"climate change" OR "climatic change" OR "climate variability" OR "climate variation" OR "climate variations" OR "climate extreme" OR "climate extremes" OR "coastal hazard" OR "coastal hazards"
*OR*
**Item title:**
"natural disaster" OR "natural disasters" OR "climate disaster" OR "climate disasters" OR flood* OR storm* OR drought* OR "sea level rise" OR "ocean acidification"
*OR*
**Item title:**
warming OR "temperature rise" OR "El Niño" OR "ENSO" OR erosion OR sedimentation OR deforestation OR "ecosystem degradation" OR "mangrove degradation" OR "reef degradation"
*OR*
**Item title:**
"unsustainable harvesting" OR "land use change" OR conversion OR pollution OR "coral mining" OR "blast fishing" OR logging OR tsunami

*AND*
**Abstract:**
coastal OR reef OR reefs OR mangrove OR mangroves

**SECOND SEARCH:**
**Item title:**
wind* OR typhoon* OR cyclone*
*AND*
**Abstract:**
coastal OR reef OR reefs OR mangrove OR mangroves
**Item title:**
hurricane*
*AND*
**Abstract:**
coastal OR reef OR reefs OR mangrove OR mangroves




With the following restrictions and filtering of results:



**Narrow by discipline and/or publication title**

- African American Studies (19 titles)
- African Studies (55 titles)
- American Indian Studies (8 titles)
- American Studies (125 titles)
- Anthropology (93 titles)
- Aquatic Sciences (17 titles)
- Asian Studies (73 titles)
- Biological Sciences (240 titles)
- Botany & Plant Sciences (57 titles)
- Development Studies (15 titles)
- Ecology & Evolutionary Biology (75 titles)
- Economics (173 titles)
- Feminist & Women's Studies (30 titles)
- General Science (29 titles)
- Geography (33 titles
- Latin American Studies (54 titles)
- Middle East Studies (55 titles)
- Political Science (152 titles)
- Population Studies (36 titles)
- Psychology (18 titles)
- Public Policy & Administration (38 titles)
- Sociology (128 titles)
- Statistics (50 titles)
- Zoology (65 titles)

# 1.3 Inclusion/exclusion criteria

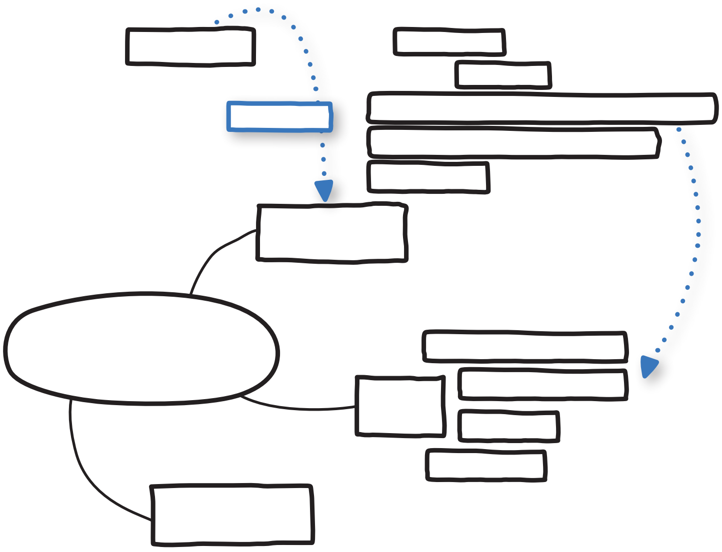
| INCLUDE FOR FURTHER ANALYSIS | EXAMPLES |
|---|---|
| Papers focusing on components of **mangrove and/or coral socio-ecological systems** that seem to have information related to **at least one question.**<br><br>By components of mangrove & coral socio-ecological system we don't only mean mangroves, corals, and humans, but also reef-dependent fish and any other related species.<br><br>**Questions:**<br><br>**GROUP 1:** What are the current and potential impacts and feedback loops of climate stressors (climate variability and change: from storms to sea-level rise etc.) and non-climate stressors (e.g. deforestation) on mangrove and coral socio-ecological systems?<br><br>1a. What are the impacts of climate stressors on mangrove and coral ecosystems?<br><br>1b. What are the combined effects of climate and non-climate stressors on mangrove and coral ecosystems?<br><br>1c. What are the impacts of climate stressors on society (people, economic sectors) in tropical and sub-tropical coastal areas?<br><br>**GROUP 2:** How can mangrove and coral reef ecosystem conservation, restoration, and management, contribute to the adaptation of society (people & economic sectors) to climate variability and change in tropical and sub-tropical coastal areas?<br><br>2a. What is the role of mangrove and coral ecosystem services in reducing the vulnerability of society?<br><br>2b. What are the management options for conserving or restoring mangrove and coral ecosystems and their services in a context of climate change?<br><br>2c. What are the institutional options for ecosystem-based adaptation (conserving/restoring/managing mangrove and coral ecosystem services for the reduction of social vulnerability)? | **Sharp, K. H., Ritchie, K. B., 2012.** Multi-partner interactions in corals in the face of climate change. Biological Bulletin 223, 66–77.<br><br>**Alongi, D. M., 2008.** Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science 76, 1–13. |
| Papers focusing only on **non-climate stressors in mangrove & coral** socio-ecological systems, or adjacent systems that influence mangrove & coral systems (such as upland watersheds) because:<br><br>• they can provide important information related to compound effects and feedback loops,<br><br>• but also more broadly related to impact chains (e.g. migration or food insecurity resulting from mangrove destruction). | **Fabricius, K. E., Golbuu, Y., Victor, S., 2007.** Selective mortality in coastal reef organisms from an acute sedimentation event. Coral Reefs 26, 69.<br><br>**Kragt, M. E., Roebeling, P. C., Ruijs, A., 2009.** Effects of Great Barrier Reef degradation on recreational reef-trip demand: A contingent behaviour approach. Australian Journal of Agricultural and Resource Economics 53, 213–229. |
| Papers that seem to focus only on **conservation/restoration in mangrove & coral** socio-ecological systems will also be included as they can provide information related to the management of mangrove & coral ecosystem services for adaptation. | **Affandi, N. A. M., Kamali, B., Mz, R., Tamin, N. M., Hashim, R., 2010.** Early growth and survival of Avicennia alba seedlings under excessive sedimentation. Scientific Research and Essays 5, 2801–2805. |

| | |
|---|---|
| Papers related to climate change, climate hazards, and/or vulnerability of people and/or ecosystems in **tropical & sub-tropical coastal areas** even if they do not directly mention mangroves or corals in title-abstract-keywords. | **Bunce, M., Brown, K., Rosendo, S., 2010.** Policy misfits, climate change and cross-scale vulnerability in coastal Africa: how development projects undermine resilience. Environmental Science and Policy 13, 485–497.<br><br>**Neil Adger, W., 1999.** Social vulnerability to climate change and extremes in coastal Vietnam. World Development 27, 249–269. |

| EXCLUDE FROM FURTHER ANALYSIS | EXAMPLES |
|---|---|
| Papers that do not seem to contain information related to our questions, such as:<br>• Papers focusing on modelling climate change but without delineating impacts;<br>• Papers focusing on the evolution/genetics of coral and mangrove species that do not mention impacts of climatic and anthropogenic stressors. | **Harding, J. M., Spero, H. J., Manna, R., Herbert, G. S., Sliko, J. L., 2010.** Reconstructing early 17th century estuarine drought conditions from Jamestown oysters. Proceedings of the National Academy of Sciences of the United States of America 107, 10549–10554.<br><br>**Gledhill, D. K., Wanninkhof, R., Eakin, C. M., 2009.** Observing ocean acidification from space. Oceanography 22, 48–59. |
| Papers focusing on **ecosystem management or degradation in coastal areas** (non-climate stressors) that do not specifically address mangroves or corals (absence of key terms from title-abstract-keywords). | **Rawlins, B. G., Ferguson, A. J., Chilton, P. J., Arthurtons, R. S., Grees, J. G., 1998.** Review of agricultural pollution in the Caribbean with particular emphasis on small island developing states. Marine Pollution Bulletin 36, 658–668. |
| Papers focusing on **climate change & vulnerability in marine environments of tropical & sub-tropical areas** (without focusing on coasts or coastal sea-scapes). | **Koehn, J. D., Hobday, A. J., Pratchett, M. S., Gillanders, B. M., 2011.** Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation. Marine and Freshwater Research 62, 1148–1164. |
| Papers focusing on **coastal areas outside of tropical & sub-tropical areas.** | **Airoldi, L., Cinelli, F., 1997.** Effects of sedimentation on subtidal macroalgal assemblages: An experimental study from a Mediterranean rocky shore. Journal of Experimental Marine Biology and Ecology 215, 269–288. |

# ANNEX 2

# NOTES ON IMPACT CHAINS



# 2.1 Acidification

## CORAL REEFS

### Decline in calcifying macroalgae and foraminifers

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Calcareous macroalgae and crustose coralline algae deposit calcium carbonate during growth and can thus contribute to reef structural strength. Relevant to calcifiers, elevated $CO_2$ lowers net calcification and this effect is amplified by high temperature. It influences fluxes that control the microenvironments promoting calcification over dissolution. Calcareous macroalgae are highly vulnerable to OA, and it is likely that fleshy macroalgae will dominate in a higher $CO_2$ ocean.
**STRESSOR INFORMATION:** Since the industrial revolution, the hydrogen ion concentration in the oceans has increased by approx. 30%, dropping the pH 0.1 units.
**SPECIFIC SPECIES DISCUSSED:** Calcareous and crustose coralline macroalgae
**RECOMMENDATIONS:** A better understanding of the stress-response mechanisms is needed. Furthermore, the biogeographical surveys of important species should be ongoing to document range shifts of economically and ecologically critical macro-autotroph species.
**REFERENCE:** Koch, M., Bowes, G., Ross, C., & Zhang, X. (2013). Climate change and ocean acidification effects on seagrasses and marine macroalgae. Global change biology, 19 (1), 103–132.

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** The common coral reef macroalgal genera Halimeda is highly susceptible to reduced pH and aragonite saturation state. Species of Halimeda produce a large proportion of the sand in the tropics and are a major contributor to framework development on reefs because of their rapid calcium carbonate production and high turnover rates.
H. opuntia suffered net dissolution and 15% reduction in photosynthetic capacity, while H. taenicola did not calcify but did not alter photophysiology in experimental treatments. The disparate responses of these species to elevated $CO_2$ partial pressure ($pCO_2$) may be due to anatomical and physiological differences and could represent a shift in their relative dominance in the face of ocean acidification. The ability for a species to exert biological control over calcification and the species specific role of the carbonate skeleton may have important implications for the potential effects of acidification on ecological functions in the future.
**SPECIFIC SPECIES DISCUSSED:** Genera Halimeda: H opuntia and H taenicola
**RECOMMENDATIONS:** Little evidence exists to date regarding the potential biological consequences of ocean acidification for different species of Halimeda. There is an urgent need to conduct field experiments that harness the naturally varying carbonate chemistry across coral reefs to study the long-term response of coral reef organisms to change in the dissolved inorganic carbon.
**REFERENCE:** Price, N. N., Hamilton, S. L., Tootell, J. S., & Smith, J. E. (2011). Species-specific consequences of ocean acidification for the calcareous tropical green algae Halimeda. Marine Ecology Progress Series, 440, 67–78.

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Experiments exposing Crustose coralline algae (CCA) to elevated $pCO_2$ (2× present day) indicate up to a 40% reduction in growth rates, 78% decrease in recruitment, 92% reduction in total area covered by CCA, and a 52% increase in non-calcifying algae.
**STRESSOR INFORMATION:** Since the Industrial Revolution, a time span of less than 250 years, the pH of surface oceans has dropped by 0.1 pH units (representing an approximately 30% increase in hydrogen ion concentration relative to the preindustrial value) and is projected to drop another 0.3–0.4 pH units by the end of this century.
**RECOMMENDATIONS:** Future ocean acidification research needs include increased resources and efforts devoted to lab, mesocosm, and in situ experiments, all of which will aid in determining the biological responses of marine taxa to increased $pCO_2$.
**REFERENCE:** Guinotte, J. M., & Fabry, V. J. (2008). Ocean acidification and its potential effects on marine ecosystems. Annals of the New York Academy of Sciences, 1134 (1), 320–342.

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** In a culture experiment with two algal symbiont-bearing, reef-dwelling foraminifers, Amphisorus kudakajimensis and Calcarina gaudichaudii, in seawater under five different $pCO_2$ conditions, 245, 375, 588, 763 and 907 atm, maintained with a precise $pCO_2$-controlling technique, net calcification of A. kudakajimensis was reduced under higher $pCO_2$, whereas calcification of C. gaudichaudii generally increased with increased $pCO_2$. In another culture experiment conducted in seawater in which bicarbonate

ion concentrations were varied under a constant carbonate ion concentration, calcification was not significantly different between treatments in Amphisorus hemprichii, a species closely related to A. kudakajimensis, or in C. gaudichaudii. The opposite responses of these two foraminifer genera probably reflect different sensitivities to these carbonate species, which may be due to their different symbiotic algae.
**SPECIFIC SPECIES DISCUSSED:** Amphisorus kudakajimensis and Calcarina gaudichaudii
**REFERENCE:** Hikami, M., Ushie, H., Irie, T., Fujita, K., Kuroyanagi, A., Sakai, K., Nojiri, Y., Suzuki, A., Kawahata, H. (2011). Contrasting calcification responses to ocean acidification between two reef foraminifers harboring different algal symbionts. Geophysical Research Letters, 38 (19), L19601.

**REGION/COUNTRY OF STUDY:** Hawaii
**IMPACT DESCRIPTION:** Acidification had a profound impact on the development and growth of crustose coralline algae (CCA) populations. During experiments of this study, CCA developed 25% cover in the control mesocosms and only 4% in the acidified mesocosms, representing an 86% relative reduction. Free-living associations of CCA known as rhodoliths living in the control mesocosms grew at a rate of 0.6 g buoyant weight year (–1) while those in the acidified experimental treatment decreased in weight at a rate of 0.9 g buoyant weight year (–1), representing a 250% difference.
**REFERENCE:** Jokiel, P., Rodgers, K., Kuffner, I., Andersson, A., Cox, E., & Mackenzie, F. (2008). Ocean acidification and calcifying reef organisms: a mesocosm investigation. Coral Reefs, 27 (3), 473–483.

## Decline in coral calcification and growth

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Ocean acidification leads to changes in marine carbonate chemistry that are predicted to cause a decline in future coral reef calcification. Experiments and in situ studies on natural coral reefs have shown a direct relationship between aragonite saturation state (Omega (arag)) and net community calcification (G (net)). Measurements of extreme diurnal variability in carbonate chemistry within a reef flat in the southern Great Barrier Reef, Australia, showed that Omega (arag) varied between 1.1 and 6.5, thus exceeding the magnitude of change expected this century in open ocean subtropical/tropical waters. The observed variability comes about through biological activity on the reef, where changes to the carbonate chemistry are enhanced at low tide when reef flat waters are isolated from open ocean water. Net community calcification was found to be linearly related to Omega (arag), while temperature and nutrients had no significant effect on G (net). Net community calcification is thus projected to decline by 55% of its preindustrial value by the end of the century.
**RECOMMENDATIONS:** It is not known at this stage whether exposure to large variability in carbonate chemistry will make reef flat organisms more or less vulnerable to the non-calcifying physiological effects of increasing ocean $CO_2$ and future laboratory studies will need to incorporate this natural variability to address this question. Future work investigating the responses of different natural coral reef communities to carbonate chemistry will also be needed and an understanding of why the different systems show different responses will be required in order to make quantitative global predictions about coral reef responses to ocean acidification.
**REFERENCE:** Shaw, E. C., McNeil, B. I., & Tilbrook, B. (2012). Impacts of ocean acidification in naturally variable coral reef flat ecosystems. Journal of Geophysical Research: Oceans (1978–2012), 117 (C3).

**REGION/COUNTRY OF STUDY:** Oceania
**IMPACT DESCRIPTION:** This study shows that endosymbiotic algae in foraminifera benefit from increased dissolved inorganic carbon (DIC) availability and may be naturally carbon limited. Productivity, respiration, and abundances of the symbiont-bearing foraminifer species Marginopora vertebralis on natural $CO_2$ seeps in Papua New Guinea and production and calcification on the Great Barrier Reef (GBR) were studied using artificially enhanced $pCO_2$.
Production of M.vertebralis increased with increasing light and increasing $pCO_2$ and declined at higher temperatures. Respiration was also significantly elevated (similar to 25%), whereas calcification was reduced (1639%) at low pH/high $pCO_2$ compared to present-day conditions. In the field, M. vertebralis was absent at three $CO_2$ seep sites at pHTotal levels below similar to 7.9 ($pCO_2$ similar to 700 similar to mu atm), but it was found in densities of over 1000 similar to $m^{-2}$ at all three control sites.
The net outcome of these two competing processes is that M. vertebralis cannot maintain populations under $pCO_2$ exceeding 700 and thus are likely to be extinct in the next century.
**SPECIFIC SPECIES DISCUSSED:** M. vertebralis and corals of the Great Barrier Reef
**RECOMMENDATIONS:** To improve predictions of the ecological effects of ocean acidification, the net gains and losses between the processes of photosynthesis and calcification need to be studied jointly on physiological and population levels.
**REFERENCE:** Uthicke, S., & Fabricius, K. E. (2012).

Productivity gains do not compensate for reduced calcification under near-future ocean acidification in the photosynthetic benthic foraminifer species Marginopora vertebralis. Global Change Biology, 18 (9), 2781–2791.

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** A substantial decrease in the number of carbonate ions available in seawater will have serious implications for coral calcification rates and skeletal formation. This will lead to erosional processes to occur at much faster rates, and slower growth rates may also reduce corals' ability to compete for space and light. The net effect of ocean acidification on coral reef ecosystems will probably be negative as many reef-building marine calcifiers will be heavily impacted by the combined effects of increasing sea-surface temperatures (coral bleaching) and decreasing carbonate saturation states of surface waters in the coming decades.
**STRESSOR INFORMATION:** Since the Industrial Revolution, a time span of less than 250 years, the pH of surface oceans has dropped by 0.1 pH units (representing an approximately 30% increase in hydrogen ion concentration relative to the preindustrial value) and is projected to drop another 0.3 – 0.4 pH units by the end of this century.
**RECOMMENDATIONS:** Future ocean acidification research needs include increased resources and efforts devoted to lab, mesocosm, and in situ experiments, all of which will aid in determining the biological responses of marine taxa to increased $pCO_2$.
**REFERENCE:** Guinotte, J. M., & Fabry, V. J. (2008). Ocean acidification and its potential effects on marine ecosystems. Annals of the New York Academy of Sciences, 1134 (1), 320–342.

**REGION / COUNTRY OF STUDY:** Bermuda
**IMPACT DESCRIPTION:** There is a seasonal 'Carbonate Chemistry Coral Reef Ecosystem Feedback' (CREF hypothesis) between the primary components of the reef ecosystem (i.e., scleractinian hard corals and macroalgae) and seawater carbonate chemistry. In early summer, strong net autotrophy from benthic components of the reef system enhance [CO(3)(2–)] and Omega (aragonite) conditions, and rates of coral calcification due to the photosynthetic uptake of CO(2). In late summer, rates of coral calcification are suppressed by release of CO(2) from reef metabolism during a period of strong net heterotrophy. It is likely that this seasonal CREF mechanism is present in other tropical reefs although attenuated compared to high-latitude reefs such as Bermuda. Due to lower annual mean surface seawater [CO(3)(2–)] and Omega (aragonite) in Bermuda compared to tropical regions, we anticipate that Bermuda corals will experience seasonal periods of zero net calcification within the next decade at [CO(3)(2–)] and Omega(aragonite) thresholds of similar to 184 mu moles $kg^{-1}$ and 2.65. However, net autotrophy of the reef during winter and spring (as part of the CREF hypothesis) may delay the onset of zero NEC or decalcification going forward by enhancing [CO(3)(2–)] and Omega (aragonite). The Bermuda coral reef is one of the first responders to the negative impacts of ocean acidification, and we estimate that calcification rates for D. labyrinthiformis have declined by > 50% compared to pre-industrial times. The study also anticipates that the Bermuda coral reef (as well as other high latitude reefs) will likely be subjected to "seasonal decalcification" with wintertime decalcification occurring many decades before summertime decalcification.
**SPECIFIC SPECIES DISCUSSED:** D. labyrinthiformis and Porites astreoides
**REFERENCE:** Bates, N., Amat, A., & Andersson, A. (2010). Feedbacks and responses of coral calcification on the Bermuda reef system to seasonal changes in biological processes and ocean acidification. Biogeosciences, 7 (8), 2509–2530.

**REGION / COUNTRY OF STUDY:** Panama
**IMPACT DESCRIPTION:** The rapid growth of scleractinian corals is responsible for the persistence of coral reefs through time. Coral growth rates have declined over the past 30 years in the western Pacific, Indian, and North Atlantic Oceans. A multi-species inventory of coral growth from Pacific Panama confirms that declines have occurred in some, but not all species. Linear extension declined significantly in the most important reef builder of the eastern tropical Pacific, Pocillopora damicornis, by nearly one-third from 1974 to 2006. The rate of decline in skeletal extension for P. damicornis from Pacific Panama (0.9% $year^{-1}$) was nearly identical to massive Porites in the Indo-Pacific over the past 20–30 years (0.89 – 1.23% $year^{-1}$). The branching pocilloporid corals have shown an increased tolerance to recurrent thermal stress events in Panama, but appear to be susceptible to acidification. In contrast, the massive pavonid corals have shown less tolerance to thermal stress, but may be less sensitive to acidification. These differing sensitivities will be a fundamental determinant of eastern tropical Pacific coral reef community structure with accelerating climate change that has implications for the future of reef communities worldwide.
**SPECIFIC SPECIES DISCUSSED:** Different species such as P.damicornis, pocilloporid and pavonid corals, etc.
**REFERENCE:** Manzello, D. (2010). Coral growth with thermal stress and ocean acidification: lessons from the eastern tropical Pacific. Coral Reefs, 29 (3), 749–758.

### Microbial shifts

**REGION/COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** The sensitivity of microbes associated with coral reef biofilms and representatives of three ecologically important calcifying invertebrate phyla [corals, foraminifera and crustose coralline algae (CCA)] to acidification was explored in this study. All reduced pH/increased $pCO_2$ treatments caused clear differences in the microbial communities associated with coral, foraminifera, CCA and reef biofilms over six weeks, while no visible signs of host stress were detected over this period. The microbial communities of coral, foraminifera, CCA and biofilms were significantly different between pH 8.1 ($pCO_2 = 464$ µatm) and pH 7.9 ($pCO_2 = 822$ µatm), a concentration likely to be exceeded by the end of the present century. This trend continues at lower pHs/higher $pCO_2$.
**RECOMMENDATIONS:** The high sensitivity of coral, foraminifera, CCA and biofilm microbes to OA conditions projected to occur by 2100 is a concern for reef ecosystems and highlights the need for urgent research to assess the implications of microbial shifts for host health and coral reef processes.
**REFERENCE:** Webster, N., Negri, A., Flores, F., Humphrey, C., Soo, R., Botté, E., Vogel, N., Uthicke, S. (2012). Near-future ocean acidification causes differences in microbial associations within diverse coral reef taxa. Environmental microbiology reports.

### Decrease in coral reef cover

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** The decline in calcium carbonate production, coupled with an increase in calcium carbonate dissolution, will diminish reef building and the benefits that reefs provide, such as high structural complexity that supports biodiversity on reefs, and breakwater effects that protect shorelines and create quiet habitats for other ecosystems, such as mangroves and seagrass beds. These changes can degrade the reef's resilience (i.e., its ability to withstand disturbance) even while it appears visibly healthy, until at some point it can no longer sustain even minor disturbances, and becomes vulnerable to an ecological "regime shift," that is, a rapid transition to a different ecosystem state. As ocean acidification proceeds, more and more species will be affected. Some species will be losers (e.g., corals) and some will be winners (e.g., seagrasses), but the higher the proportion of species that are affected (including winners and losers), the higher the probability that some major function of the ecosystem (e.g., reef building, grazing, filter feeding, sediment turnover) will collapse, leading to a regime shift.
**REFERENCE:** Kleypas, J. A., & Yates, K. K. (2009). Coral reefs and ocean acidification. Oceanography, 22 (4), 108–117.

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Ocean acidification is expected to cause declines in carbonate communities due to decreases in carbonate availability, reductions in the creation of carbonate structures, their structural stability, and larvae survival and growth. Cold water communities are predicted to decline first due to a lower aragonite saturation horizon in cold waters.
**REFERENCE:** Lundquist, C. J., Ramsay, D., Bell, R., Swales, A., & Kerr, S. (2011). Predicted impacts of climate change on New Zealand's biodiversity. Pacific Conservation Biology, 17 (3), 179.

## REEF FISH

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** The effect of $CO_2$ on predator-prey relationships in reef fish communities was examined in this study. Mortality rate and predator selectivity were compared across $CO_2$ treatments, prey size and species. Evidence suggests that $CO_2$ induces marked changes in behaviour. Acidification may affect the predators by switching their foraging preference and/or the prey by creating species-specific alterations in anti-predator responses. Research showed that exposure to elevated $CO_2$ affects both olfactory and auditory senses and a diverse range of behavioural activities in larval and adult fishes. It also directly affects brain function in larval fishes.
Small juveniles of all species sustained greater mortality at high $CO_2$ levels, while large recruits were not affected. For large prey, the pattern of prey selectivity by predators was reversed under elevated $CO_2$. The results demonstrate both quantitative and qualitative consumptive effects of $CO_2$ on small and larger damselfish recruits respectively, resulting from $CO_2$-induced behavioural changes likely mediated by impaired neurological functions.
**SPECIFIC SPECIES DISCUSSED:** Pseudochromis fuscus (predator fish), Pomacentrus moluccensis, P.amboinensis, P.nagasakiensis and P.chrysurus (prey fish)
**RECOMMENDATIONS:** Further research should also examine neurological effects and not just focus on impaired sensory perception.
**REFERENCE:** Ferrari, M. C., McCormick, M. I., Munday, P. L., Meekan, M. G., Dixson, D. L., Lonnstedt, Ö., & Chivers, D. P. (2011). Putting prey and predator into the $CO_2$ equation-qualitative and quantitative effects of

ocean acidification on predator-prey interactions. Ecology letters, 14 (11), 1143–1148.

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Elevated $CO_2$ partial pressures (hypercapnia) will affect the physiology of water-breathing animals by inducing acidosis in the tissues and body fluids of marine organisms, including fishes. pH, bicarbonate, and $CO_2$ levels within the organism are altered with long-term effects on metabolic functions, growth, and reproduction, all of which could be harmful at population and species levels.
**STRESSOR INFORMATION:** Since the Industrial Revolution, a time span of less than 250 years, the pH of surface oceans has dropped by 0.1 pH units (representing an approximately 30% increase in hydrogen ion concentration relative to the preindustrial value) and is projected to drop another 0.3 – 0.4 pH units by the end of this century.
**RECOMMENDATIONS:** Future ocean acidification research needs include increased resources and efforts devoted to lab, mesocosm, and in situ experiments, all of which will aid in determining the biological responses of marine taxa to increased $pCO_2$.
**REFERENCE:** Guinotte, J. M., & Fabry, V. J. (2008). Ocean acidification and its potential effects on marine ecosystems. Annals of the New York Academy of Sciences, 1134 (1), 320–342.

## SEAGRASS BEDS

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Although photosynthetic and growth rates of marine macro-autotrophs are likely to increase under elevated $CO_2$ (similarly to terrestrial species), there has been a serious decline of seagrass meadows with a loss accelerating from about 1% $year^{-1}$ before 1940 to 7% $year^{-1}$ presently. Furthermore, certain invasive species will be able to grow faster due to the change in pH.
**STRESSOR INFORMATION:** Since the industrial revolution, the hydrogen ion concentration in the oceans has increased by approx. 30%, dropping the pH 0.1 units.
**RECOMMENDATIONS:** A better understanding of the stress-response mechanisms is needed. Furthermore, the biogeographical surveys of important species should be ongoing to document range shifts of economically and ecologically critical macro-autotroph species.
**REFERENCE:** Koch, M., Bowes, G., Ross, C., & Zhang, X. (2013). Climate change and ocean acidification effects on seagrasses and marine macroalgae. Global change biology, 19 (1), 103–132.

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Seagrass ecosystems could be one of the few ecosystems that stand to benefit from increasing levels of $CO_2$ in the seawater. Seagrasses are capable of dehydrating HCO−3, but many appear to use $CO_2$ (aq) for at least 50% of their carbon requirements used for photosynthesis. It is probable that an increase in total seagrass area will lead to more favourable habitat and conditions for associated invertebrate and fish species.
**STRESSOR INFORMATION:** Since the Industrial Revolution, a time span of less than 250 years, the pH of surface oceans has dropped by 0.1 pH units (representing an approximately 30% increase in hydrogen ion concentration relative to the preindustrial value) and is projected to drop another 0.3 – 0.4 pH units by the end of this century.
**RECOMMENDATIONS:** Future ocean acidification research needs include increased resources and efforts devoted to lab, mesocosm, and in situ experiments, all of which will aid in determining the biological responses of marine taxa to increased $pCO_2$.
**REFERENCE:** Guinotte, J. M., & Fabry, V. J. (2008). Ocean acidification and its potential effects on marine ecosystems. Annals of the New York Academy of Sciences, 1134 (1), 320–342.

## COASTAL COMMUNITIES

### Decline in fishery harvests & revenues

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** Ocean acidification will change marine ecosystems profoundly by increasing dissolved $CO_2$ and decreasing ocean pH, carbonate ion concentration, and calcium carbonate mineral saturation state worldwide. These conditions hinder growth of calcium carbonate shells and skeletons by many marine plants and animals. The first direct impact on humans may be through declining harvests and fishery revenues from shellfish, their predators, and coral reef habitats. This study examines US commercial fishery revenues to project the economic effects of ocean acidification over the next 50 years using atmospheric $CO_2$ trajectories and laboratory studies of its effects, focusing especially on mollusks. In 2007, the $ 3.8 billion US annual domestic ex-vessel commercial harvest ultimately contributed $ 34 billion to the US gross national product. Mollusks contributed 19%, or $ 748 million, of the ex-vessel revenues that year. Substantial revenue declines, job losses, and indirect economic costs may occur if ocean acidification broadly damages marine habitats, alters marine resource availability, and disrupts other ecosystem services.

**RECOMMENDATIONS:** Designing new policies must begin with comprehensive research targeted towards regional needs. First, expanded time series studies of coastal and open ocean seawater chemistry are needed to monitor ocean acidification's progress. Second, basic studies at the organism level are required to enhance our currently limited knowledge of commercial and keystone species' responses to decreased pH and elevated $CO_2$. Third, ecosystem-wide studies are needed to shed light on secondary effects from habitat and prey losses. Fourth, economic and social science studies are needed to understand better how markets, prices, and communities will respond to declining fishery harvests and how best to mitigate potential socio-economic impacts.
**REFERENCE:** Cooley, S.R., & Doney, S.C. (2009). Anticipating ocean acidification's economic consequences for commercial fisheries. Environmental Research Letters, 4 (2), 024007.

# 2.2 Ocean-SST warming

## CORAL REEFS

### Growth decline

**REGION / COUNTRY OF STUDY:** Red Sea region
**IMPACT DESCRIPTION:** Sea surface temperature (SST) across much of the tropics has increased by 0.4° to 1° C since the mid-1970s, with a parallel increase in the frequency and extent of coral bleaching and mortality. Steadily rising SSTs are already driving dramatic changes in the growth of an important reef-building coral in the central Red Sea. Three-dimensional computed tomography analyses of the massive coral Diploastrea heliopora reveal that skeletal growth of apparently healthy colonies has declined by 30% since 1998. The same corals responded to a short-lived warm event in 1941/1942, but recovered within three years as the ocean cooled. Combining our data with climate model simulations by the Intergovernmental Panel on Climate Change, we predict that should the current warming trend continue, this coral could cease growing altogether by 2070.
**STRESSOR INFORMATION:** SST will reach a high of 2.5° to 3° C relative to the 2000–2008 mean by 2099
**SPECIFIC SPECIES DISCUSSED:** Diploastrea heliopora
**REFERENCE:** Cantin, N.E., Cohen, A.L., Karnauskas, K.B., Tarrant, A.M., & McCorkle, D.C. (2010). Ocean warming slows coral growth in the central Red Sea. Science, 329 (5989), 322–325.

### Bleaching

**REGION / COUNTRY OF STUDY:** Western Indian Ocean
**IMPACT DESCRIPTION:** The impact of climate change through thermal stress-related coral bleaching on coral reefs of the Western Indian Ocean has been well documented and is caused by rising sea water temperatures associated with background warming trends and extreme climate events. Bleaching occurs when corals' ability to sustain zooxanthellae (algae residing in corals through a symbiotic relationship) with nutrients for photosynthesis is compromised due to environmental factors such as increases in temperatures and other conditions. This leads to the expulsion of the zooxanthellae.
**RECOMMENDATIONS:** Reef management planning should embrace three concepts that relate to coral-zooxanthellae holobiont and reef vulnerability to thermal stress: 'ther-

mal protection', where some reefs are protected from the thermal conditions that induce bleaching and/or where local physical conditions reduce bleaching and mortality levels; 'thermal resistance', where individual corals bleach to differing degrees to the same thermal stress; and 'thermal tolerance', where individual corals suffer differing levels of mortality when exposed to the same thermal stress.

'Resilience to bleaching' is a special case of ecological resilience, where recovery following large-scale bleaching mortality varies according to ecological and other processes. Thermal resistance and tolerance are genetic properties and may interact with environmental protection properties resulting in phenotypic variation in bleaching and mortality of corals. The presence or absence of human threats and varying levels of reef management may alter the influence of the above factors, particularly through their impacts on resilience, offering the opportunity for management interventions to mitigate the impacts of thermal stress and recovery on coral reefs.

**REFERENCE:** Obura, D. O. (2005). Resilience and climate change: lessons from coral reefs and bleaching in the Western Indian Ocean. Estuarine, Coastal and Shelf Science, 63 (3), 353–372.

**REGION / COUNTRY OF STUDY:** Global

**IMPACT DESCRIPTION:** In 1998, tropical sea surface temperatures were the highest on record, topping off a 50-year trend for some tropical oceans. In the same year, coral reefs around the world suffered the most extensive and severe bleaching (loss of symbiotic algae) and subsequent mortality on record. The global threat of rising temperatures compounds the effects of more localized anthropogenic factors that already place reefs at risk.

**STRESSOR INFORMATION:** Steadily rising baseline of marine temperatures, combined with regionally specific El Niño and La Niña events.

**RECOMMENDATIONS:** Significant attention needs to be given to the monitoring of coral reef ecosystems, research on the projected and realized effects of global climate change, and measures to curtail greenhouse gas emissions. Even those reefs with well-enforced legal protection as marine sanctuaries, or those managed for sustainable use, are threatened by global climate change. Even under ideal conditions, significant changes in community structure will occur. There is thus a need to increase the urgency and effectiveness with which we manage the stressors that already place reefs at risk (e.g. anthropogenic).

**REFERENCE:** Reaser, J. K., Pomerance, R., & Thomas, P. O. (2000). Coral bleaching and global climate change: scientific findings and policy recommendations. Conservation Biology, 14 (5), 1500–1511.

**REGION / COUNTRY OF STUDY:** India

**IMPACT DESCRIPTION:** Bleaching events in three Indian coral reef regions were examined in relation to rising sea surface temperatures using quantitative rapid assessment methods between April and July, 1998. The Gulf of Kutch reefs showed an average of 11% bleached coral with no apparent bleaching-related mortality. In contrast, bleached coral comprised 82% of the coral cover in lagoon reefs of Lakshadweep and 89% of the coral cover in the Gulf of Mannar reefs. Bleaching-related mortality was high – 26% in Lakshadweep and 23% in Mannar.

**STRESSOR INFORMATION:** SST warming related to the 1997–1998 El Niño Southern Oscillation (ENSO) events

**RECOMMENDATIONS:** The coral mass mortality may have profound ecological and socio-economic implications and highlights the need for sustained monitoring for coral reef conservation in India.

**REFERENCE:** Arthur, R. (2000). Coral bleaching and mortality in three Indian reef regions during an El Niño southern oscillation event. Current Science, 79 (12), 1723–1729.

## Coral degradation and mortality

**REGION / COUNTRY OF STUDY:** Indian Ocean

**IMPACT DESCRIPTION:** Many corals in this region bleached and subsequently died during the 1998 ENSO events, probably due to the high water temperatures in combination with other meteorological and climatic factors. Massive mortality occurred on the reefs of Sri Lanka, Maldives, India, Kenya, Tanzania, and Seychelles with mortalities of up to 90% in many shallow areas. On reefs in other parts of the Indian Ocean, or in waters below 20 m, coral mortality was typically 50%. Hence, coral death during 1998 was unprecedented in severity.

**STRESSOR INFORMATION:** The year 1998, was the warmest year since the start of temperature recordings some 150 years ago. Similarly, the 1990s have been the warmest decade recorded. In addition, 1998 saw the strongest El Niño ever recorded. As a consequence of this, very high water temperatures were observed in many parts of the oceans, particularly in the tropical Indian Ocean, often with temperatures of 3° to 5° C above normal.

**RECOMMENDATIONS:** Enhance current reef management by reducing anthropogenic impacts and implementing integrated coastal management.

**REFERENCE:** Wilkinson, C., Lindén, O., Cesar, H., Hodgson, G., Rubens, J., & Strong, A. E. (1999). Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? Ambio, 28 (2).

**REGION / COUNTRY OF STUDY:** Panama
**IMPACT DESCRIPTION:** Abundance and size structure of two populations of the massive reef coral Gardineroseris planulata in non-upwelling (Uva Island reef in the Gulf of Panama) and upwelling (Pearl Island reefs in the Gulf of Chiriqui) environments affected by the 1997–1998 El Nino-Southern Oscillation (ENSO) event were measured in May 1999. A dynamic simulation model was used to predict changes in abundance and size structure of these two populations incorporating major ecological processes, and predictions were compared to the field measures. The results suggest that the rate of sea-surface temperature increase during an ENSO event is a key predictor of mortality for these species of coral. However, mortality also depends on the condition of the reefs prior and during the disturbance event.
**SPECIFIC SPECIES DISCUSSED:** G. planulata
**REFERENCE:** Fong, P., & Glynn, P.W. (2001). Population abundance and size-structure of an eastern tropical Pacific reef coral after the 1997–98 Enso: a simulation model predicts field measures. Bulletin of marine science, 69 (1), 187–202.

**REGION / COUNTRY OF STUDY:** Ecuador, Panama
**IMPACT DESCRIPTION:** Bleaching and mortality of zooxanthellate corals during the 1997–1998 ENSO event are documented for eastern equatorial Pacific localities in Panama and Ecuador. Overall, the very strong 1997–1998 and 1982–1983 ENSOs were similar in magnitude and duration, but varied spatially, resulting in different patterns of elevated sea temperature stress and coral responses during the two disturbance events. Coral mortality was notably higher (52–97%) in the eastern equatorial Pacific in 1982–1983 than in 1997–1998. Coral mortality among most sites within localities was also significantly different. Highest coral mortalities occurred at offshore compared with near-shore sites in Panama, and at the Galápagos Islands compared with mainland Ecuador. Although species responses varied among localities, tissue death was especially high in Millepora spp., Pavona spp., Pocillopora spp., and Porites spp. Corals present in relatively deep (12–18 m), inter-reef habitats suffered lower rates of bleaching and mortality than similar and different species present in shallow (1–10 m) habitats. Furthermore, the use of molecular DNA techniques to compare algal symbionts in bleached and healthy coral colonies revealed a strong correlation between bleaching severity and symbiont genotype, regardless of depth. However, coral reef response to the 1997–1998 ENSO events cannot be fully understood without an appreciation of spatial/temporal variability and the historical stresses to which these reefs have been subject over the past 25+ yrs.
**SPECIFIC SPECIES DISCUSSED:** Millepora spp., Pavona spp., Pocillopora spp., and Porites spp., among others
**REFERENCE:** Glynn, P.W., Mate, J.L., Baker, A.C., & Calderon, M.O. (2001). Coral bleaching and mortality in panama and ecuador during the 1997–1998 El Nino Southern Oscillation Event: spatial/temporal patterns and comparisons with the 1982–1983 event. Bulletin of Marine Science, 69 (1), 79–109.

## Coral cover decline

**REGION / COUNTRY OF STUDY:** Western Indian Ocean (WIO)
**IMPACT DESCRIPTION:** Average coral cover in the Western Indian Ocean (WIO) declined by 37.72 ± 31.34% (Standard Deviation) across the 1998 climatic oscillation event. There was a significant regional variation in the cover before 1998, after 1998 and the relative change (decline) in coral cover across 1998 (from an increase of 13.89 ± 23.89% in NW Madagascar to a decline of 95.72 ± 3.67% in the central atolls of the Maldives). The highest decline in cover occurred in the central and central-northern WIO regions and the Arabian and Oman Gulfs. The most severely affected reef areas were southern India, Sri Lanka, central atolls of the Maldives and Granite Seychelles. The Red Sea, Mayotte, Comoros, southern Mozambique, South Africa, Madagascar, Reunion, Mauritius and Rodrigues were the least affected. Finally, cover change was negatively associated with standard deviation (SD) SST until about SD 2.3, with increasing flatness of the SST frequency distributions. It increased with further increase in SD as the SST distributions became strongly bimodal in the Arabian/Persian Gulf area.
**STRESSOR INFORMATION:** SST warming related to the 1997–1998 El Niño Southern Oscillation (ENSO) events.
**RECOMMENDATIONS:** The study indicates that environmental resistance/tolerance to extreme anomalous events could be predicted and management priorities directed accordingly for a warmer and more variable future climate. Prioritizing conservation in areas that have the ecological capacity to resist and tolerate climatic changes is recommended.
**REFERENCE:** Ateweberhan, M., & McClanahan, T.R. (2010). Relationship between historical sea-surface temperature variability and climate change-induced coral mortality in the western Indian Ocean. Marine Pollution Bulletin, 60 (7), 964–970.

## Fish stock decline

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Climate change will impact coral-reef fishes through effects on individual performance, trophic linkages, recruitment dynamics, population connectivity and other ecosystem processes. The most immediate impacts will be a loss of diversity and changes to fish community composition as a result of coral bleaching. Coral-dependent fishes suffer the most rapid population declines as coral is lost; however, many other species will exhibit long-term declines due to loss of settlement habitat and erosion of habitat structural complexity.
**RECOMMENDATIONS:** Improved projections of how ocean currents and primary productivity will change are needed to better predict how reef fish population dynamics and connectivity patterns will change. Need to maintain healthy predator and herbivore fish populations to provide a certain amount of resilience to climatically induced changes.
**REFERENCE:** Munday, P. L., Jones, G. P., Pratchett, M. S., & Williams, A. J. (2008). Climate change and the future for coral reef fishes. Fish and Fisheries, 9 (3), 261–285.

## Loss of livelihoods

**REGION / COUNTRY OF STUDY:** Indian Ocean
**IMPACT DESCRIPTION:** Many corals in this region bleached and subsequently died during the 1998 ENSO events due to the high water temperatures in combination with other meteorological and climatic factors. The secondary socioeconomic effects of coral bleaching for coastal communities of the Indian Ocean are likely to be long lasting and severe. One such impact, which was also observed in the aftermath of the 1998 bleaching events, was the decrease in tourism income due to the changes in reef fish populations that are main attraction for divers.
**STRESSOR INFORMATION:** The year 1998 was the warmest year since the start of temperature recordings some 150 years ago. Similarly, the 1990s have been the warmest decade recorded. In addition, 1998 saw the strongest El Niño ever recorded. As a consequence of this, very high water temperatures were observed in many parts of the oceans, particularly in the tropical Indian Ocean, often with temperatures of 3° to 5° C above normal.
**RECOMMENDATIONS:** Enhance current reef management by reducing anthropogenic impacts and implementing integrated coastal management.
**REFERENCE:** Wilkinson, C., Lindén, O., Cesar, H., Hodgson, G., Rubens, J., & Strong, A. E. (1999). Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? Ambio, 28 (2).

## Loss of protective services & coastal erosion

**REGION / COUNTRY OF STUDY:** Indian Ocean
**IMPACT DESCRIPTION:** Many corals in this region bleached and subsequently died during the 1998 ENSO events due to the high water temperatures in combination with other meteorological and climatic factors. The secondary socioeconomic effects of coral bleaching for coastal communities of the Indian Ocean are likely to be long lasting and severe. In addition to potential decreases in fish stocks and negative effects on tourism, erosion may become an acute problem, particularly in the Maldives and Seychelles. Erosion will result from losses of the protective barrier function of the reefs.
**STRESSOR INFORMATION:** The year 1998 was the warmest year since the start of temperature recordings some 150 years ago. Similarly, the 1990s have been the warmest decade recorded. In addition, 1998 saw the strongest El Niño ever recorded. As a consequence of this, very high water temperatures were observed in many parts of the oceans, particularly in the tropical Indian Ocean, often with temperatures of 3° to 5° C above normal.
**RECOMMENDATIONS:** Enhance current reef management by reducing anthropogenic impacts and implementing integrated coastal management.
**REFERENCE:** Wilkinson, C., Lindén, O., Cesar, H., Hodgson, G., Rubens, J., & Strong, A. E. (1999). Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? Ambio, 28 (2).

## Susceptibility to disease & predators

**REGION / COUNTRY OF STUDY:** Ecuador, Panama
**IMPACT DESCRIPTION:** Bleaching and mortality of zooxanthellate corals during the 1997–1998 ENSO event are documented for eastern equatorial Pacific localities in Panama and Ecuador. Numerous delayed effects of coral bleaching were observed including predator concentration, increased bio-erosion, susceptibility to disease by parasites and pathogens, and a decreased capacity for wound healing.
**SPECIFIC SPECIES DISCUSSED:** Millepora spp., Pavona spp., Pocillopora spp., and Porites spp., among others.
**REFERENCE:** Glynn, P. W., Mate, J. L., Baker, A. C., & Calderon, M. O. (2001). Coral bleaching and mortality in panama and ecuador during the 1997–1998 El Nino

Southern Oscillation Event: spatial/temporal patterns and comparisons with the 1982–1983 event. Bulletin of Marine Science, 69 (1), 79–109.

### Decrease in tourism

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Climate change impacts such as coral bleaching are now evident on many coral reefs visited by tourists. Coral bleaching affects the tourism industry as the appearance of corals is no longer attractive. Unsustainable tourism practices add to the compound effects, aggravating reef degradation further.
**RECOMMENDATIONS:** Adaptation of the tourist industry by certain tourism operators include: lowering the running speed of boats by 30%, replanting in the GBR catchment, and encouraging environmental protection by customers. It would be useful to compare climate change responses by agencies in other coral reef parks, the use of greening initiatives as a marketing tool by reef tourism operators and whether these responses influence tourist behaviour in choosing a reef destination or tour operator.
**REFERENCE:** Zeppel, H. (2012). Climate change and tourism in the Great Barrier Reef Marine Park. Current Issues in Tourism, 15 (3), 287–292.

### Adaptive symbiont shifts

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** The long-term response to climate change of coral reefs that survive extreme events depends on the ability of reef-building coral symbioses to adapt or acclimatize to warmer temperatures. Corals containing unusual algal symbionts that are thermally tolerant and commonly associated with high-temperature environments were found to be much more abundant on reefs that have been severely affected by recent climate change. This adaptive shift in symbiont communities indicates that these devastated reefs could be more resistant to future thermal stress, resulting in significantly longer extinction times for surviving corals than had been previously assumed.
**REFERENCE:** Baker, A. C., Starger, C. J., McClanahan, T. R., & Glynn, P. W. (2004). Coral reefs: corals' adaptive response to climate change. Nature, 430 (7001), 741–741.

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** However, adaptive symbiont shift does not happen easily and is not possible in all environments. To test the ability of corals to acquire exogenous symbionts, bleached colonies of Porites divaricata were exposed to symbiont types not normally found within this coral and symbiont acquisition was monitored. After three weeks exposure to exogenous symbionts, these novel symbionts were detected in some of the recovering corals, providing the first experimental evidence that scleractinian corals are capable of temporarily acquiring symbionts from the water column after bleaching. However, the acquisition was transient, indicating that the new symbioses were unstable. Only those symbiont types present before bleaching were stable upon recovery, demonstrating that recovery was from the resident in situ symbiont populations. Some corals do not have the ability to adjust to climate warming by acquiring and maintaining exogenous, more stress-tolerant symbionts.
**REFERENCE:** Coffroth, M. A., Poland, D. M., Petrou, E. L., Brazeau, D. A., & Holmberg, J. C. (2010). Environmental symbiont acquisition may not be the solution to warming seas for reef-building corals. PloS one, 5 (10), e13258.

## REEF FISH

### Changes in species composition

**REGION / COUNTRY OF STUDY:** Arabian Gulf
**IMPACT DESCRIPTION:** To examine the role of climatic extremes in structuring reef fish communities in the Arabian region, reef fish communities were visually surveyed at four sites within the southern Persian Gulf (also known as the Arabian Gulf and The Gulf), where sea-surface temperatures are extreme (range: 12–35° C annually), and these were compared with communities at four latitudinally similar sites in the biogeographically connected Gulf of Oman, where conditions are more moderate (range: 22–31° C annually). Although sites were relatively similar in the cover and composition of coral communities, substantial differences in the structure and composition of associated fish assemblages were apparent. Fish assemblages in the southern Persian Gulf held significantly lower estimates of abundance, richness and biomass, with significantly higher abundances of smaller sized individuals than Gulf of Oman assemblages. Functionally, southern Persian Gulf sites held significantly lower abundances of nearly all the common fish trophic guilds found on Gulf of Oman sites, although higher abundances of herbivorous grazers were apparent. These results suggest the potential for substantial changes in the structure of reef-associated fish communities, independent of changes in habi-

tat within an environment of increasing fluctuations in oceanic climate.
**REFERENCE:** Feary, D., Burt, J., Bauman, A., Usseglio, P., Sale, P., & Cavalcante, G. (2010). Fish communities on the world's warmest reefs: what can they tell us about the effects of climate change in the future? Journal of fish biology, 77 (8), 1931–1947.

**REGION / COUNTRY OF STUDY:** Tropical Eastern Pacific
**IMPACT DESCRIPTION:** If sea temperature continues to increase at the current rate, in about a century it could exceed the thermal tolerance of some reef fishes and threaten them with extinction. Such risk, however, might occur sooner if the sea temperature during El Niño also increases in step with global warming, but also because other processes involved in maintaining population, such as reproduction, can be affected at lower temperatures.
**SPECIFIC SPECIES DISCUSSED:** Cirrhitichthys oxycephalus, Coryphopterus urospilus, Bathygobius ramosus, and Malcotemus zonifer among others.
**RECOMMENDATIONS:** Long-term monitoring of effects is needed.
**REFERENCE:** Mora, C., & Ospina, A. (2001). Tolerance to high temperatures and potential impact of sea warming on reef fishes of Gorgona Island (tropical Eastern Pacific). Marine Biology, 139 (4), 765–769.

## Recruitment variability

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Increased ocean temperature will affect the physiological performance and behaviour of coral reef fishes, especially during their early life history. Small temperature increases might favour larval development, but this could be counteracted by negative effects on adult reproduction. Already variable recruitment will become even more unpredictable. This will make optimal harvest strategies for coral reef fisheries more difficult to determine and populations more susceptible to overfishing. A substantial number of species could exhibit range shifts, with implications for extinction risk of small-range species near the margins of reef development.
**RECOMMENDATIONS:** Improved projections of how ocean currents and primary productivity will change are needed to better predict how reef fish population dynamics and connectivity patterns will change. Need to maintain healthy predator and herbivore fish populations to provide a certain amount of resilience to climatically induced changes.
**REFERENCE:** Munday, P.L., Jones, G.P., Pratchett, M.S., & Williams, A.J. (2008). Climate change and the future for coral reef fishes. Fish and Fisheries, 9 (3), 261–285.

## Susceptibility to over-fishing

*See above*

## Range shifts

**REGION / COUNTRY OF STUDY:** South Africa
**IMPACT DESCRIPTION:** Using measurements of sea surface temperature and spear-fishing records for 84 species spanning a 19-year period, the effects of ocean warming on sub-tropical reef-fish communities were examined in the Southeastern coast of Africa. Corresponding with a 0.46° C increase in average sea surface temperature between the time periods 1989–1997 and 2002–2007, the relative abundance of temperate species as a whole decreased by 10–13% whereas that of tropical species increased by 9%, and broadly distributed species showed little change. Average species richness and diversity increased 33% and 15% respectively between the two time periods. These results are broadly consistent with a predicted poleward shift in species ranges and a predicted increase in species richness and diversity with increasing sea temperature. The findings confirm that large-scale climate change will cause a widening of the tropical belt and subsequent ocean warming will have a profound impact on marine species abundance patterns and community composition at a local scale in the subtropics.
**STRESSOR INFORMATION:** Temperature has an important influence on the physiology, growth, reproduction, and survival of marine species.
**REFERENCE:** Lloyd, P., Plaganyi, E.E., Weeks, S.J., Magno-Canto, M., & Plaganyi, G. (2012). Ocean warming alters species abundance patterns and increases species diversity in an African sub-tropical reef-fish community. Fisheries Oceanography, 21 (1), 78–94.

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** Indicative of a warming trend, total species composition of reef fishes had become more tropical in Northern Carolina, and a tropical sponge previously unrecorded at this latitude became common. Two new (to the area) families and 29 new species of tropical fishes were recorded. Observations of 28 species of tropical reef fishes increased significantly. No new temperate species were observed, and the most abundant temperate species decreased by a factor of 22. Mean monthly bottom water temperatures in winter were 1–6° C warmer during the recent study.
**REFERENCE:** Parker Jr, R., & Dixon, R. (1998). Changes in a North Carolina reef fish community after 15 years of intense fishing – global warming implications. Transactions of the American Fisheries Society, 127 (6), 908–920.

### Acclimatisation

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Tropical reef fish are highly sensitive to small increases in water temperature, but can rapidly acclimate over multiple generations. Acute exposure to elevated temperatures (+1.5° and +3.0° C) in an experimental setting, which are predicted to occur this century, caused a 15% and 30% respective decrease in individual's maximum ability to perform aerobic activities such as swimming or foraging, known as aerobic scope. However, complete compensation in aerobic scope occurred when both parents and offspring were reared throughout their lives at elevated temperature. Such acclimation could reduce the impact of warming temperatures and allow populations to persist across their current range.
**STRESSOR INFORMATION:** Ocean warming between +1.5° and + 3.0° C
**RECOMMENDATIONS:** Trans-generational acclimation as a mechanism for coping with rapid climate change should be considered when evaluating climate change impacts. Single generation studies risk underestimating the potential of species to cope.
**REFERENCE:** Donelson, J., Munday, P., McCormick, M., & Pitcher, C. (2011). Rapid transgenerational acclimation of a tropical reef fish to climate change. Nature Climate Change, 2 (1), 30–32.

## BIODIVERSITY

### Changes in ecosystem structure and function

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Due to ocean warming different organisms will replace the current ones and they may have different physiological and ecological characteristics, leading to rapid changes in the quantity and quality of species suitable for harvesting by coastal people.
**RECOMMENDATIONS:** The understanding of how reef-dependent economies would be affected by a decline in reef resources is still in its infancy, so further research is needed.
**REFERENCE:** Hoegh-Guldberg, O. (2011). Coral reef ecosystems and anthropogenic climate change. Regional Environmental Change, 11 (1), 215–227.

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Increasing sea surface temperatures may decrease survivorship and increase the developmental rate of non-coral tropical benthic invertebrates, as well as alter the timing of gonad development, spawning, and food availability.
**RECOMMENDATIONS:** In order to accurately predict a species' response to climate stressors, one must consider the magnitude and duration of exposure to each stressor, as well as the physiology, mobility, and habitat requirements of the species. Stressors will not act independently, and many organisms will be exposed to multiple stressors concurrently, including anthropogenic stressors.
**REFERENCE:** Przeslawski, R., Ahyong, S., Byrne, M., Woerheide, G., & Hutchings, P. (2008). Beyond corals and fish: the effects of climate change on noncoral benthic invertebrates of tropical reefs. Global Change Biology, 14 (12), 2773–2795.

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Increased sea temperatures have been implicated in declining phytoplankton biomass, which limits nutrients supply from below in coastal and marine ecosystems. This affects population and community dynamics, and ultimately ecosystem structure and function.
**RECOMMENDATIONS:** Coastal management must better account for the cumulative, synergistic, and mounting stresses arising from climate change and concurrent human activities.
**REFERENCE:** Moser, S. C., Jeffress Williams, S., & Boesch, D. F. (2012). Wicked Challenges at Land's End: Managing Coastal Vulnerability Under Climate Change. Annual Review of Environment and Resources, 37, 51–78.

## COASTAL COMMUNITIES

### Pollution – increased vulnerability of coral reefs

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Rising sea water temperatures will lead to the rapid decline of coral reefs due to bleaching. Anthropogenic pressures are shown to greatly affect coral tolerance and recovery from climate pressures (e.g. sedimentation, nutrient enrichment, overfishing). Reducing coral exposure to dissolved inorganic nitrogen (DIN) from terrestrial runoff can raise the thermal tolerance of coastal coral communities in the central Great Barrier Reef. Modelling simulations highlight that an 80% reduction in DIN 'buys' an additional ~50–60 years of reef-building capacity for No Mitigation ('business-as-usual') bleaching projections. Moreover, the integrated management benefits provided by: (i) local reductions of ~50% in DIN contained in

river loads, and (ii) global stabilisation of atmospheric $CO_2$ below 450 ppm can help ensure the persistence of hard-coral-dominated reefscapes beyond 2100.
**RECOMMENDATIONS:** Beyond the global imperative to mitigate future atmospheric $CO_2$ emissions there still remains the need for effective local management actions that enhance the resistance and resilience of coral reef communities to the impacts of climate change
**REFERENCE:** Wooldridge, S. A., Done, T. J., Thomas, C. R., Gordon, I. I., Marshall, P. A., & Jones, R. N. (2012). Safeguarding coastal coral communities on the central Great Barrier Reef (Australia) against climate change: realizable local and global actions. Climatic change, 112 (3-4), 945–961.

## Overfishing – increased vulnerability of coral reefs

**REGION / COUNTRY OF STUDY:** Kenya
**IMPACT DESCRIPTION:** Herbivory, which is higher in areas without fishing, is believed to be a factor that increases the rate at which hard coral communities return to pre-disturbance conditions. This hypothesis was tested in and out of the marine protected areas (MPA) of Kenya after the 1998 El Nino Southern Oscillation (ENSO). Even though the effect of ENSO was high in the MPAs, where reefs underwent a transition from dominance by hard and soft coral to a temporary dominance of turf and erect algae, the return of dominance by calcifying algae, massive Porites, Pocillopora and a few faviids materialized six years after the disturbance. Even though the fished reefs were impacted to a lesser extent, they had a greater cover of turf and erect algae and sponge shortly after the disturbance. Higher herbivory in the protected areas reduced the abundance and persistence of herbivore-susceptible erect algae and created space and appropriate substratum for recruiting corals. Nonetheless, other post-settlement processes may have had strong influences such that annual rates of coral recovery were low (similar to 2%) and not different between the management regimes. Recovery, as defined as and measured by the return to pre-disturbance coral cover and the dominant taxa, was slower in fishery closures than unmanaged reefs.
**RECOMMENDATIONS:** Different management plans are needed for fished and protected (unfished) reefs.
**REFERENCE:** McClanahan, T. (2008). Response of the coral reef benthos and herbivory to fishery closure management and the 1998 ENSO disturbance. Oecologia, 155 (1), 169–177.

# 2.3 Precipitation change

## Increased rainfall & flooding

### COASTAL COMMUNITIES

#### Increased sedimentation & pollution

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** Changes in precipitation impact sedimentation patterns thus influencing coastal erosion and the formation of barrier islands. The transportation of nutrients, sediments, organic matter, and pollutants increase under intense precipitation and flooding events.
**RECOMMENDATIONS:** Implementing, coordinating, and/or strengthening permanent monitoring networks of oceanographic, environmental and biological variables is needed to allow the measurement of deviations to the general patterns in coastal and marine environments
**REFERENCE:** Martínez Arroyo, A., Manzanilla Naim, S., & Zavala Hidalgo, J. (2011). Vulnerability to climate change of marine and coastal fisheries in México. Atmósfera, 24 (1), 103–123.

#### Food insecurity

**REGION / COUNTRY OF STUDY:** South Pacific
**IMPACT DESCRIPTION:** Climate change will adversely affect food systems in South Pacific islands, including the supply of food from agriculture and fisheries, the ability of countries to import food, systems for the distribution of food, and the ability of households to purchase and utilize food. Drought can have serious consequences to rural food systems due to the lack of irrigation water but too much rainfall can be devastating too. The severe flooding in Fiji in 2004 for example, resulted in the loss of 50% – 70% of all crops.
**REFERENCE:** Barnett, J. (2011). Dangerous climate change in the Pacific Islands: food production and food security. Regional Environmental Change, 11 (1), 229–237.

### CORAL REEFS

#### Turbidity & sediment transport

**REGION / COUNTRY OF STUDY:** Mozambique
**IMPACT DESCRIPTION:** This study examines the impact of the 2000 flood on the coral communities in Xai-Xai lagoon. A decrease in hard coral cover of the order of 58.5% was observed. The soft coral community was significantly affected, with a decrease in percentage cover of 90.4%. Coralline algae also decreased by 85.1%. All other categories increased in percentage cover: turf algae (164.4%), other invertebrates (e.g. sponges, sea urchins – 111.1%), fleshy algae (80.4%), rubble (34.4%) and dead coral (379.0%). The main causes of this degradation were the reduced water salinity and the large amount of sediment discharged by the Limpopo River. Some massive (e.g. Porites, Favia, Favites and Goniopora) and encrusting (e.g. Echinopora) hard coral genera seemed less affected, suggesting an elevated capacity to cope with this kind of stress through mucus-sheet formation.
**STRESSOR INFORMATION:** In early 2000 the southern part of Mozambique suffered the worst flooding in 50 years, causing fatalities and considerable material loss.
**SPECIFIC SPECIES DISCUSSED:** Porites, Favia, Favites, Goniopora, Echinopora and other hard coral genera, soft coral genera, coralline and fleshy algae, different invertebrate species
**REFERENCE:** Pereira, M. A., & Gonçalves, P. M. B. (2004). Effects of the 2000 southern Mozambique floods on a marginal coral community: the case at Xai-Xai. African Journal of Aquatic Science, 29 (1), 113–116.

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Adjacent marine ecosystems can be regularly exposed to land-derived material and riverine flood plumes during heavy precipitation events. Flood plumes can be grouped into three plume types: primary, secondary and tertiary plumes, based on water-quality characteristics (suspended solids, coloured dissolved organic matter and chlorophyll). The number of reefs and seagrasses exposed to plume waters varied from year to year in the Tully coastal region (Great Barrier Reef,) and was dependent on the characteristics of the event. Over the 11 years, out of the major 37 reefs and 13 seagrass meadows identified in the Tully marine area, between 11 (30%) and 37 coral reefs (100%) and most of the seagrass meadows were inundated by either a primary or secondary plume every year. This can be detrimental to reef health.
**REFERENCE:** Devlin, M., Schaffelke, B., 2009. Spatial extent of riverine flood plumes and exposure of marine

ecosystems in the Tully coastal region, Great Barrier Reef. Marine and Freshwater Research 60, 1109–1122.

### Freshwater discharge – bleaching

**REGION / COUNTRY OF STUDY:** Mozambique
**IMPACT DESCRIPTION:** In the Inhaca Island, southern Mozambique, reef development is spatially and bathymetrically restricted to the margins of channels which dissect intertidal flats on the Maputo Bay side of the island, and to depths of around 6 m. These natural stress levels were exacerbated, via increased freshwater and sediment discharge, during the severe floods of late 1999/early 2000. Flood impacts varied but were most significant on reefs on the inner (western) side of the island where live coral cover (LCC) decreased from 60.5% (1999) to 24.0% (2001). This is attributed to freshwater-induced bleaching. Dead in situ coral cover increased from 18.6% (1999) to 51.3% (2001). Reefs closer to the open Indian Ocean mitigated the effects of freshwater dilution, compared to other reefs located further away in lagoons. Some changes in the original faunal composition of the reefs was noticed. It is suggested that this largely reflects a closer proximity to the open Indian Ocean which mitigated the effects of freshwater dilution.
**REFERENCE:** Perry, C. T. (2003). Reef development at Inhaca Island, Mozambique: coral communities and impacts of the 1999/2000 southern African floods. AMBIO: A Journal of the Human Environment, 32 (2), 134–139.

### Spread of non-native species

**REGION / COUNTRY OF STUDY:** Mozambique
**IMPACT DESCRIPTION:** Big loads of freshwater and sediments were discharged into the Inhaca Island coral reef community during the severe floods of late 1999/early 2000. Apart from freshwater-induced bleaching and mortality, some changes in the original faunal composition of the reefs was noticed. Non-native species such as zoanthids and Palythoa have started to spread rapidly, something which will restrict the availability of substrate for renewed coral recruitment.
**REFERENCE:** Perry, C. T. (2003). Reef development at Inhaca Island, Mozambique: coral communities and impacts of the 1999/2000 southern African floods. AMBIO: A Journal of the Human Environment, 32 (2), 134–139.

## MANGROVES

### Increase in mangrove areas

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Increased rainfall will result in increased growth rates and biodiversity, increased diversity of mangrove zones, and an increase in mangrove area, with the colonization of previously unvegetated areas of the landward fringe within the tidal wetland zone.
**REFERENCE:** Gilman, E. L., Ellison, J., Duke, N. C., & Field, C. (2008). Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany, 89 (2), 237–250.

### Dieback after extreme floods

**REGION / COUNTRY OF STUDY:** Tanzania
**IMPACT DESCRIPTION:** During the 1997–1998 El Niño events, heavy rains caused the Rufiji River to swell well beyond its banks resulting in extensive floods, which lasted for at least six months. The flow of the Rufiji River during this period had reached an exceptionally high peak maximum, and after the floodwaters had receded, it became apparent that significant tracts of mangrove forest in the upper reaches of the northern delta had died. Analysis of a series of 1999 aerial photographs indicated that an area of approximately 117 ha of mangrove forest had experienced massive tree mortality. A detailed field survey three years after the flood revealed that this mortality was for the major part limited to mature trees of the economically valuable mangrove species Heritiera littoralis. Another tree species, Barringtonia racemosa, co-occurring in the same forest stands, had largely survived the excessive floods. Forest regeneration of the affected areas was characterized by a massive development of B. racemosa seedlings and saplings (>9,000 and >4,000 $ha^{-1}$ respectively). Regrowth of H. littoralis was minimal (20 seedlings $ha^{-1}$ and 22 saplings $ha^{-1}$) and viable Heritiera seeds on the forest floor were absent (unlike Barringtonia seeds, which reached densities of over 4,000 $ha^{-1}$).
**SPECIFIC SPECIES DISCUSSED:** Heritiera littoralis and Barringtonia racemosa
**REFERENCE:** Erftemeijer, P. L., Hamerlynck, O. (2005). Die-back of the mangrove Heritiera littoralis Dryand, in the Rufiji Delta (Tanzania) following El Niño floods. Journal of Coastal Research 228–235.

### WETLANDS & ESTUARIES

#### Increased resilience

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Changes in fresh water intrusion will bring about respective decreases and increases in sediment and nutrient input to estuaries, which will affect organisms that depend on this supply. On the other hand, freshwater input into coastal systems reduces the level of a number of stressors (e.g., freshwater reduces salinity, mineral sediments directly stimulate accretion, iron precipitates sulfides, and nutrients stimulate belowground productivity and thus organic soil formation.
**RECOMMENDATIONS:** Sediment, freshwater, and nutrient supplies need to be managed at the regional level.
**REFERENCE:** Day, J. W., Christian, R. R., Boesch, D. M., Yáñez-Arancibia, A., Morris, J., Twilley, R. R., Naylor, L., Schaffner, L. (2008). Consequences of climate change on the ecogeomorphology of coastal wetlands. Estuaries and Coasts, 31 (3), 477–491.

## Decreased rainfall & drought

### MANGROVES

#### Decreased photosynthesis

**REGION / COUNTRY OF STUDY:** Venezuela
**IMPACT DESCRIPTION:** Drought effects on leaf photosynthesis of A. germinans growing under two contrasting salinities were studied in a Venezuelan fringe mangrove. During both wet and dry seasons, severe chronic-photoinhibition at predawn was not observed but strong down regulation occurred at midday during both seasons. Carbon assimilation rates declined during the dry season in plants from low and high salinity sites, respectively. Significant decrease in leaf photosynthesis was observed. However, a reduction in $CO_2$ diffusion due to lowered stomatal conductance was not large enough to explain the dramatic effect of drought on leaf photosynthesis. Decreased carbon assimilation and photosynthesis leads to reductions in growth. Stomatal response could be mitigated by the capability of A. germinans for osmotic adjustment under high salinity and/or drought. However, this intracellular salt accumulation may reduce carbon assimilation capacity further by decreasing the metabolism of leaf cells, increasing dark respiration and/or photorespiration.
**SPECIFIC SPECIES DISCUSSED:** Avicennia germinans
**REFERENCE:** Sobrado, M. (1999). Drought effects on photosynthesis of the mangrove, Avicennia germinans, under contrasting salinities. Trees, 13 (3), 125–130.

#### Higher salinity

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** Decreased rainfall and increased evaporation will increase salinity, decreasing net primary productivity, growth and seedling survival, altering competition between mangrove species, decreasing the diversity of mangrove zones, causing a notable reduction in mangrove area due to the conversion of upper tidal zones to hypersaline flats.
**RECOMMENDATIONS:** Eliminate non-climate stresses on mangroves (e.g. filling, conversion for aquaculture, pollution) in order to augment overall ecosystem health, in part, to reduce mangrove vulnerability to and increase resilience to stresses from climate change. Ensure representation, replication and refugia through a system of protected area networks, and establish regional monitoring systems.
**REFERENCE:** Gilman, E. L., Ellison, J., Duke, N. C., & Field, C. (2008). Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany, 89 (2), 237–250.

### COASTAL COMMUNITIES

#### Food insecurity

**REGION / COUNTRY OF STUDY:** South Pacific
**IMPACT DESCRIPTION:** Climate change will adversely affect food systems in South Pacific islands, including the supply of food from agriculture and fisheries, the ability of countries to import food, systems for the distribution of food, and the ability of households to purchase and utilize food. Crop loss will be significant due to the lack of fresh water for irrigation. People are already engaged in the sale of different products or labor for cash, as well as gardening or fishing to meet a proportion of their food needs.
**REFERENCE:** Barnett, J. (2011). Dangerous climate change in the Pacific Islands: food production and food security. Regional Environmental Change, 11 (1), 229–237.

# 2.4 Sea-level rise

## CORAL REEFS

### Turbidity & sediment re-suspension

**REGION / COUNTRY OF STUDY:** Hawaii
**IMPACT DESCRIPTION:** Accelerating sea level rise will increase energy and sediment re-suspension. Sedimentation is known to increase coral stress and bleaching as particles that settle on coral surfaces interfere with photosynthesis and feeding, and turbidity induced by suspended sediment reduces incident light levels.
The sediment flux is predicted to increase and removal of fine grained sediment may be expedited on some fringing reefs. Sediment in storage on the inner reef could ultimately be reduced. However, increased shoreline erosion may add sediment and offset removal from the reef flat.
The shifts in sediment availability and transport that will occur as a result of even modest increases in sea level can be related to fringing coral reefs elsewhere as well as other shoreline environments.
**RECOMMENDATIONS:** Ecosystem management at the landscape level to decrease sediment input from adjacent watersheds, limiting other stresses to the reef habitat (e.g. anthropogenic).
**REFERENCE:** Ogston, A. S., & Field, M. E. (2010). Predictions of turbidity due to enhanced sediment resuspension resulting from sea-level rise on a fringing coral reef: evidence from Molokai, Hawaii. Journal of Coastal Research, 26 (6), 1027–1037.

### Drowning & decreased photosynthesis

**REGION / COUNTRY OF STUDY:** Global review
**IMPACT DESCRIPTION:** Corals grow in shallow waters and as sea-level rise increases, habitats with ideal growing conditions will decrease.
**SPECIFIC SPECIES DISCUSSED:** Scleractinia
**REFERENCE:** Hoegh-Guldberg, O. (2011). Coral reef ecosystems and anthropogenic climate change. Regional Environmental Change, 11 (1), 215–227.

**REGION / COUNTRY OF STUDY:** Caribbean
**IMPACT DESCRIPTION:** Corals are drowned and have less access to light.
**STRESSOR INFORMATION:** Future sea-level rise in the tropical oceans, and coral reef responses, will take place against a backdrop of inter-regional differences in Holocene sea levels, resulting from the varying interaction of eustatic and hydro-isostatic processes. These differences have generated varying constraints on the development of modern reefs and varying inherited topographies upon which future sea-level changes will be superimposed. These controls are particularly important in assessing differences in vulnerability to future sea-level rise for reef islands in the Pacific Ocean and the Caribbean Sea.
**RECOMMENDATIONS:** Improved monitoring for coral reefs using standardised techniques to cover the full range of reef structures and environmental settings.
**REFERENCE:** Spencer, T. (1995). Potentialities, uncertainties and complexities in the response of coral reefs to future sea-level rise. Earth surface processes and landforms, 20 (1), 49–64.

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** If sea levels rise rapidly, reefs are drowned. Reef islands will be affected differently due to differences in tidal range. Geomorphological investigations of reef islands indicate that they are generally resilient, having formed in various situations under a range of conditions. Continued accretion seems likely under gradual sea-level rise, but may no longer be sustainable if the sea drowns the reef platform on which they have formed. The resilience of reefs also depends on the synergistic interaction with other pressures.
**RECOMMENDATIONS:** Research on the processes that operate on platform reefs (and atolls) to understand the quasi-equilibrium and corals' morphological persistence.
**REFERENCE:** Woodroffe, C. D. (2007). Critical thresholds and the vulnerability of Australian tropical coastal ecosystems to the impacts of climate change. J Coast Res (special issue), 50, 469–473.

### Losses of habitat for aquatic biota & forced migration of reef fish

**REGION / COUNTRY OF STUDY:** Global review
**IMPACT DESCRIPTION:** Forced migration of certain species due to inundation of coastal areas and drowning of reefs.
**REFERENCE:** Munday, P. L., Jones, G. P., Pratchett, M. S., & Williams, A. J. (2008). Climate change and the future for coral reef fishes. Fish and Fisheries, 9 (3), 261–285.

## MANGROVES

### Landward migration

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** Mangrove areas in the Pacific coast of Mexico have been increasing in the recent past due to the flooding of new areas as a consequence of sea-level rise. However, the mangrove fringe is receding as it is directly affected by sea-level rise. The inland expansion (or landward retreat) of mangroves does not ease conservation concerns, as it is the seaward fringes, and not the inland margins, that provide the most valuable ecosystem services for fisheries and coastal protection.
**SPECIFIC SPECIES DISCUSSED:** Avicennia germinans, Rhizophora mangle, Laguncularia racemosa
**RECOMMENDATIONS:** Seaward fringes should be conserved with priority, although there is a need to better understand the balance between mangrove loss and mangrove expansion in order to foster more effective conservation activities in coastal areas.
**REFERENCE:** López-Medellín, X., Ezcurra, E., González-Abraham, C., Hak, J., Santiago, L. S., & Sickman, J. O. (2011). Oceanographic anomalies and sea-level rise drive mangroves inland in the Pacific coast of Mexico. Journal of Vegetation Science, 22 (1), 143–151.

**REGION / COUNTRY OF STUDY:** American Samoa
**IMPACT DESCRIPTION:** The observed mean landward migration of three mangroves' seaward margins in American Samoa over four decades was 25, 64, and 72 $mm \cdot a^{-1}$, 12 to 37 times the observed relative sea-level rise rate. Two of the sites had clear trends in reductions in mangrove area, where there was a highly significant correlation between the change in position of the seaward mangrove margin and change in relative sea-level. Here it can be inferred that the force of sea-level rise relative to the mangrove surface is causing landward migration. Shoreline movement was variable at a third site and not significantly correlated with changing sea-level, where it is likely that forces other than change in relative sea-level are predominant. Currently, 16.5%, 23.4%, and 68.0% of the three mangroves' landward margins are obstructed by coastal development which inhibits natural landward migration. The three mangrove ecosystems could experience as high as a 50.0% reduction in area by the year 2100. A 12% reduction in mangrove area by the year 2100 is possible in the Pacific islands region.
**RECOMMENDATIONS:** Management authorities are encouraged to assess shoreline response to projected relative SLR and adopt appropriate policies to provide adequate lead time to minimise social disruption and cost, minimise losses of valued coastal habitats, and maximise available options. Use of hard engineering technology including seawalls, revetments, and bulkheads are likely to result in increased vulnerability. Rehabilitating mangroves as a means to mitigate predicted mangrove losses resulting from SLR is a no-regret option that should be pursued.
**REFERENCE:** Gilman, E., Ellison, J., & Coleman, R. (2007). Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. Environmental monitoring and assessment, 124 (1–3), 105–130.

### Inundation

**REGION / COUNTRY OF STUDY:** Global review
**IMPACT DESCRIPTION:** Sea-level rise is considered to be the biggest threat to mangrove ecosystems when the rate of mangrove sediment accretion and elevation is exceeded by the rate of relative sea-level change. Relative sea-level change is the observed change in water level at a particular point, relative to the level of the nearby land. Sea-level rise induces erosion and weakening of root structures, increased salinity, and too high duration, frequency and depth of mangrove inundation which can go beyond mangrove tolerance levels.
Mangroves in environments characterized by sediment deficits (e.g. in low relief islands with a very limited number of rivers), low ground water tables, and erosion are thought to be the most sensitive to sea-level rise. However, various surface and subsurface processes control the rate of mangrove sediment surface elevation, and thus their ability to accommodate sea-level rise, but these processes are poorly understood.
**STRESSOR INFORMATION:** The range of projections for global sea-level rise from 1980 to 1999 to the end of the 21st century (2090–2099) is 0.18 – 0.59 m.
**RECOMMENDATIONS:** To enhance resilience to relative sea-level rise, activities within the mangrove catchment can be conducted to minimize long-term reductions in sediment or enhance elevation. These can include, for example, limiting the development of impervious surfaces within the mangrove catchment and managing rates and locations of groundwater extraction. Such activities can reduce alterations to natural groundwater recharge which influences mangrove elevation. Limiting human activities that reduce mangrove soil organic matter accumulation, such as deforestation and pollution inputs, can contribute to maintaining relatively natural controls on trends in sediment elevation. Depending on the tree species and nutrient added, nutrient enrichment can also have a positive effect. Enhancement of mangrove sediment accretion rates, such as through the beneficial use of dredge spoils, could also augment mangrove sedi-

ment elevation but excessive or sudden sediment depositions should be avoided.
**REFERENCE:** Gilman, E. L., Ellison, J., Duke, N. C., & Field, C. (2008). Threats to mangroves from climate change and adaptation options: a review. Aquatic Botany, 89 (2), 237–250.

**REGION / COUNTRY OF STUDY:** Micronesia
**IMPACT DESCRIPTION:** High islands are subjected to erosion over time which constitutes an important source of sediments for mangrove forests. These sediments offer mangroves a potentially important means for adjusting surface elevation with rising sea level. Mangrove surface elevation change varies by hydrogeomorphic setting and rivers, suggesting differential susceptibilities among Pacific high island mangroves to sea-level rise. Fringe, riverine, and interior settings registered elevation changes of −1.30, 0.46, and 1.56 $mm \cdot y^{-1}$, respectively, with the greatest elevation deficit (−3.2 $mm \cdot y^{-1}$) from a fringe zone on Pohnpei and the highest rate of elevation gain (4.1 $mm \cdot y^{-1}$) from an interior zone on Kosrae. Fringe mangrove forests are most susceptible to sea-level rise.
**SPECIFIC SPECIES DISCUSSED:** Sonneratia alba, Bruguiera gymnorrhiza, Rizophora apiculata
**RECOMMENDATIONS:** Protection of fringe mangroves from anthropogenic disturbances (for example, harvesting) may slow down mangrove inundation and conversion due to sea-level rise.
**REFERENCE:** Krauss, K. W., Cahoon, D. R., Allen, J. A., Ewel, K. C., Lynch, J. C., & Cormier, N. (2010). Surface elevation change and susceptibility of different mangrove zones to sea-level rise on pacific high islands of Micronesia. Ecosystems, 13 (1), 129–143.

### Losses of protective services & increased exposure to SLR and vulnerability

**REGION / COUNTRY OF STUDY:** Pacific Islands
**IMPACT DESCRIPTION:** The effects of inundation and shore erosion due to SLR have been exacerbated on many coasts by the clearance of coastal vegetation, particularly mangroves, the mining of sand, and construction of other artificial structures without a clear understanding of coastal dynamics. Coastal ecosystems can act as a shield for the shoreline against climatic hazards, but as sea-level rises the protective functions tend to decrease.
**REFERENCE:** Nunn, P. D., & Mimura, N. (1997). Vulnerability of South Pacific island nations to sea-level rise. Journal of coastal research, 133–151.

## COASTAL COMMUNITIES

### Shoreline erosion

**REGION / COUNTRY OF STUDY:** Singapore
**IMPACT DESCRIPTION:** Beach erosion will move the shoreline, shifting the beach profile closer inland.
**RECOMMENDATIONS:** One method preventing beach erosion is continual beach nourishment, which preserves beaches in their current conditions and discourages further erosion. Another approach is to build seawalls and back-fill sand behind these hard structures. Conserving mangroves and/or allowing them to migrate landwards is another option in places where this ecosystem is found.
**REFERENCE:** Ng, W.-S., & Mendelsohn, R. (2006). The economic impact of sea-level rise on nonmarket lands in Singapore. AMBIO: A Journal of the Human Environment, 35 (6), 289–296.

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** Sea level rise and alteration of water flows of the Himalayan headwaters are among the major disturbances threatening the Sundarbans coastal areas. Accretion rate has declined in the recent years but erosion rate has remained relatively high. As a result the delta front has undergone a net erosion of similar to 170 $km^2$ of coastal land in the 37 years of the study period (based on Landsat images spanning from 1973 to 2010). These numbers are significantly higher than the previously reported rates and magnitudes of erosion in the area.
**RECOMMENDATIONS:** Maintenance of environmental stability, preservation of the remaining natural mangrove forests, increase in the forest cover through afforestation and social forestry programs, and support an enhanced productivity of mangrove forests to meet essential local and national needs as mentioned under the Forest Act concerning mangrove management. The land-gain areas long the Sundarbans coastlines can be targeted for enhanced afforestation with appropriate salt-tolerant mangrove species. The land-loss areas can be targeted for selective dike building (with proper consideration of down-current erosion) to prevent further land loss.
**REFERENCE:** Rahman, A. F., Dragoni, D., & El-Masri, B. (2011). Response of the Sundarbans coastline to sea level rise and decreased sediment flow: a remote sensing assessment. Remote Sensing of Environment, 115 (12), 3121–3128.

**REGION / COUNTRY OF STUDY:** Venezuela
**IMPACT DESCRIPTION:** Assuming a no-protection response and a one-meter rise in sea level, nearly 6,000 $km^2$ of land could be lost, mainly by inundation of the Orinoco

delta. Land loss due to erosion is minor compared to inundation, but it could damage Venezuela's coastal oil and other infrastructures, as well as several coastal urban areas.
**STRESSOR INFORMATION:** Sea-level rise is assumed to be the driving force of future coastal change, with most attention focused on a scenario of a one-meter rise by 2100.
**RECOMMENDATIONS:** Nourishment of recreational beaches and construction of seawalls along 200 km of developed coastlines combined with harbor upgrade could cost U.S. $1.0 to $1.5 billion for a one-meter rise in sea level. Assuming this investment occurred linearly over 50 years (2051–2100), this represents annual expenditure of 0.46% to 0.70% of Venezuela's gross national investment (in 1990). While Venezuela's developed coastline appears vulnerable to accelerated sea-level rise, increasing planning and coastal management efforts could avoid increasing future vulnerability, particularly for the large coastal frontage (>2,000 km) where little or no development exists today.
**REFERENCE:** Volonté, C.R., & Arismendi, J. (1995). Sea-level rise and Venezuela: potential impacts and responses. Journal of Coastal Research, 285–302.

**REGION / COUNTRY OF STUDY:** Martinique
**IMPACT DESCRIPTION:** At a sea level rise of 50 cm, one fourth of Martinique's coastline will be affected by erosion and one fifth of the islands surface will have high probability to get flooded during coastal hazards. Saltwater intrusion and erosion are serious consequences of SLR. More than 60% of the human coastal resources are at risk at present conditions and this number will increase if sea level continues to rise. Beach tourism, the main economic activity in Martinique, will be greatly affected.
**STRESSOR INFORMATION:** During the last century, a relative SLR of about 20 cm has been observed in the Caribbean.
**RECOMMENDATIONS:** An optimal and no-regret adaptation measure is mangrove forest conservation and rehabilitation.
**REFERENCE:** Schleupner, C. (2007). Spatial assessment of sea level rise on Martinique's coastal zone and analysis of planning frameworks for adaptation. Journal of Coastal Conservation, 11(2), 91–103.

## Land inundation

**REGION / COUNTRY OF STUDY:** Ghana
**IMPACT DESCRIPTION:** The Dansoman coastline could recede by about 202 m by the year 2100 relative to the baseline of 1970–1990. Analysis of the likely impacts of coastal inundation in the Panbros, Grefi and Gbegbeyise communities revealed that about 650,000 people, 926 buildings and a total area of about 0.80 km² of land are vulnerable to permanent inundation by the year 2100. Significant losses to both life and property will occur in this scenario.
**STRESSOR INFORMATION:** Mid-range scenarios concerning the coastal area of Dansoman show a sea-level rise of 15.73 cm by 2050 and 46.41 cm by 2100. Best-case scenarios project 14.86 cm by 2050 and 33.74 cm by 2100.
**REFERENCE:** Appeaning Addo, K., Larbi, L., Amisigo, B., & Ofori-Danson, P.K. (2011). Impacts of coastal inundation due to climate change in a cluster of urban coastal communities in Ghana, West Africa. Remote Sensing, 3(9), 2029–2050.

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** In the low-lying area of Vellar-Coleroon estuarine, Tamil Nadu coast, India, about 1,570 ha of the LULC (Land use and Land cover) of the study area would be permanently inundated to 0.5 m and 2,407 ha for 1 m SLR. This will result in the loss of three major coastal natural resources: coastal agriculture, mangroves and aquaculture.
**STRESSOR INFORMATION:** Vulnerability assessed based on the projected SLR scenarios of 0.5 m and 1 m.
**REFERENCE:** Saleem Khan, A., Ramachandran, A., Usha, N., Punitha, S., & Selvam, V. (2012). Predicted impact of the sea-level rise at Vellar-Coleroon estuarine region of Tamil Nadu coast in India: Mainstreaming adaptation as a coastal zone management option. Ocean & Coastal Management.

**REGION / COUNTRY OF STUDY:** Venezuela
**IMPACT DESCRIPTION:** Assuming a no-protection response and a one-meter rise in sea level, nearly 6,000 km² of land could be lost, mainly by inundation of the Orinoco delta. Land loss due to erosion is minor compared to inundation, but it could damage infrastructure and buildings. In total, land and buildings presently worth about U.S. $350 million could be destroyed (excluding damage to harbors) and 56,000 to 62,000 people could be displaced from their homes.
**STRESSOR INFORMATION:** Sea-level rise is assumed to be the driving force of future coastal change, with most attention focused on a scenario of a one-meter rise by 2100.
**RECOMMENDATIONS:** Nourishment of recreational beaches and construction of seawalls along 200 km of developed coastlines combined with harbor upgrade could cost U.S. $1.0 to $1.5 billion for a one-meter rise

in sea level. Assuming this investment occurred linearly over 50 years (2051–2100), this represents annual expenditure of 0.46% to 0.70% of Venezuela's gross national investment (in 1990). While Venezuela's developed coastline appears vulnerable to accelerated sea-level rise, increasing planning and coastal management efforts could avoid increasing future vulnerability, particularly for the large coastal frontage (>2,000 km) where little or no development exists today.
**REFERENCE:** Volonté, C. R., & Arismendi, J. (1995). Sea-level rise and Venezuela: potential impacts and responses. Journal of Coastal Research, 285–302.

**REGION / COUNTRY OF STUDY:** Philippines
**IMPACT DESCRIPTION:** Modeling results for Manila Bay show that land inundation due to one-meter rise in sea-level would affect coastal barangays from 19 municipalities of Metro Manila, Bulacan, and Cavite and would cover an area of 5,555 ha.
**RECOMMENDATIONS:** Proposed response strategies consist of protecting the coast by building sea walls; institutional actions such as formulation of setback policies and construction regulations; and adaptive planning in the context of an integrated coastal zone management to address the short- and long-term problems, with the involvement of communities in the area. Information, education, and communication are essential along with the technical and scientific efforts to achieve a well-balanced adaptation plan.
**REFERENCE:** Perez, R. T., Amadore, A., & Feir, R. B. (1999). Climate change impacts and responses in the Philippines coastal sector. Climate Research, 12, 97–107.

**REGION / COUNTRY OF STUDY:** Mozambique
**IMPACT DESCRIPTION:** The sea water will inundate the low relief marshes which will openly connect to the sea following erosion of the existing beach ridge beyond the sea wall. Water-logging problems already exist and they are expected to increase (Scenario 1). The remaining coastal ridges will be overwashed by waves and the low relief plains inundated by sea water. Part of the town, including the port and probably the airport, will be inundated at high tides during spring. (Scenario 2). A kind of relief induced barrier islands could be formed. It is estimated that 40% or around 42.5 km² of the total area of the city will be permanently inundated (Scenario 3).
**STRESSOR INFORMATION:** Scenario 1: sea-level rise of 0.2 m by the year 2025, Scenario 2: sea-level rise of 0.5 m by the year 2080, Scenario 3: sea-level rise of 1 m by the year 2100.
**RECOMMENDATIONS:** The National Environmental Management Programme (NEMP) establishes integrated coastal zone management (ICZM) that will be based on coordination between the relevant stakeholders (institutions and communities) and on a programme which should be designed and accepted by them. The main issues for this programme are (1) fisheries, (2) coastal and marine ecosystems management, (3) coastal and marine protection, (4) marine parks and (5) tourism.
**REFERENCE:** Chemane, D., Motta, H., & Achimo, M. (1997). Vulnerability of coastal resources to climate changes in Mozambique: a call for integrated coastal zone management. Ocean & coastal management, 37 (1), 63–83.

## Saline intrusion into freshwater lens

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** In the low-lying area of Vellar-Coleroon estuarine, Tamil Nadu coast, India, agricultural lands are threatened not only due to inundation but also due to erosion and salt water intrusion. Salinity intrusion due to SLR will decrease agricultural production by limiting fresh water supplies and inducing soil degradation. Salt water intrusion coupled with rising temperatures will threaten many aquaculture farming species such as finfish and shellfish (prawns and crabs).
**STRESSOR INFORMATION:** Vulnerability assessed based on the projected SLR scenarios of 0.5 m and 1 m.
**REFERENCE:** Saleem Khan, A., Ramachandran, A., Usha, N., Punitha, S., & Selvam, V. (2012). Predicted impact of the sea-level rise at Vellar-Coleroon estuarine region of Tamil Nadu coast in India: Mainstreaming adaptation as a coastal zone management option. Ocean & Coastal Management.

## Coastal flooding

**REGION / COUNTRY OF STUDY:** Bangladesh
**IMPACT DESCRIPTION:** Bangladesh lies in the delta of three of the largest rivers in the world (the Ganges, the Brahmaputra, and the Meghna) that have a combined peak discharge of 180,000 m³ per second during the flood season, and carry about two billion tons of sediments each year. SLR will increase river water levels, water logging, erosion, and flooding during monsoons. Flooding intensity depends on water flows coming from three different directions (SLR, river flooding, glacier melting) rendering the country extremely vulnerable. Rivers surrounding polders may increase in the range of

30–80 cm, completely flooding human settlements by 2100.
**RECOMMENDATIONS:** The Government of Bangladesh, with the support of development partners, has invested more than $ 10 billion over the last 35 years to manage disaster-related risks. These investments have included flood management schemes, coastal polders, cyclone and flood shelters, and the raising of roads and highways above flood levels. A project lead by the Ministry of Environment and Forests has four components: (1) Enhancing the adaptive capacity of coastal communities and protective ecosystems through community-led interventions focusing on afforestation, (2) strengthening national and sub-national, and local capacities, (3) Reviewing and revising coastal management practices and policies, (4) developing a functional system for the collection, distribution and internalisation of climate related knowledge.
**REFERENCE:** Rawlani, A. K., & Sovacool, B. K. (2011). Building responsiveness to climate change through community based adaptation in Bangladesh. Mitigation and Adaptation Strategies for Global Change, 16 (8), 845–863.

## Losses of land, property, livelihoods & migration

**REGION / COUNTRY OF STUDY:** Islands in South-east Asia and the Pacific
**IMPACT DESCRIPTION:** People will have to migrate due to the fact that coastal areas will get inundated and they will have to shift their agricultural activities elsewhere. approximately 3–32% of island coastal zones could be lost (primary effects) leading to the migration of 8–52 million people.
**RECOMMENDATIONS:** Findings show that primary and secondary SLR effects can have enormous consequences for human inhabitants and island biodiversity, and consequently, both need to be incorporated into ecological risk assessment, conservation, and regional planning.
**REFERENCE:** Wetzel, F. T., Kissling, W. D., Beissmann, H., & Penn, D. J. (2012). Future climate change driven sea-level rise: secondary consequences from human displacement for island biodiversity. Global Change Biology, 18 (9), 2707–2719.
**REGION / COUNTRY OF STUDY:** The Gambia and Côte d'Ivoire
**IMPACT DESCRIPTION:** The entire population of Banjul (42,000 inhabitants), people living in the eastern parts of Bakau and Cape St. Mary, and the swampy parts of Old Jeswang, Kanifing Industrial Estate, Eboe Town, Tallinding Kunjang, Fagikunda, and Abuko will be displaced.
**STRESSOR INFORMATION:** The scenarios considered are the current rate of sea level rise of 0.2 (no acceleration), 0.5, and 1.0 m by the end of the century.
**RECOMMENDATIONS:** (1) Public awareness and outreach activities to inform the public about the risks associated with SLR; (2) Increase coastal infrastructure and enforce planning and building regulations; (3) Wetland preservation; (4) Coastal zone management
**REFERENCE:** Jallow, B. P., Toure, S., Barrow, M. M., & Mathieu, A. A. (1999). Coastal zone of The Gambia and the Abidjan region in Côte d'Ivoire: sea level rise vulnerability, response strategies, and adaptation options. Climate Research, 12, 129–136.

## Increased pressure on biodiversity

**REGION / COUNTRY OF STUDY:** Islands in South-east Asia and the Pacific
**IMPACT DESCRIPTION:** People will have to migrate due to the fact that coastal areas will get inundated and shift their agricultural activities elsewhere. This will increase the pressure on biodiversity and the environment. Using three SLR scenarios (1, 3, and 6 m elevation, where 1 m approximates most predictions by the end of this century), the consequences of primary and secondary SLR effects from human displacement on habitat availability and distributions of selected mammal species was assessed. Approximately 3–32% of island coastal zones could be lost (primary effects) leading to the migration of 8–52 million people. Assuming that inundated urban and intensive agricultural areas will be relocated with an equal area of habitat loss in the hinterland, secondary SLR effects can lead to an equal or even higher percentage of loss (in comparison to primary effects) for at least 10–18% of the sample mammals in a moderate range loss scenario and for 22–46% in a maximum range loss scenario. Some species will be more vulnerable to secondary than primary effects. Island species of Oceania are more vulnerable to primary SLR effects, whereas species on Indo-Malaysian islands are more vulnerable to secondary effects (as SLR will potentially create 7–48 million refugees).
**RECOMMENDATIONS:** Findings show that primary and secondary SLR effects can have enormous consequences for human inhabitants and island biodiversity, and consequently, both need to be incorporated into ecological risk assessment, conservation, and regional planning.
**REFERENCE:** Wetzel, F. T., Kissling, W. D., Beissmann, H., & Penn, D. J. (2012). Future climate change driven sea-level rise: secondary consequences from human displacement for island biodiversity. Global Change Biology, 18 (9), 2707–2719.

## BIODIVERSITY

### Changes in structure and composition of wetlands

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Land inundation, flooding and salinity intrusion due to SLR will lead to changes in the structure and composition of coastal wetlands as the environment will become more saline. Models project a general decline in wetland communities under SLR, with a noted exception of mangroves that are more saline-tolerant. Under the A1FI scenario, SLR allows mangroves to migrate inland, with urban development acting as an obstruction in some areas. Mangrove expansion provides an unexpected benefit for dependent X. myoides populations, although the inclusion of predation and habitat loss due to urban development still suggests extirpation in c. 50 years.
**STRESSOR INFORMATION:** Global sea-level rise (SLR) could be as much as 1.8 m by 2100, which will impact coastal wetland communities and threatened species. SLR was simulated based on the IPCC B1 and A1FI scenarios, as well as the maximal limit of 1.8 m by 2100.
**RECOMMENDATIONS:** A new generation of conservation decision support tools need to be developed, that balance numerous competing objectives in the context of dynamic and complex systems.
**REFERENCE:** Traill, L. W., Perhans, K., Lovelock, C. E., Prohaska, A., McFallan, S., Rhodes, J. R., & Wilson, K. A. (2011). Managing for change: wetland transitions under sea-level rise and outcomes for threatened species. Diversity and Distributions, 17 (6), 1225–1233.

### Changes in fish populations

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** SLR will result in changes in tidal patterns and increased turbidity and salinity. It will lead to the modification of specific habitats which can determine the distribution and abundance of fish catch. For example, the estuary species with less tolerance to salinity changes will be significantly affected by SLR, which in turn will influence commercial fish reproduction, migration and survival.
**RECOMMENDATIONS:** It is necessary to monitor the health of ecosystems, identifying key commercial species which may be indicators of impacts, as well as analysing their populations to redefine fishery management at the levels of target species and total catch. Implementing, coordinating, and/or strengthening permanent monitoring networks of oceanographic, environmental and biological variables is needed to allow the measurement of deviations to the general patters in the coastal and marine environments. Adaptation measures should take into consideration the fisheries' multi-species characteristics and their different biological and socioeconomic stressors associated with physical impacts on the natural environment.
**REFERENCE:** Martínez Arroyo, A., Manzanilla Naim, S., & Zavala Hidalgo, J. (2011). Vulnerability to climate change of marine and coastal fisheries in México. Atmósfera, 24 (1), 103–123.

### Habitat and ecosystem losses

**REGION / COUNTRY OF STUDY:** Caribbean
**IMPACT DESCRIPTION:** SLR will lead to beach losses in the region which in turn will decrease the available habitats for many species. For example, up to 30% of turtle nesting areas would be lost from a 0.5 m rise in sea level.
**STRESSOR INFORMATION:** The average rate of sea-level rise has increased from 1.8 mm/year prior to 1993, to 3.1 mm/year.
**RECOMMENDATIONS:** The restoration and protection of native coastal vegetation at nesting sites. Implementation and enforcement of adequate setback regulations creates the potential to maintain the ecological and economic function of beaches in the face of extensive coastal development and sea-level rise.
**REFERENCE:** Hansen, L., Hoffman, J., Drews, C., & Mielbrecht, E. (2010). Designing Climate-Smart Conservation: Guidance and Case Studies. Conservation Biology, 24 (1), 63–69.

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Sea level rise will result in landward migration of wetlands as tidal boundaries move upslope. Loss of wetlands on the seaward margin is likely if wetlands cannot accrete as fast as sea level rises. Models of wetland change in South East Queensland indicate that with a 0.64 cm rise in sea level, 50% of the high intertidal and non-saline coastal wetlands may be lost by 2100.
**RECOMMENDATIONS:** 'Hard' adaptation strategies for maintaining coastal wetland areas faced with sea level rise involve technical and engineering solutions, such as infrastructure design, removal and construction of walls/built structures and wetland restoration. 'Soft' adaptation strategies involve knowledge, knowledge generation processes (such as models, regulations, standards of practice) and information systems (models), and changing the institutional, financial and legal infrastructures.
**REFERENCE:** Burley, J. G., McAllister, R. R., Collins, K. A., & Lovelock, C. E. (2012). Integration, synthe-

sis and climate change adaptation: a narrative based on coastal wetlands at the regional scale. Regional Environmental Change, 12 (3), 581–593.

**REGION / COUNTRY OF STUDY:** Mozambique
**IMPACT DESCRIPTION:** The sea water will inundate the low relief marshes which will openly connect to the sea following erosion of the existing beach ridge beyond the sea wall. The remaining coastal ridges will be overwashed by waves and the low relief plains will be inundated by sea water.
**STRESSOR INFORMATION:** Scenario 1: sea-level rise of 0.2 m by the year 2025, Scenario 2: sea-level rise of 0.5 m by the year 2080, Scenario 3: sea-level rise of 1 m by the year 2100.
**RECOMMENDATIONS:** The National Environmental Management Programme (NEMP) establishes integrated coastal zone management (ICZM) that will be based on coordination between the relevant stakeholders (institutions and communities) and on a programme which should be designed and accepted by them. The main issues for this programme are (1) fisheries, (2) coastal and marine ecosystems management, (3) coastal and marine protection, (4) marine parks and (5) tourism.
**REFERENCE:** Chemane, D., Motta, H., & Achimo, M. (1997). Vulnerability of coastal resources to climate changes in Mozambique: a call for integrated coastal zone management. Ocean & coastal management, 37 (1), 63–83.

# 2.5 Tropical storms

## SEAGRASS BEDS

### Turbidity and sediment transport

**REGION / COUNTRY OF STUDY:** Puerto Rico
**IMPACT DESCRIPTION:** Tens of square kilometres of highly productive seagrass meadows were destroyed by the formation of large sediment “blowouts.”
**STRESSOR INFORMATION:** Hurricane Hugo struck Puerto Rico on 18 September 1989. Coastal zone resources as diverse as offshore sand deposits, recreational beaches, and coral reefs were affected. During the storms, winds greater than 240km/hr were observed.
**REFERENCE:** Rodriguez, R., Webb, R., & Bush, D. (1994). Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research, 278–296.

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** The passage of Hurricane Georges on September 25, 1998 caused an immediate loss of 3% of the density of T. testudinum, compared to 19% of the S. filiforme and 24% of the calcareous green algae. Areas that had little to moderate sediment deposition recovered from the storm within one year, while the one buried by 50 cm of sediment and the two areas that experienced substantial erosion showed very little recovery in the following three years after the storm. Early colonizers to these severely disturbed sites were calcareous green algae. Hurricanes may increase benthic macrophyte diversity by creating disturbed patches with the landscape, but moderate storm disturbance may actually reduce macrophyte diversity by removing the early successional species from mixed-species seagrass beds.
**SPECIFIC SPECIES DISCUSSED:** Thalassia testudinum, Syringodium filiforme
**REFERENCE:** Fourqurean, J. W., & Rutten, L. M. (2004). The impact of hurricane Georges on soft-bottom, back reef communities: site-and species-specific effects in South Florida seagrass beds. Bulletin of Marine Science, 75 (2), 239–257.

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** The impact of Hurricane Gilbert (September 1988) on Thalassia testudinum was assessed in the Puerto Morelos coral reef lagoon. At two back-

reef stations and one mid-lagoon station, population/age distributions corresponded with those of undisturbed ones, suggesting that the hurricane had not left any lasting traces on vegetative growth. At the other mid-lagoon and coastal stations, T. testudinum plants had disappeared from the populations, which could be deduced from a decrease in the number of pre-hurricane short-shoots. These affected populations showed either a decrease or an increase in short-shoot internode distance shortly after the hurricane. This suggests that either sediment had been removed or accumulated at the stations of the affected populations. However, at all stations, short-shoots older than the time lapsed since the hurricane were reported, indicating that at none of the studied areas T. testudinum was wiped out completely.
**STRESSOR INFORMATION:** Hurricane Gilbert produced the lowest atmospheric pressure and highest winds ever recorded in the Caribbean.
**SPECIFIC SPECIES DISCUSSED:** Thalassia testudinum
**REFERENCE:** Van Tussenbroek, B. (1994). The impact of hurricane Gilbert on the vegetative development of Thalassia testudinum in Puerto Morelos coral reef lagoon, Mexico: a retrospective study. Botanica Marina, 37 (5), 421–428.

### Species-specific elimination

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** The passage of hurricane Wilma (October 2005) over Puerto Morelos, Mexican Caribbean, resulted in the significant reduction of the seagrass Syringodium filiforme and macro-algae Udotea spp., Penicillus spp., and Rhipocephalus spp. in two research stations, whereas the populations of the seagrass Thalassia testudinum and Halimeda spp. were unaffected. Apart from known impacts such as complete or partial destruction of seagrass beds, hurricanes may also change the community structure of persistent beds through species-specific elimination. Removal of these species may have liberated resources, enabling a possible posterior increase in the density of survivors or alternatively enabling invasion of rapid colonizers of seagrass and macroalgae.
**STRESSOR INFORMATION:** The duration of the hurricane (force 4) was 60 h and the average wave height of the back-reef lagoon was 3 m.
**SPECIFIC SPECIES DISCUSSED:** Thalassia testudinum and Syringodium filiforme, and macroalgae Udotea spp, Penicillus spp, and Halimeda spp.
**REFERENCE:** Van Tussenbroek, B. I., Barba Santos, M. G., Van Dijk, J. K., Sanabria Alcaraz, S. M., & Téllez Calderón, M. L. (2008). Selective elimination of rooted plants from a tropical seagrass bed in a back-reef lagoon: a hypothesis tested by Hurricane Wilma (2005). Journal of Coastal Research, 278–281.

## CORAL REEFS

### Reduced thermal stress & accelerated recovery from bleaching

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** This is actually a positive impact. At broad spatial scales, tropical cyclones can induce cooling of the upper ocean (SST drops up to 6° C) which can persist for weeks and thus reduce thermal stress and accelerate the recovery of bleached corals due to sea-surface temperature (SST) warming). From an analysis of a global dataset (1985–2009) related to tropical cyclones (TC), significant correlations were found between TC activity and the severity of thermal stress at various spatial scales, particularly for Caribbean reefs. From this, it is apparent that TCs play a role in bleaching dynamics at a global scale. During years of high thermal stress and frequent TCs, thermal stress at reef areas was generally low when TC activity was high. However, the prevalence and distribution of this interaction varies by region and requires further examination at finer spatial and temporal scales using actual SST data.
**REFERENCE:** Carrigan, A. D., & Puotinen, M. L. (2011). Assessing the potential for tropical cyclone induced sea surface cooling to reduce thermal stress on the world's coral reefs. Geophysical Research Letters, 38 (23).

### Turbidity & sediment transport

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** Moderate storms have been shown to affect the Flower Garden Banks (FGB) coral reefs positively. The wave-current flows transports sediment particles, uplifting the near-bottom nepheloid layer to the banks tops but without breaking coral skeletons. Storm-driven turbulence induces cooling by heat extraction, mixing, and upwelling, which reduces coral bleaching potential and deepens the mixed layer by about 20 m. Tropical storms also aid larvae dispersal from and onto the FGB reefs. The FGB reefs and neighbouring reef banks act as coral refugia because of their offshore location and deep position in the water column, which shields them from the negative effects of all but the strongest hurricanes. Low storm activity in 1994–2004 actually contributed to an 18% coral cover increase. Very strong storms, however, have negative effects. Hurricane Rita for example, which hit FGB in 2005,

reduced coral cover by 11% to nearly pre-1994 levels due to severe damages from high-force waves, turbidity, and sedimentation.

**STRESSOR INFORMATION:** A 100-year climatology of tropical storms and hurricanes within a 200 km buffer was developed to study impacts on the FGB coral reefs and neighbouring banks of the northwestern Gulf of Mexico. The FGB are most commonly affected by tropical storms from May through November, peaking in August-September. Storms approach from all directions; however, the majority of them approach from the southeast and southwest, which suggests a correlation with storm origin in the Atlantic and Gulf of Mexico. On average there is 52% chance of a storm approaching within 200 km of the FGB annually, but there is only a 17% chance of the storms making a direct hit. Storm-generated waves 5–25 m in height and periods of 11–15 s induce particle speed of 1–4 $m \cdot s^{-1}$ near these reefs.

**REFERENCE:** Lugo-Fernandez, A., & Gravois, M. (2010). Understanding impacts of tropical storms and hurricanes on submerged bank reefs and coral communities in the northwestern Gulf of Mexico. Continental Shelf Research, 30 (10), 1226–1240.

## Reduced salinity

**REGION / COUNTRY OF STUDY:** Australia

**IMPACT DESCRIPTION:** Prolonged intense rainfall due to tropical storms can reduce salinity levels in coastal waters. Optimal coral growth occurs at salinities around 34–36 parts per thousand (ppt). Corals appear to tolerate intermittent conditions around 27–48 ppt. Exposure to salinities below 27 ppt induces fast growing opportunists to expel their zooxanthellae – a condition that may be lethal to corals. Mortality usually arises because of irreversible osmotic exchange, for example, gross swelling and lysis of the epidermal cells. Massive corals (e.g., faviids) appear more tolerant to salinity changes and generally different species have varying tolerance levels.

**REFERENCE:** Van Woesik, R. (1994). Contemporary disturbances to coral communities of the Great Barrier Reef. Journal of Coastal Research, 233–252.

## Reduced recruitment

**REGION / COUNTRY OF STUDY:** Tobago

**IMPACT DESCRIPTION:** Even though Tobago does not lie within the main hurricane belt, regional hurricane events negatively impact coral recruitment patterns through-out the Southern Caribbean. In years following hurricanes, tropical storms and bleaching events, coral recruitment was reduced when compared to normal years ($p = 0.016$). Following Hurricane Ivan in 2004 and the 2005–2006 bleaching event, coral recruitment was markedly limited with only 2% ($n = 6$) of colonies estimated to have recruited during 2006 and 2007.

**REFERENCE:** Mallela, J., & Crabbe, M. (2009). Hurricanes and coral bleaching linked to changes in coral recruitment in Tobago. Marine environmental research, 68 (4), 158–162.

## Breakage & dislodgment

**REGION / COUNTRY OF STUDY:** United Arab Emirates

**IMPACT DESCRIPTION:** Cyclone Gonu hit the Gulf of Oman in June 2007. Storm damage caused > 50% losses of live branching and tabular coral cover by fragmentation and dislodgment of pocilloporid and acroporid colonies.

Physical damage to coral varied considerably between sites, depending primarily on colony morphology. Losses tend to be higher at locations with an abundance of branching and tabular colonies (53–56% losses).

**STRESSOR INFORMATION:** Cyclone Gonu was the strongest storm in the area since record-keeping began in 1945, battered the Arabian Peninsula with reported waves > 10 m.

**SPECIFIC SPECIES DISCUSSED:** Pocilloporid and acroporid colonies

**RECOMMENDATIONS:** Conservation efforts should be implemented to minimise pressures and allow the coral sufficient time to recover.

**REFERENCE:** Foster, K. A., Foster, G., Tourenq, C., & Shuriqi, M. K. (2011). Shifts in coral community structures following cyclone and red tide disturbances within the Gulf of Oman (United Arab Emirates). Marine biology, 158 (5), 955–968.

**REGION / COUNTRY OF STUDY:** USA

**IMPACT DESCRIPTION:** Four hurricanes impacted the reefs of Florida in 2005: Dennis, Katrina, Rita, and Wilma. Storm damage to Acropora palmata was surprisingly limited; only 2 out of 19 colonies were removed from the study plot at Molasses Reef. The net tissue losses for those colonies that remained were only 10% and mean diameter of colonies decreased slightly from 88.4 to 79.6 cm. In contrast, the damage to the reef framework was more severe, and a large section (6 m in diameter) was dislodged, overturned, and transported to the bottom of the reef spur.

**STRESSOR INFORMATION:** During the summer of 2005, an

unprecedented sequence of four hurricanes impacted the reefs of the Florida Keys
**SPECIFIC SPECIES DISCUSSED:** Acropora palmata
**REFERENCE:** Gleason, A. C., Lirman, D., Williams, D., Gracias, N. R., Gintert, B. E., Madjidi, H., … Miller, M. (2007). Documenting hurricane impacts on coral reefs using two-dimensional video-mosaic technology. Marine Ecology, 28 (2), 254–258.

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** The initial recovery process of Acropora palmata in two distant reefs, impacted in 1988 by a hurricane (class V) and a tropical storm, was analyzed for a five year period. Colonies of A. palmata are prone to storm damage because the species colonize the shallow areas of the reef, and its colonies show a relatively fragile branching growth-form. Quite variable conditions may exist after the storms impact inducing a patchiness which may be further enhanced by temporal replacement by other species, mostly algae.
**STRESSOR INFORMATION:** Eight major storms passed over the study area from 1915 to 1993, greatly damaging coral reefs. Even storms that do not pass exactly over the area affect the reef (e.g. the track of Hurricane Allen passed 150 km away from the study area but the waves generated were still able to break branching and dislodge part of the reef).
**SPECIFIC SPECIES DISCUSSED:** Acropora palmata
**REFERENCE:** Jordan-Dahlgren, E., & Rodriguez-Martinez, R. E. (1998). Post-hurricane initial recovery of Acropora palmata in two reefs of the Yucatán Peninsula, México. Bulletin of marine science, 63 (1), 213–228.

**REGION / COUNTRY OF STUDY:** Netherlands Antilles (Caribbean)
**IMPACT DESCRIPTION:** In November 1999, Hurricane Lenny took an unusual west-to-east track, bisecting the Caribbean Basin and passing approximately 200 miles north of Curaçao and Bonaire. The leeward shores of both islands were pounded for 24 h by heavy waves (3–6 m) generated while the storm was centered far to the west. Reef damage surveys at 33 sites documented occurrences of toppling, fragmentation, tissue damage, bleaching, and smothering due to the storm. Reefs were severely damaged along westward-facing shores but less impacted where the reef front was tangential to the wave direction or was protected by offshore islands. At the most severely damaged sites, massive coral colonies 2–3 m high (older than 100 years) were toppled or overturned, smaller corals were broken loose and tumbled across the shallow reef platform and either deposited on the shore or dropped onto the deeper forereef slope. Branching and plating growth forms suffered more damage than massive species and large colonies experienced greater damage than small colonies. In general, the fragile finger coral Madracis mirabilis incurred the most damage due to fragmentation and toppling, while massive, head, and plate corals fared better.
**SPECIFIC SPECIES DISCUSSED:** Montastrea annularis, Montastrea cavernosa, Agaricia agaricites, Madracis mirabilis, Diploria strigosa
**REFERENCE:** Bries, J. M., Debrot, A. O., & Meyer, D. L. (2004). Damage to the leeward reefs of Curacao and Bonaire, Netherlands Antilles from a rare storm event: Hurricane Lenny, November 1999. Coral Reefs, 23 (2), 297–307.

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** In 2005, severe tropical cyclone Ingrid crossed the far northern Great Barrier Reef, a region that had not been affected by a major disturbance for several decades. While offshore reefs had the deepest depth of damage, inshore reefs had the greatest rates of coral breakage and dislodgement. On a severely affected inshore reef, hard coral cover decreased about 800%, taxonomic richness decreased 250%, the density of coral recruits decreased by 30%, while massive coral cover remained unaltered. Maximum winds $< 28\,m{\cdot}s^{-1}$ for $< 12$ h inflicted only minor damage on any reef, but winds $> 33\,m{\cdot}s^{-1}$ and $> 40\,m{\cdot}s^{-1}$ caused catastrophic damage on inshore and offshore reefs, respectively.
In particular, the genera Acropora, Montipora, Pachyseris, and Merulina each declined to 0–7% of precyclone cover. Prior to the storm, the group of branching and foliose corals contributed 84% to total hard coral cover (46% of 55%), but only 37% to generic hard coral richness. After the storm, their contribution to total hard coral cover had dropped to 52% (4.8% of 9.2%), while their contribution to generic richness remained unchanged (40%). Corals with massive growth forms and unattached Fungiidae did not change in cover or richness in response to the wind at either depth or aspect. The genera Porites and Lobophyllia appeared to have increased by 22% and 12%, respectively, possibly because they were more conspicuous after the canopy of branching corals had disappeared at MacDonald Reef
**STRESSOR INFORMATION:** Tropical cyclone Ingrid was a category 4 cyclone with a central atmospheric pressure minimum of 925 h Pa. Modelled maximum wind speeds ranged from $46\,m{\cdot}s^{-1}$ (equivalent to category 4) near the path to $22\,m{\cdot}s^{-1}$ (category 1) similar to 70 km to either side of the path.
**SPECIFIC SPECIES DISCUSSED:** Acropora, Montipora, Pachyseris, Merulina, Porites and Lobophyllia
**REFERENCE:** Fabricius, K. E., De'Ath, G., Puotinen, M. L., Done, T., Cooper, T. F., & Burgess, S. C. (2008). Disturbance gradients on inshore and offshore coral

reefs caused by a severe tropical cyclone. Limnology and Oceanography, 53 (2), 690–704.

## Coral degradation and losses – losses of habitat for aquatic biota

**REGION / COUNTRY OF STUDY:** New Caledonia (collectivity of France)
**IMPACT DESCRIPTION:** Cyclone Erica (Class 5) that hit the South Lagoon Marine Park of New Caledonia on 14 March 2003 had a significant impact on reef fish. The fragile coral forms cover (branching, tubular and foliose) decreased significantly, resulting in a loss of habitat for the fish communities. Species richness and biomass of the commercial reef fish and the Chaetodontidae decreased just after Erica, but not the density. The species assemblage was modified in the areas with the lowest remaining live coral cover. The loss of shelter modified the behaviour of potential prey, which constituted unusual shoals and attracted predators. Twenty months after Erica, the habitat had not recovered and the broken coral colonies were transformed into rubble or coloinzed by algae. The mid-term impact on the fish communities was even more significant than the initial impact. Species richness per area, density and biomass were significantly lower than before and just after Erica. This pattern was confirmed for all the main families, with the exception of Acanthuridae. Herbivorous species and benthic macroinvertebrate feeders associated with rubble replaced the coral associated species that characterized the assemblages before the cyclone.
**STRESSOR INFORMATION:** When a Class 5 cyclone affects an area where perturbations of such intensity are uncommon, its impact is immediate and the mid-term consequences are even more significant.
**REFERENCE:** Wantiez, L., Chateau, O., & Le Mouellic, S. (2006). Initial and mid-term impacts of cyclone Erica on coral reef fish communities and habitat in the South Lagoon Marine Park of New Caledonia. Journal of the Marine Biological Association of the United Kingdom, 86 (5), 1229–1236.

## Increased vulnerability of reefs to disturbances

**REGION / COUNTRY OF STUDY:** United Arab Emirates
**IMPACT DESCRIPTION:** This study documents the effects of two consecutive disturbances on coral community structures in the Gulf of Oman (United Arab Emirates); Cyclone Gonu in June 2007 and the Cochlodinium polykrikoides harmful algal bloom (HAB) that persisted from August 2008 until May 2009. Pocillopora damicornis colonies that survived the cyclone experienced mass mortality during the first three months of the HAB, resulting in localized extirpation of this species. Variable Acropora mortality during the HAB indicated individual colony, rather than taxa-wide, susceptibility, where massive colony coral taxa are more resistant to both disturbances.
**SPECIFIC SPECIES DISCUSSED:** Pocilloporid and acroporid colonies
**RECOMMENDATIONS:** Conservation efforts should be implemented to minimise pressures and allow the coral sufficient time to recover.
**REFERENCE:** Foster, K. A., Foster, G., Tourenq, C., & Shuriqi, M. K. (2011). Shifts in coral community structures following cyclone and red tide disturbances within the Gulf of Oman (United Arab Emirates). Marine biology, 158 (5), 955–968.

## Species displacement

**REGION / COUNTRY OF STUDY:** Colombia
**IMPACT DESCRIPTION:** Cliona tenuis, an encrusting and excavating brown sponge (Hadromerida, Clionaidae), displaces live coral tissue by undermining the polypal skeletal support. On the windward fringing reef of Islas del Rosario, 26% of C. tenuis individuals currently dwelling on live corals had colonized their host from sponge-carrying branches of A. palmata thrown against the corals during storms. Times of initial colonization were found to coincide approximately with the hurricanes that affected the area. C. tenuis was additionally found to undermine encrusting and foliose corals settled on dead A. palmata branches, thus also retarding the process of reef recovery to an unknown degree.
**SPECIFIC SPECIES DISCUSSED:** Cliona tenuis (sponge), Acropora palmata (coral)
**REFERENCE:** López-Victoria, M., & Zea, S. (2004). Storm-mediated coral colonization by an excavating Caribbean sponge. Climate Research, 26 (3), 251–256.

## Further impact: Loss of provisioning services & increased vulnerability of coastal communities

## MANGROVES

### Breakage & uprooting

**REGION / COUNTRY OF STUDY:** Honduras
**IMPACT DESCRIPTION:** Following Hurricane Mitch in 1998, the trunks of adult red mangroves were broken, while adult black mangrove trunks were uprooted on the islands of Guanaja and Roatan. Continued severe impact in Mangrove Bight was indicated by a complete lack of recovery (i.e. no regrowth) within the high impact area in 2001, 27 months after the storm. Few trees survived and recovery of high impact mangrove forests will thus depend primarily on seedling recruitment.
**STRESSOR INFORMATION:** Hurricane Mitch was a category 4 hurricane with estimated maximum surface winds of 240 km·h$^{-1}$
**SPECIFIC SPECIES DISCUSSED:** Rhizophora (red) mangle
**REFERENCE:** Cahoon, D.R., Hensel, P., Rybczyk, J., McKee, K.L., Proffitt, C.E., & Perez, B.C. (2003). Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. Journal of ecology, 91 (6), 1093–1105.

**REGION / COUNTRY OF STUDY:** Mexico
**IMPACT DESCRIPTION:** Fishermen observations regarding the impact of hurricanes on the mangrove forests of the Mexican Pacific indicated that mangrove survival is related to three attributes: main stem condition, diameter of main stem and species. The results suggest a high degree of consistency amongst the villages and with the observations of a previous investigation, and with a few exceptions, the fishermen indicated that large diameter trees were the most susceptible to hurricanes. Conversely, that black mangrove (Avicennia germinans) and an intact main stem condition would indicate a better likelihood of surviving such an event.
**SPECIFIC SPECIES DISCUSSED:** Rhizophora mangle, Laguncularia racemosa, Avicennia germinans
**REFERENCE:** Kovacs, J.M., Malczewski, J., & Flores-Verdugo, F. (2004). Examining local ecological knowledge of hurricane impacts in a mangrove forest using an analytical hierarchy process (AHP) approach. Journal of Coastal Research, 792–800.

### Peat collapse

**REGION / COUNTRY OF STUDY:** Honduras
**IMPACT DESCRIPTION:** Following Hurricane Mitch in 1998, few mangrove trees survived on the islands of Guanaja and Roatan. Mass tree mortality caused rapid elevation loss and the collapse of underlying peat. This impacts recovery processes and future resilience to climate hazards.
**STRESSOR INFORMATION:** Hurricane Mitch was a category 4 hurricane with estimated maximum surface winds of 240 km·h$^{-1}$
**SPECIFIC SPECIES DISCUSSED:** Rhizophora (red) mangle
**REFERENCE:** Cahoon, D.R., Hensel, P., Rybczyk, J., McKee, K.L., Proffitt, C.E., & Perez, B.C. (2003). Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. Journal of ecology, 91 (6), 1093–1105.

### Changes in soil elevation

**REGION / COUNTRY OF STUDY:** Global
**IMPACT DESCRIPTION:** In addition to causing tree mortality, stress, and sulphide soil toxicity, storms can alter mangrove sediment elevation through soil erosion, soil deposition, peat collapse, and soil compression.
**RECOMMENDATIONS:** Manage activities in the catchment area that affect mangrove sediment elevation and eliminate non-climate stresses on mangroves (e.g., filling, conversion for aquaculture, pollution) in order to increase their resilience.
**REFERENCE:** Gilman, E.L., Ellison, J., Duke, N.C., & Field, C. (2008). Threats to mangroves from climate change and adaptation options: a review. Aquatic Botany, 89 (2), 237–250.

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** Hurricanes affect soil elevation in mangrove ecosystems by either increasing it or decreasing it. When soil elevation is increased, the impact for the ecosystem can be positive as soil elevation is important for counter-balancing the effects of relative sea-level rise. A case-study of mangrove ecosystems along the Shark River in Everglades National Park, Florida, USA, demonstrated that hurricane Wilma (2005) contributed to an increase in soil elevation by 42.8 mm. However, the soil profile had lost 10.0 mm in soil elevation one year after the hurricane, with 8.5 mm of the loss due to erosion. The remaining soil elevation loss was due to compaction from shallow subsidence. Prolific growth of new fine rootlets was found in the storm deposited material suggesting that deposits may become more stable in the near future (i.e., erosion rate will decrease). Expansion and contraction in the shallow soil zone may be due to hydrology, and in the middle and bottom soil zones due to shallow subsidence. Findings thus far indicate that soil elevation has made substantial gains compared to site specific relative sea-level rise, but

data trends suggest that belowground processes, which differ by soil zone, may come to dominate the long term ecological impact of storm deposit.
**SPECIFIC SPECIES DISCUSSED:** Rhizophora mangle, Laguncularia racemosa, Avicennia germinans
**RECOMMENDATIONS:** Understanding where the soil zone is changing is important to help explain what processes are driving long-term changes in soil elevation. This is critical as increases in storm activities and sea level rise rates are expected in the region.
**REFERENCE:** Whelan, K. R., Smith, T. J., Anderson, G. H., & Ouellette, M. L. (2009). Hurricane Wilma's impact on overall soil elevation and zones within the soil profile in a mangrove forest. Wetlands, 29 (1), 16–23.

**REGION / COUNTRY OF STUDY:** Australia
**IMPACT DESCRIPTION:** Storm sediments can also cause negative impacts on mangroves. Changes in mangal area were quantified in the eastern Exmouth Gulf over six years (1999–2004) after Cyclone Vance. Some 12,800 ha of mangrove habitat was present before the cyclone and approximately 5700 ha (44%) was removed by it. Most mangroves lost (74%) between 1999 and 2004 were converted either to bare sediment or to live saltmarshes and this occurred mostly between 1999 and 2002. Five basic categories of damage were conspicuous from imagery and field observations, and evidence suggests that much of the loss was due to the longer term consequences of sediment deposition or smothering, rather than the immediate effects of wind or waves. Mangroves exhibited accelerated recovery between 2002 and 2004, and around 1580 ha regenerated during this time, amounting to a return of 68% of their former coverage. At this recovery rate we estimate that they should have returned to their pre-cyclone area by 2009.
**STRESSOR INFORMATION:** Vance was the strongest tropical cyclone ever to impact the Australian mainland before 2006 and produced wind gusts of more than 280 $km \cdot h^{-1}$.
**SPECIFIC SPECIES DISCUSSED:** Avicennia marina, Rhizophora stylosa
**REFERENCE:** Paling, E., Kobryn, H., & Humphreys, G. (2008). Assessing the extent of mangrove change caused by Cyclone Vance in the eastern Exmouth Gulf, northwestern Australia. Estuarine, coastal and shelf science, 77 (4), 603–613.

## Mangrove degradation and losses – losses of habitat for aquatic biota & species redistribution

**REGION / COUNTRY OF STUDY:** Belize
**IMPACT DESCRIPTION:** Hattie, a category five hurricane, hit the Belizean coast in 1961, and especially the Turneffe Atoll. Hurricane destruction influenced mangrove structure and the heterogeneity of species dominance. By changing the space available to different species, hurricanes play a role resetting succession and altering composition. This could also be a positive impact, depending on the site and species that dominated before the disturbance event.
Depending on the destruction levels at the different sites of analysis, variations in species dominance was identified. Different levels of destruction are shown to have had varying effects on current patterns of species and structural zonation at Calabash. Disturbance regimes are thus one important factor that influences mangrove horizontal zonation patterns.
**SPECIFIC SPECIES DISCUSSED:** Rhizophora, Avicennia germinans
**RECOMMENDATIONS:** Need to document further the long-term effects of hurricanes on the horizontal zonation patterns of mangrove forests.
**REFERENCE:** Piou, C., Feller, I. C., Berger, U., & Chi, F. (2006). Zonation Patterns of Belizean Offshore Mangrove Forests 41 Years After a Catastrophic Hurricane. Biotropica, 38 (3), 365–374.

## Carbon emissions, losses of provisioning services & losses of protective services

## Further impact: Increased vulnerability of coastal communities

## Further impact: Increased exposure and vulnerability of coastal communities

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** Villages protected by the Bhitarkanika mangrove ecosystem suffered significantly less damage than the villages that were unprotected. In the mangrove-protected villages, variables had the lowest values for adverse factors (such as damage to houses), and the highest values for positive factors (such as crop yield). The loss incurred per household was greatest in the village that was not sheltered by mangroves but had an embankment, followed toy the village that was neither in the shadow of mangroves or the embankment.
**STRESSOR INFORMATION:** A super cyclone with a wind speed of around 260 km/h and a storm surge about 9 m hit the Bhitarnika area. The strom travelled more than 250 km inland within a period of 36 h.
**SPECIFIC SPECIES DISCUSSED:** Sonneratia apetala, Heritiera fomes, H. littoralis are the dominant species. There are also several Avicennia species in the Bhitarkanika Conservation Area.
**REFERENCE:** Badola, R., & Hussain, S. (2005). Valuing ecosystem functions: an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. Environmental Conservation, 32 (1), 85–92.

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** This study examines 262 villages lying within a 10 km of the coast in one of the most cyclone prone districts of India and estimates the probability of expected human fatality due to severe cyclone for these villages. Villages established in mangrove habitat areas (after clearing the forest) and those with more marginal workers (without any regular jobs) were estimated to face a very high death risk. In contrast, villages situated in the leeward side of existing mangrove forests or near a major river are seen to be facing a much lower risk of deaths.
**RECOMMENDATIONS:** The results have important implications like conserving mangroves in cyclone-prone areas, priority evacuation of villages established in the mangrove habitat before a high-intensity cyclone, etc., for cyclone hazard management. To aid decision-making a compact vulnerability map of the coastal regions likely to be affected by climate extremes should be developed.
**REFERENCE:** Das, S. (2012). The role of natural ecosystems and socio-economic factors in the vulnerability of coastal villages to cyclone and storm surge. Natural hazards, 64 (1), 531–546.

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** Data on several hundred villages was used to test the impact of mangroves on human deaths during a 1999 super cyclone that struck the state of Orissa. Villages with wider mangroves between them and the coast experienced significantly fewer deaths than ones with narrower or no mangroves.
**RECOMMENDATIONS:** Although mangroves evidently saved fewer lives than an early warning issued by the government, the retention of remaining mangroves in Orissa is economically justified even without considering the many benefits they provide to human society besides storm-protection services.
**REFERENCE:** Das, S., & Vincent, J. R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. Proceedings of the National Academy of Sciences, 106 (18), 7357–7360.

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** A hurricane surge acts like a very high tide event that fosters a temporary increase in sea level above the one expected from a normal high tide. Mangrove forests are able to slow the storm surge thus reduce the amount of water reaching inland areas. Recent hurricane strikes along the Gulf Coast of the United States have impacted wetland integrity in some areas but it was also found that mangrove wetlands reduced water level height by as much as 9.4 cm/km inland. Intact mangroves can support a protective role in reducing maximum water level height associated with storm surges.
**REFERENCE:** Krauss, K. W., Doyle, T. W., Doyle, T. J., Swarzenski, C. M., From, A. S., Day, R. H., & Conner, W. H. (2009). Water level observations in mangrove swamps during two hurricanes in Florida. Wetlands, 29 (1), 142–149.

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** The 6-to-30-km-wide mangrove forest along the Gulf Coast of South Florida effectively attenuated storm surges from hurricane Wilma (category 3), by reducing both the amplitude and extent of overland flooding and protecting the freshwater marsh behind the mangrove zones from surge inundation. The surge amplitude decreases at a rate of 40–50 cm/km across the mangrove forest and at a rate of 20 cm/km across the areas with a mixture of mangrove islands with open water. In contrast, the amplitudes of storm surges at the front of the mangrove zone increase by about 10–30% because of the blockage of mangroves to surge water, which can cause greater impacts on structures at the front of mangroves than the case without mangroves. The mangrove forest can also protect the

wetlands behind the mangrove zone against surge inundation from a Category 5 hurricane with a fast forward speed of 11.2 m/s (25 mph). However, the forest cannot fully attenuate storm surges from a Category 5 hurricane with a slow forward speed of 2.2 m/s (5 mph) and reduced surges can still affect the wetlands behind the mangrove zone. The effects of widths of mangrove zones on reducing surge amplitudes are nonlinear with large reduction rates (15–30%) for initial width increments and small rates (< 5%) for subsequent width increments.
**REFERENCE:** Zhang, K., Liu, H., Li, Y., Xu, H., Shen, J., Rhome, J., & Smith, T. J. (2012). The role of mangroves in attenuating storm surges. Estuarine, Coastal and Shelf Science.

## COASTAL COMMUNITIES

### Coastal flooding

**REGION / COUNTRY OF STUDY:** Puerto Rico
**IMPACT DESCRIPTION:** Wave impact and coastal flooding were augmented by a 0.6 m high tide and a 0.7 m storm surge in San Juan.
**STRESSOR INFORMATION:** Hurricane Hugo struck Puerto Rico on 18 September 1989. Coastal zone resources as diverse as offshore sand deposits, recreational beaches, and coral reefs were affected. During the storms, winds greater than 240 km/h were observed.
**REFERENCE:** Rodriguez, R., Webb, R., & Bush, D. (1994). Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research, 278–296.

### Further impact: Increased transmission of infectious diseases

### Coastal erosion

**REGION / COUNTRY OF STUDY:** Puerto Rico
**IMPACT DESCRIPTION:** In the aftermath of Hurricane Hugo (1989), cores and aerial photographs revealed that at least 100,000 m³ of sand was removed from the Escollo de Arenas, a large offshore sand deposit (90 x 106 m³). The berms of the beaches along the eastern and northern coast of Puerto Rico were severely eroded. Follow-up profiling shows that Hugo provided only a minor perturbation in the seasonal cycle of beach changes at most sites. In areas where a large volume of sand was deposited inland or below the seasonal wave base, the recovery has been slow.
**STRESSOR INFORMATION:** Hurricane Hugo struck Puerto Rico on 18 September 1989. Coastal zone resources as diverse as offshore sand deposits, recreational beaches, and coral reefs were affected. During the storms, winds greater than 240 km/h were observed.
**REFERENCE:** Rodriguez, R., Webb, R., & Bush, D. (1994). Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research, 278–296.

### Beach degradation

**REGION / COUNTRY OF STUDY:** Puerto Rico
**IMPACT DESCRIPTION:** Hurricane Hugo struck Puerto Rico on 18 September 1989. Coastal zone resources as diverse as offshore sand deposits, recreational beaches, and coral reefs were affected. Damage was caused by direct wave impact, sand overwash, destruction of infrastructure, and local flooding. Beaches and tourist infrastructure were greatly degraded due to the debris and material washed on shore, affecting tourism activities.
**STRESSOR INFORMATION:** During the storms, winds greater than 240 km/h were observed.
**REFERENCE:** Rodriguez, R., Webb, R., & Bush, D. (1994). Another look at the impact of Hurricane Hugo on the shelf and coastal resources of Puerto Rico, USA. Journal of Coastal Research, 278–296.

### Loss of lives and property

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** Unprotected villages in the Bhitarkanika area suffered significant damages from the super cyclone that hit the state of Orissa in 1999, related to destruction of houses and agricultural fields. Villages protected by mangroves incurred fewer damages.
**STRESSOR INFORMATION:** A super cyclone with a wind speed of around 260 km/h and a storm surge about 9 m hit the Bhitarnika area. The strom travelled more than 250 km inland within a period of 36 h.
**RECOMMENDATIONS:** Mangrove and ecosystem conservation and restoration, early warning systems.
**REFERENCE:** Badola, R., & Hussain, S. (2005). Valuing ecosystem functions: an empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. Environmental Conservation, 32 (1), 85–92.

**REGION / COUNTRY OF STUDY:** India
**IMPACT DESCRIPTION:** Several hundred unprotected villages suffered losses of lives during the 1999 super cyclone that struck the state of Orissa. Villages protected by mangroves suffered significantly less losses of lives and property.
**RECOMMENDATIONS:** Although mangroves evidently saved fewer lives than an early warning issued by the government, the retention of remaining mangroves in Orissa is economically justified even without considering the many benefits they provide to human society besides storm-protection services.
**REFERENCE:** Das, S., & Vincent, J. R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. Proceedings of the National Academy of Sciences, 106 (18), 7357–7360.

**REGION / COUNTRY OF STUDY:** Bangladesh
**IMPACT DESCRIPTION:** Bangladesh is especially vulnerable to tropical cyclones, with around 718,000 deaths from them in the past 50 years. However, cyclone-related mortality in Bangladesh has declined by more than 100-fold over the past 40 years, from 500,000 deaths in 1970 to 4,234 in 2007. The main factors responsible for these reduced fatalities and injuries are improved defensive measures, including early warning systems, cyclone shelters, evacuation plans, coastal embankments, reforestation schemes and increased awareness and communication.
**RECOMMENDATIONS:** Modernizing early warning systems, developing shelters and evacuation plans, constructing coastal embankments, maintaining and improving coastal forest cover and raising awareness at the community level. The development of a 500 m coastal mangrove forest zone will further reduce the vulnerability to cyclones, which is especially important given the likelihood of a rise in sea level and an increase in tropical storm frequency and strength due to climate change. Mapping of areas at high risk of flooding can be prepared to use during evacuations ahead of cyclone-related coastal surges. Planners, policy-makers and development practitioners should endeavour to incorporate local knowledge into environmental and adaptation strategies. The building code in coastal zones should be changed to ensure that concrete houses are raised 3 m off the ground. More broadly, a more compact development style may be recommended.
**REFERENCE:** Haque, U., Hashizume, M., Kolivras, K. N., Overgaard, H. J., Das, B., & Yamamoto, T. (2012). Reduced death rates from cyclones in Bangladesh: what more needs to be done? Bulletin of the World Health Organization, 90 (2), 150–156.

### Livelihood loss & food insecurity

**REGION / COUNTRY OF STUDY:** Vietnam
**IMPACT DESCRIPTION:** Typhoons heavily disrupt harvests and affect the germination of rice seedlings. Major economic activities of coastal communities such as salt-making are also disrupted due to the landfall of typhoons and storms.
**RECOMMENDATIONS:** Secure tenure and access over important coastal resources to increase community resilience.
**REFERENCE:** Neil Adger, W. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. World Development, 27 (2), 249–269.
**REGION / COUNTRY OF STUDY:** Fiji
**IMPACT DESCRIPTION:** Cyclone Ami (2003) severely impacted areas of Fiji due to heavy rains, flooding and landslides. Crop losses (e.g. sugarcane) were estimated to be worth over U.S. $35 million.
**REFERENCE:** Barnett, J. (2011). Dangerous climate change in the Pacific Islands: food production and food security. Regional Environmental Change, 11 (1), 229–237.

### Further impact: Migration

### Infrastructure and land development

### Increased vulnerability of coral reefs to storms

**REGION / COUNTRY OF STUDY:** St. Lucia
**IMPACT DESCRIPTION:** Land development ranks among the most significant human threats to coral reefs, causing damage by promoting the erosion and transport of soil and sediment in water. Following a tropical storm, more sediment and coral damage was found on reefs closest to the mouths of large rivers, where coral mortality depended on the amount of sediment and even exceeded 50% at some sites. Significantly more sediment was found at sites near road construction works at the time of the storm. This problem is likely to grow in scale given the growing demands for development and the increasing frequency of large storms in the tropical Atlantic.
**REFERENCE:** Nowlis, J. S., Roberts, C. M., Smith, A. H., & Siirila, E. (1997). Human-enhanced impacts of a tropical storm nearshore coral reefs. Ambio, 26 (8), 515–521.

## Increased vulnerability of mangroves to storms

**REGION / COUNTRY OF STUDY:** USA
**IMPACT DESCRIPTION:** In Florida, mosquito impoundments were constructed to reduce mosquito populations by flooding the substrate they require for breeding. This artificial flooding however has been shown to affect mangrove ecosystems, and especially their regeneration and composition of species following disturbance events by hurricanes. The canopy turnover has been found to be greater in forests in higher succession stages with median tree diameter at breast height of 7.6 ± 5.7 cm compared to the intact forest with 3.7 ± 1.2 cm. Larger trees with lower densities are more susceptible to hurricane damage. In the aftermath of destruction by two hurricanes, the regeneration of the open patches was dominated by the flood-tolerant species Rhizophora mangle (89.9%) instead of the faster-growing pioneer species Laguncularia racemosa (7.0%). Some of the disturbed areas created by the hurricanes were not recolonized.
**SPECIFIC SPECIES DISCUSSED:** Rhizophora mangle, Languncularia racemosa, Avicennia germinans
**REFERENCE:** Vogt, J., Skóra, A., Feller, I. C., Piou, C., Coldren, G., & Berger, U. (2012). Investigating the role of impoundment and forest structure on the resistance and resilience of mangrove forests to hurricanes. Aquatic Botany, 97 (1), 24–29.

# ANNEX 3

# COUNTRY DOCUMENT REVIEW METHODS

# 3.1 Indonesia

## Search terms and methods

As a first step, documents were searched using *Google advanced search* (www.google.com/advanced_search). Websites of important governmental and non-governmental organizations in the country, as well as adaptation programme and project databases were searched as a second step.

Google advanced search was performed in English using Google.com with the following keyword configurations:
- **All the words:** Indonesia coast
- **Any of these words:** adaptation OR development OR law OR management OR policy OR project OR programme

Google advanced search was also performed in Bahasa Indonesia using Google.co.id with the following keyword configurations:

### SEARCH 1
- **All the words:** Indonesia pesisir
- **Any of these words:** adaptasi OR pembangunan OR peraturan OR pengelolaan OR Kebijakan OR proyek OR program

### SEARCH 2
- **All the words:** Indonesia terumbu karang (coral)
- **Any of these words:** adaptasi OR pembangunan OR peraturan OR pengelolaan OR Kebijakan OR proyek OR program

### SEARCH 3
- **All the words:** Indonesia mangrove
- **Any of these words:** adaptasi OR pembangunan OR peraturan OR pengelolaan OR Kebijakan OR proyek OR program

### SEARCH 4
- **All the words:** Indonesia padang lamun (seagrass)
- **Any of these words:** adaptasi OR pembangunan OR peraturan OR pengelolaan OR Kebijakan OR proyek OR program

Wildcards are not supported in Google, but the search engine automatically finds variations of the keywords (e.g. the keyword Indonesia also triggers results with the keyword Indonesian, unless placed in quotation marks).

Relevant documents were also searched in the following websites:
1. weADAPT http://weadapt.org
2. Asia-Pacific Adapt www.asiapacificadapt.net
3. Websites of different ministries and local government agencies
4. Websites of research institutions and organizations such as LIPI and FORDA
5. Websites of NGOs and regional programmes such as:
   - Wetlands International
   - Planete Urgence
   - Flora & Fauna International
   - BirdLife Indonesia
   - Conservation International
   - Live and Learn Indonesia www.livelearn.org/locations/indonesia
   - Mangroves for the Future www.mangrovesforthefuture.org/countries/members/indonesia

## LIST OF DOCUMENTS REVIEWED

| No. | TITLE | NAME OF ORGANIZATION OR NETWORK | YEAR | DOCUMENT TYPE | MAIN FOCUS OF DOCUMENT | TARGET LOCATION(S) | DOWNLOAD LINK |
|---|---|---|---|---|---|---|---|
| 1 | Carter et al (2011). Panduan untuk Meningkatkan Efektivitas Pengelolaan Kawasan Konservasi Laut di Indonesia (Guidelines for Improving Management Effectiveness of Marine Protected Areas in Indonesia) | USAID; WWF; TNC; CI | 2011 | National project or programme | Ecosystem/ resource management | Indonesia | http://www.nature.or.id/wp-content/uploads/2012/06/Panduan-EPKKL-Maret-2011.pdf |
| 2 | Wetlands International. Mangrove Capital, Melalui mangrove mengamankan ketahanan pesisir yang rentan (Through mangrove securing the resiliency of vulnerable coastal areas) | Wetlands International, The Nature Conservancy, Wageningen univ, IPB, Ministry of Forestry | | National project or programme | Ecosystem/ resource management | Indonesia | http://www.wetlands.or.id/PDF/Mangrove_Capital.pdf |
| 3 | Pemprov Lampung, 2000. Rencana strategis pengelolaan wilayah pesisir Lampung (Strategic plan of Lampung coastal management) | Proyek Pesisir: Provincial Goventment of Lampung, Rhode Island University, IPB, USAID | 2000 | Sub-national/ local policy | Development | Lampung Province | http://imcafs.org/download/Renstra_Lampung.pdf |
| 4 | Kajian Risiko dan Adaptasi Terhadap Perubahan Iklim Pulau Lombok Provinsi Nusa Tenggara Barat. Sektor Pesisir dan Laut (Risk Assessment and Adaptation to Climate Change, Lombok, West Nusa Tenggara Province. Coastal and Marine Sectors) | Ministry of Environment, GTZ, WWF | 2010 | Sub-national/ local project or programme | Adaptation | Lombok Island, West Nusatenggara | http://awsassets.wwf.or.id/downloads/sektor_pesisir_dan_laut.pdf |
| 5 | Kajian Risiko dan Adaptasi Terhadap Perubahan Iklim Pulau Lombok Provinsi Nusa Tenggara Barat. Analisis dan Proyeksi Kenaikan Muka Laut dan Iklim Ekstrim (Risk Assessment and Adaptation to Climate Change, Lombok, West Nusa Tenggara Province. Analysis and Projections of Sea Level Rise and Climate Extremes) | Ministry of Environment, GTZ, WWF | 2010 | Sub-national/ local project or programme | Adaptation | Lombok Island, West Nusa Tenggara | http://awsassets.wwf.or.id/downloads/analisis_dan_proyeksi_kenaikan_muka_laut_dan_iklim_ekstrim.pdf |
| 6 | MOE 2021 Kajian risiko dan adaptasi perubahan iklim Tarakan, Sumatera Selatan, Makang Raya. Ringkasan untuk pembuat kebijakan (Climate change Risk and adaptation study in Tarakan, South Sumatera and Malang Raya. Policy brief) | Ministry of Environment, GIZ, BMZ, AusAID | 2012 | Sub-national/ local policy | Multiple | Tarakan, Sumatera Selatan | |
| 7 | Wiranto 2004. Pembangunan wilayah pesisir dan laut dalam kerangka pembangunan perekonomian daerah (Development of coastal and marine areas within the framework of local economic development) | Ministry of National Planning and Development | 2004 | National policy | Ecosystem/ resource management | Indonesia | www.bappenas.go.id/get-file-server/node/3008/ |

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| 8 | Muslim Aid, 2012. Muslim Aid conduct a mangrove plantation and DRR integrated program in East Coast of Aceh | Muslim Aid Indonesia, District Social Agency, Marine and Fishery Agency, Disaster Alert community (TAGANA) | 2012 | Sub-national/ local project or programme | Disaster-risk reduction | East Coast of Aceh Province | http://muslimaid-id.org/index.php?option=com_content&view=article&id=152%3A-muslim-aid-indonesia-conduct-a-manggrove-plantation-and-drr-integrated-program-in-east-coast-of-aceh&catid=69%3Apress-release-2012&Itemid=69&lang=en |
| 9 | Purwaka & Sunoto, 2011. Coastal Resources Management in Indonesia: Legal and Institutional Aspects | Center for Archipelago, Law and Development Studies | 2011 | Assessment/ research only | Ecosystem/ resource management | Ameth Village-Maluku; Sulamu Village-Nusa Tenggara Timur and Kampung Laut-Central Java | http://www.worldfish-center.org/Pubs/institutional_sea/pub_insea4.pdf |
| 10 | University of Gothenburg, 2008. Indonesia environmental and climate change policy brief | University of Gothenburg | 2008 | National policy | Multiple | Indonesia | http://www.sida.se/Global/Countries%20and%20regions/Asia%20incl.%20Middle%20East/Indonesia/Environmental%20policy%20brief%20Indonesia.pdf |
| 11 | De Guzman et al, 2010. Training Manual for Monitoring Marine Protected Areas in the Asia-Pacific Region | Asia-Pacific Network (APN) for Global Change Research | 2010 | Regional project or programme | Ecosystem/ resource management | Asia Pacific Region | www.apn-gcr.org/.../files/01b8aae7fea04d979f-b4a598661d75d6.pdf |
| 12 | Murdiyarso & Kauffman, 2011. Addressing climate change adaptation and mitigation in tropical wetland ecosystems of Indonesia | CIFOR, United States Department of State, USAID, USDA Forest service, FORDA Indonesia and Sekala Foundation | 2011 | National project or programme | Adaptation | Indonesia | http://www.cifor.org/publications/pdf_files/infobrief/3512-infobrief.pdf |
| 13 | CIFOR, 2011. Tropical wetlands initiative for climate adaptation and mitigation | CIFOR, United States Department of State, USAID, USDA Forest service, Indonesia climate change center, Oregon State University | 2011 | National project or programme | Multiple | Indonesia | http://www.cifor.org/publications/pdf_files/infobrief/3761-flyer.pdf |
| 14 | Hillman & Sagala. Safer Community through Disaster Risk Reduction (DRR) in Development. Evaluation Report | UNDP, DFID, AusAID, UNESCAP, ISDR, National Development and Planning Agency (Bappenas, Ministry of Home Affairs, National Agency for Disaster Management (BNPB) | 2012 | National project or programme | Disaster-risk reduction | Indonesia | http://www.undp.org/content/undp/en/home/librarypage/crisis-prevention-and-recovery/safer-communities-through-disaster-risk-reduction--sc-drr--in-de/ |
| 15 | Green Coast Phase I: for Nature and people after Tsunami | Wetlands International, IUCN NL, WWF-NL, Both ENDS and NOVIB/ Oxfam Netherlands | 2005 – 2006 | Regional project or programme | Disaster-risk reduction | Indonesia, India, Sri Lanka, Thailand and Malaysia | http://www.wetlands.org/LinkClick.aspx?fileticket=XYR7%2BWlatbI%3D&tabid=56 |

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| 16 | Green Coast Phase I: Project in Indonesia | Wetlands International, IUCN NL, WWF-NL, Both ENDS and NOVIB/ Oxfam Netherlands, Wetlands International Indonesia, WWF-Indonesia, BRR NAD-Nias, Syahkuala University | 2006 – 2008 | Sub-national/ local project or programme | Disaster-risk reduction | Aceh and Nias | http://www.wetlands.or.id/PDF/Green_Coast_Indonesia.pdf |
| 17 | Green Coast Phase I: A model for coastal ecosystem rehabilitation in Kuala Gigeng Area, Aceh Besar | Wetlands International, IUCN NL, WWF-NL, Both ENDS and NOVIB/ Oxfam Netherlands, Wetlands International Indonesia, WWF-Indonesia, BRR NAD-Nias, Yayasan Lebah | Phase I = 2005 – 2006 | Sub-national/ local project or programme | Disaster-risk reduction | Aceh Besar District | http://www.wetlands.org/Portals/0/publications/Factsheet/Profil%20KAJHU%20Aceh%20Besar%20(English).pdf |
| 18 | Green Coast for Nature and people after Tsunami Phase II | Wetlands International, IUCN NL, WWF-NL, Both ENDS and NOVIB / Oxfam Netherlands, Wetlands International Indonesia, WWF-Indonesia, BRR NAD-Nias | 2006 – 2008 | National project or programme | Disaster-risk reduction | Aceh | http://www.wetlands.org/LinkClick.aspx?fileticket=BtjtEg1RPik%3D&tabid=56 |
| 19 | UNDP, 2012. Climate Risk Management: An integrated approach for Climate Change Adaptation and Disaster Risk Reduction in Indonesia | UNDP Indonesia | 2012 | National project or programme | Disaster-risk reduction | Indonesia | http://www.undp.or.id/pubs/docs/Climate%20Risk%20Management%20concept%20paper%20-%20September%202012.pdf |
| 20 | Lasco and Boer, 2006. An integrated assessment of climate change impacts, adaptations and vulnerability in watershed areas and communities in Southeast Asia | Global Environment Facility, United Nations Environment Programme, Global Change SysTem for Analysis, Research and Training (START), Third World Academy of Sciences (TWAS), Canadian International Development Agency, the U.S. Agency for International Development, the U.S. Environmental Protection Agency, and the Rockefeller Foundation, University of the Philippines Los Baños College, Bogor Agricultural University | 2002 – 2005 | Assessment/ research only | Disaster-risk reduction | Indonesia & Philippines | http://www.aiaccproject.org/Final%20Reports/Final%20Reports/FinalRept_AIACC_AS21.pdf |

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| 21 | BMKG, 2013. Prakiraan harian tinggi gelombang satu minggu ke depan/ 3 – 9 Maret 2013 (Daily forecast of wave heights for the next one week/ 3 – 9 March 2013) | Meteorology, Climatology an Geo-Physic Agency | 2013 | National project or programme | Disaster-risk reduction | Indonesia | http://maritim.bmkg.go.id/uploads/pdf/prakiraan_tinggi_gelombang_7hari.pdf |
| 22 | BMKG, 2012. Prakiraan musim hukan 2012 (Rainy season forecast 2012) | Meteorology, Climatology an Geo-Physic Agency | 2012 | National project or programme | Development | Indonesia | http://www.bmkg.go.id/bmkg_pusat/Klimatologi/Prakiraan_Musim.bmkg |
| 23 | PEMSEA Regional Review: Implementation of the Sustainable Development Strategy for the Seas of East Asia (SDS-SEA) 2003 – 2011 | GEF, UNDP, the World Bank,ASAEN centre for Biodiversity, CI Philippines, IOI, IUCN-ARO, UNEP/GPA, National Governments, 29 Local Government in those countries, etc. | 2000 – … | Regional project or programme | Ecosystem/ resource management | Brunei Darussalam, Cambodia, PR China, DPR Korea, Indonesia, Japan, Malaysia, Philippines, RO Korea, Singapore, Thailand, Vietnam, Lao PDR and Timor-Leste | http://beta.pemsea.org/sites/default/files/regional-sdssea-review_0.pdf |
| 24 | DNPI, 2012. Rencana aksi nasional adaptasi perubahan iklim Indonesia (National action plan for climate change adaptation Indonesia) | DNPI (National Climate cHange Council) | 2012 | National policy | Adaptation | Indonesia | http://adaptasi.dnpi.go.id/filedata/20120730104434.BUKU%20RENCANA%20DNPI%20ADAPTASI%20(26022012).pdf |
| 25 | MOE, 2007. National action plan addressing climate change | Ministry of Environment, Indonesia | 2007 | National policy | Multiple | Indonesia | http://www.uncsd2012.org/rio20/content/documents/Indonesia%20National%20Action%20Plan%20Addressing%20Climate%20Change.pdf |
| 26 | 1st share learning workshop in Surabaya and Balikpapan mangrove conservation as part of coastal management | JICA, Ministry of Forestry | 2011 – 2014 | Regional project or programme | Ecosystem/ resource management | ASEAN | http://www.mangrove-mecs.org/index.php/news-and-event/12-shared-learning-regional |
| 27 | 2nd shared learning workshop in Alas Purwo, ecotourism development for mangrove conservation | JICA, Ministry of Forestry | 2011 – 2014 | Regional project or programme | Ecosystem/ resource management | ASEAN | http://www.mangrove-mecs.org/images/pdf_files/2nd%20Shared%20Learning%20Work-shop%20in%20Alas%20Purwo%20PDF.pdf |
| 28 | Kemenhut, 2010. Rencana Strategis 2010 – 2014 (Ministry of Forestry, Strategic Plan 2010 – 2014) | Forestry Ministry | 2010 – 2014 | National policy | Multiple | Indonesia | http://www.dephut.go.id/files/Renstra_2010_2014.pdf |
| 29 | Balitbanghut, 2012. Rencana strategis tahun 2010 – 2014 (Forest Research and Development Agency, Strategic Plan 2010 – 2014) | Forest Research and Development Agency | 2010 – 2014 | Assessment/ research only | Multiple | Indonesia | |
| 30 | Balitbanghut, 2010. Pengelolaan hutan mangrove. Rencana penelitian integratif tahun 2010 – 2014 (Forest Research and Development Agency, Mangrove management: integrative research plan 2010 – 2014) | Forest Research and Development Agency | 2010 – 2014 | National project or programme | Ecosystem/ resource management | Indonesia | http://www.forda-mof.org/files/RPI_4_Pengelolaan_Hutan_Mangrove.pdf |

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| 31 | Puspijak draft revisi rencana strategis 2010 – 2014 (Research and Development Center for Climate Change and Policy, Strategic Plan 2010 – 2014, revised draft) | Research and Development Center for Climate Change and Policy, Forest Research and Development Agency | 2010 – 2014 | Assessment/ research only | Multiple | Indonesia | http://www.puspijak.org/phocadownload/draft_renstra.pdf |
| 32 | Anwar & Gunawan, 2006. Peranan ekologis dan sosial ekonomis hutan mangrove dalam mendukung pembangunan wilayah pesisir (Ecological and socio-economic roles of mangrove in supporting coastal areas development) | Forest Research and Development Agency | 2006 | Assessment/ research only | Multiple | Indonesia | http://www.dephut.go.id/files/chairil_hendra.pdf |
| 33 | Irawan & Sari, 2008. Kajian implikasi terbitnya UU RI No. 27 tahun 2007 tentang pengelolaan wilayah pesisir dan pulau-pulau kecil terhadap pengelolaan hutan mangrove (Study on the implication of UU No 27 2007 on Coastal region and small islands management on mangrove forest management) | University of Mulawarman and Propagation Technology Research agency, East Kalimantan | 2008 | Assessment/ research only | Ecosystem/ resource management | Indonesia | http://puslitsosekhut.web.id/publikasi.php?id=217 |
| 34 | IUCN, 2002. The Coral Reef Rehabilitation and Management Program (COREMAP) Phase I Evaluation Report | Government of Indonesia, World Bank, ADB dan AusAID | 1998 – 2001 | Assessment/ research only | Ecosystem/ resource management | Indonesia | http://cmsdata.iucn.org/downloads/indonesia_coralreef_rehab.pdf |
| 35 | Coral Reef Rehabilitation and Management Program Phase II | Government of Indonesia, World Bank, ADB | 2001 – 2007 | National project or programme | Ecosystem/ resource management | Indonesia | http://www.coremap.or.id/downloads/downloads/Lib/Images/Merch/brosur_coral_reef_rehabilitation_1.jpg |
| 36 | Data and information mangement on adaptation to climate change (DATACLIM) | GIZ, Meteorology Climatology & Geophysic Agency | | National project or programme | Multiple | Indonesia | http://www.dataclim.org/index.php?id=test2 |
| 37 | KKP, 2013. Peta prakiraan daerah penangkapan ikan (Map of fish catch area pediction) | Ministry of Marine and Fishery | 2013 | National project or programme | Development | Indonesia | http://www.kkp.go.id/index.php/arsip/c/8736/Informasi-Peta-Prakiraan-Daerah-Penangkapan-Ikan-Tanggal-01-03-Maret-2013/ |
| 38 | BMKG, 2013. Peringatan Dini (EARLY WARNING) Gelombang Tinggi (high wave) Tanggal 06 Maret – 08 Maret 2013 | Meteorology Climatology & Geophysic Agency | 2013 | National project or programme | Multiple | Indonesia | http://www.kkp.go.id/index.php/arsip/c/8753/Peringatan-Dini-EARLY-WARNING-Gelombang-Tinggi-Tanggal-06-Maret-08-Maret-2013/?category_id= |
| 39 | Direktorat pesisir dan lautan, 2012. Panduan penilaian ketangguhan desa pesisir (Guidelines for assessing coastal village resilience) | Ministry of Marine and Fishery | 2012 | National project or programme | Multiple | Indonesia | http://forumpdpt2012.files.wordpress.com/2012/10/panduan_penilaian_ketangguhan_desa.pdf |
| 40 | WWF Sulu-Sulawesi Marine Ecoregion Programme 2004. Conservation Plan for the Sulu-Sulawesi Marine Ecoregion | WWF | 2004 | Regional project or programme | Ecosystem/ resource management | Indonesia, Malaysia, Philippines | http://www.sulusulawesi.net/publish/ECP.pdf |

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| 41 | Government of Indonesia, 2010. Indonesia Climate Change Sectoral Roadmap. Summary Report Forestry sector | Ministry of National Planning and Development | 2010 | National policy | Multiple | Indonesia | http://www.bappenas.go.id/print/2839/policy-paper/ |
| 42 | Government of Indonesia, 2010. Indonesia Climate Change Sectoral Roadmap. Marine and fishery sector | Ministry of National Planning and Development | 2010 | National policy | Multiple | Indonesia | http://www.bappenas.go.id/print/2839/policy-paper/ |
| 43 | Government of Indonesia, 2010. Indonesia Climate Change Sectoral Roadmap. Scientific Basis: Analysis and Projection of Temperature and Rainfall | Ministry of National Planning and Development | 2010 | National policy | Multiple | Indonesia | http://www.bappenas.go.id/print/2839/policy-paper/ |
| 44 | Government of Indonesia, 2010. Indonesia Climate Change Sectoral Roadmap. Scientific Basis: Analysis and projection of sea level rise and extreme weather event | Ministry of National Planning and Development | 2010 | Assessment/ research only | Adaptation | Indonesia | http://www.bappenas.go.id/print/2839/policy-paper/ |
| 45 | DNPI, 2012. Direktori data dan informasi, adaptasi perubahan iklim (Data and information directory, adaptation to climate change) | DNPI (National Climate change Council) | 2012 | Assessment/ research only | Adaptation | Indonesia | |
| 46 | Hasan, 2004. Mekanisme pengelolaan Program Marginal Fishing Community (Management mechanism of Program Marginal Fishing Community Development (MFCDP)) | Ministry of National Planning and Development; World Bank | 2004 | National project or programme | Development | Indonesia | www.bappenas.go.id/get-file-server/node/3010/Similar |
| 47 | Bengen, 2003. Contoh pencapaian oleh proyek pesisir PKSPL-IPB dan INCUNE (1997 – 2003) (Examples of Coastal Resources Management Project achievements, PKSPL-IPB and INCUNE (1997 – 2003) | Ministry of National Planning and Development; USAID; IPB | 1996 – 2003 | National project or programme | Ecosystem/ resource management | Indonesia | http://imcafs.org/download/Contoh_Penca-paian-OK.pdf |
| 48 | Bappenas, 2011. Indonesia adaptation strategy. Improving capacity to adapt | Ministry of National Planning and Development | 2011 | Assessment/ research only | Adaptation | Indonesia | http://www.bappenas.go.id/get-file-server/node/11988/ |
| 49 | DNPI, 2010. Adaptation science and policy study. Book 1, final report | DNPI (National Climate Change Council) | 2010 | Assessment/ research only | Adaptation | Indonesia | http://dnpi.go.id/portal/en/lumbung-pengetahuan/publikasi/tulisan/284-adaptation-science-and-policy-study-book-1-final-report |
| 50 | MOE, 2010. Indonesia Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC) | Ministry of Forestry | 2010 | National policy | Multiple | Indonesia | http://unfccc.int/files/national_reports/non-annex_i_natcom/submitted_natcom/application/pdf/indonesia_snc.pdf |

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| 51 | DNPI & Pemprov Sumatera Utara, 2010. Penyusunan pemetaan kerentanan perubahan iklim provinsi. Ringkasan Eksekutif (Climate change vulnerability assessment in a province) | DNPI (National Climate Change Council) & North Sumatera Povincial Government | 2010 | Assessment/ research only | Multiple | North Sumatera | http://dnpi.go.id/portal/id/lumbung-pengetahuan/publikasi/tulisan/285-ringkasan-eksekutif-penyusunan-pemetaan-kerentanan-perubahan-iklim-provinsi |
| 52 | DNPI, 2011. Ringkasan eksekutif. Pemetaan kerentanan di daerah provinsi serta inventarisasi kebijakan dan kelembagaan dalam antisipasi dampak perubahan iklim (Executive summary. Provincial vulnerability mapping and policy inventory to anticipate climate change impatcs) | DNPI (National Climate Change Council) | 2011 | Assessment/ research only | Multiple | South Sulawesi; Gorontalo; Kalimantan & Indonesia | http://adaptasi.dnpi.go.id/filedata/20120730112852.Ringkasan%20Eksekutif%20Pemetaan.pdf |
| 53 | Climate change consequences on local level. A field assessment by CARE International Indonesia | Raks Thai Foundation, CARE Indonesia, CARE Deutschland-Luxemburg; Poverty, Environment & Climate Change Network | 2010 – 2012 | Regional project or programme | Multiple | Indonesia & Thailand | http://www.careclimatechange.org/files/adaptation/BCRCC_Indonesia_CVCA.pdf |
| 54 | Partners for Resilience. Climate-Proof disaster risk reduction | The Netherlands Red Cross, CARE Netherlands, Cordaid, Wetlands International and the Red Cross/Red Crescent Climate Centre | 2011 – 2015 | Regional project or programme | Multiple | Indonesia, the Philippines, India, Ethiopia, Kenya, Mali, Uganda, Guatemala and Nicaragua | http://www.rimd.org/advf/documentos/4bf0462f9adde.pdf |
| 55 | Vulnerability of ecosystem dependent villagers to climate variability: a case study from two villages by the Sentarum Lake, Kalimantan | WWF Indonesia | | Sub-national/ local project or programme | Multiple | 2 villages by Sentarum lake, Kalimantan | http://www.forestsclimatechange.org/fileadmin/tropical-workshop/Plenary-4/30A_SantosoH_Vulnerability%20of%20ecosystem.pdf |
| 56 | CI, 2010. Program rehabilitasi pesisir Deyah Raya. Peningkatan ekonomi masyarakat melalui penanaman mangrove (Deyah Raya coastal rehabilitation program. Improving community wellbeing through mangrove planting) | Conservation International Indonesia, Yayasan Gajah Sumatera, Kelompok Tambak Deyah Raya. | 2010 | Sub-national/ local project or programme | Multiple | Banda aceh city and Aceh besar District | http://www.conservation.org/global/indonesia/publikasi/Documents/Publikasi/2010_CI-Indonesia_program_rehabilitasi_pesisir-deyahraya.pdf |
| 57 | Huffard et al, 2010. Pengelolaan berbasis ekosistem di Bentang Laut Kepala Burung Indonesia (Ecosystem based management of Bird-head seascape Indonesia) | TNC, WWF, CI, other stakeholders | 2001 – 2010 | Sub-national/ local project or programme | Ecosystem/ resource management | Bird-head seascape, Papua | http://dropbox.wwf.or.id/SitePages/Home.aspx?RootFolder=%2FShared%20Documents%2FBHS%20EBM%20Publication%20for%20share&FolderCTID=0x0120006AF9F8A7B8A10044AF4EAADCC9394296&View={1E9938B4-C05C-4A55-BA9C-5896CF8CDB22} |

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| 58 | Pada, 2011. Persepsi masyarakat di kawasan konservasi laut daerah kabupaten Kaimana, Indonesia (Community perceptions at Kaimana Marin Conservation Area) | CI, Ministry of Forestry, Ministry of Marine and Fisheries | 2010 | Sub-national/ local project or programme | Ecosystem/ resource management | Kaimana District, West Papua | http://www.conservation.org/global/indonesia/publikasi/Pages/PersepsiMasyarakatdiK-KLDKabKaimana.aspx |
| 59 | CTI, 2011. Region-wide early action plan for climate change adaptation | National Coordination Committees of CTI-CFF; Governments of Indonesia, Malaysia, Papua New Guinea, the Philippines, the Solomon Islands and Timor-Leste; GEF; ADB; Government of USA; Government of Australia; CI; WWF; TNC; Private Sectors; Communities | 2007 | Regional project or programme | Adaptation | Indonesia, Malaysia, Papua New Guinea, the Philippines, the Solomon Islands and Timor-Leste | http://www.coraltrian-gleinitiative.org/sites/default/files/resources/FINAL_CCA%20REAP_17Oct2011_lg_V6.pdf |
| 60 | CoralWatch. Bertindaklah sekarang demi masa depan terumbu karang (Act now for the future of our reefs) | CoralWatch; University of Queensland; AWARE Foundation | | Assessment/ research only | Multiple | Global/ worldwide | http://www.coralwatch.org/c/document_library/get_file?uuid=d8a76ca3-3e6a-423a-b177-c2cae2d3752b&groupId=10136 |
| 61 | Mangrove Action Project Indonesia, 2006. Annual Report | Mangrove Action Project, Yayasan Laksana Samudera NGO, Natural Resources Conservation Agency, KELOLA NGO, USAID | 2001 – 2006 | National project or programme | Multiple | Riau, North Sumatera, North Sulawesi | http://mangroveactionpro-ject.org/files/map-indone-sia/MAP-Indonesia%20Annual%20Report%202006.pdf |
| 62 | Mangrove for the Future Empowering coastal communities in mangrove forest areas | Mangrove for the Future, Institut Penelitian dan Pengembangan Masyarakat | 2010 – 2011 | Sub-national/ local project or programme | Multiple | Makassar, South Sulawesi | http://www.mangrovesfor-thefuture.org/assets/Repository/Documents/013-SG-ID-01-06-09.pdf |
| 63 | Mangrove for the Future. Pesantren and community involvement in managing disaster risks in coastal areas through mangrove planting | Mangrove for the Future, Community-Based Disaster Risk Management – Nahdlatul Ulama | 2010 | Sub-national/ local project or programme | Multiple | Lamongan, East Java | http://www.mangrovesfor-thefuture.org/grants/small-grant-facilities/indonesia/pesantren-and-community-involvement-in-managing-disaster-risks-in-coastal-areas-through-mangrove-plant-ing/ |
| 64 | Mangrove for the Future. Rehabilitation and sustainable use of mangrove forests in Pesantren village | Mangrove for the Future, Kelompok Mitra Bahari NGO | 2010 – 2011 | Sub-national/ local project or programme | Multiple | Pemalang, Central Java | http://www.mangrovesfor-thefuture.org/grants/small-grant-facilities/indonesia/rehabilitation-and-sustainable-use-of-mangrove-forests-in-pesantren-village/ |
| 65 | Asian Cities Climate Change Resilience Network. Pilot Project in Tugurejo, Semarang, Indonesia | MercyCorps Indonesia, Rockefeller Foundation | 2010 | Sub-national/ local project or programme | Multiple | Tugurejo, Semarang, Central Java | http://indonesia.mercycorps.org/index.php/en/features/blog/191-acccrn-pilot-project-in-tugurejo-semarang-indo-nesia |

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|---|---|---|---|---|---|---|---|
| 66 | Habibi et al, 2007. A Decade of Reef Check Monitoring: Indonesian Coral Reefs, Condition and Trends | Yayasan Reef Check Indonesia | 1997 – 2006 | National project or programme | Ecosystem/ resource management | Indonesia | http://reefcheck.org/PDFs/indo10year.pdf |
| 67 | Ecosystem-based management of the bird's head seascape | Conservation International, The Nature Conservancy, WWF Indonesia, David and Lucile Packard Foundation | | Sub-national/ local project or programme | Ecosystem/ resource management | Sorong, Sorong Selatan, Raja Ampat, Manokwari, Teluk Wondama, Biak Numfor, Yapen, Supiori, Naboire, Waropen, Teluk Bintuni, Fak Fak, Kaimana (Papua ) | http://www.reefresilience.org/pdf/Birds_Head_EBM_Fact_Sheets_09_051-1.pdf |
| 68 | Live and Learn. Marine Biodiversity Awareness | Live and Learn; Packard Foundation | 2010 – 2012 | Sub-national/ local project or programme | Other | East Lombok | http://www.livelearn.org/projects/marine-biodiversity-awareness |
| 69 | Sihombing et al, 2012. Kajian Kenaikan Muka Air Laut di Kawasan Pesisir Kabupaten Tuban, Jawa Timur | Sepuluh Nopember Technology Institute | 2012 | Assessment/ research only | Other | Tuban District, East Java | www.ejurnal.its.ac.id/index.php/teknik/article/download/1811/635 |
| 70 | Syahrir, 2009. Lesson Learned from Coral Reef Ornamental Fisheries Management in Seribu Islands, Indonesia: Beyond MAC Standards | Yayasan Terumbu Karang Indonesia | 2002 | Assessment/ research only | Ecosystem/ resource management | Pulau Seribu, Jakarta | http://www.terangi.or.id/publications/pdf/syahrir_et_al_2009web.pdf |

## LAWS AND REGULATIONS

| No. | TITLE | NAME OF ORGANIZATION OR NETWORK | YEAR | DOCUMENT TYPE | MAIN FOCUS OF DOCUMENT | TARGET LOCATION(S) | DOWNLOAD LINK |
|---|---|---|---|---|---|---|---|
| 1 | UU 41 1999 Kehutanan (Law on Forestry) | Signed by President of Indonesia | 1999 | National law | Ecosystem/ resource management | Indonesia | http://www.dephut.go.id/files/UNDANG-UNDANG%20REPUBLIK%20INDONESIA%20NOMOR%2041%20TAHUN%201999.pdf |
| 2 | UU 26 2007 Spatial arrangement | Signed by President of Indonesia | 2007 | National law | Multiple | Indonesia | http://www.bkprn.org/peraturan/the_file/UU_No26_2007.pdf |
| 3 | UU 27 2007 Pengelolaan wilayah pesisir dan pulau pulau kecil (Law on Coastal areas and small islands management) | Signed by President of Indonesia | 2007 | National law | Ecosystem/ resource management | Indonesia | http://hukum.unsrat.ac.id/uu/uu_27_2007.pdf |
| 4 | UU 32 2009 Perlindungan dan pengelolaan lingkungan hidup (Law on Protection and management of environment) | Signed by President of Indonesia | 2009 | National law | Ecosystem/ resource management | Indonesia | http://www.komisiinformasi.go.id/assets/data/arsip/UU_32_Tahun_2009.pdf |
| 5 | UU 16 2006 Penyuluhan pertanian, perikanan dan kehutanan (Law on Agriculture, fishery and forestry extention systems) | Signed by President of Indonesia | 2006 | National law | Other | Indonesia | http://www.deptan.go.id/feati/dokumen/uu_sp3k.pdf |
| 6 | UU 45 2009 Tentang perubahan atas UU 31 2004 Tentang perikanan (Law on revision on fishery law) | Signed by President of Indonesia | 2009 | National law | Ecosystem/ resource management | Indonesia | http://dapp.bappenas.go.id/website/peraturan/file/pdf/UU_2009_045.pdf |
| 7 | UU 17 2007 Rencana pembangunan jangka panjang nasional tahun 2005 – 2025 (Law on Long-term national development plan 2005 – 2025) | Signed by President of Indonesia | 2007 | National law | Development | Indonesia | http://www.itjen.depkes.go.id/public/upload/unit/pusat/files/Undang-undang/uu17_2007.pdf |
| 8 | PP 19 1999 Pengendalian pencemaran dan/atau perusakan laut (Government Act on Controlling marine polution and degradation) | Signed by President of Indonesia | 1999 | National law | Ecosystem/ resource management | Indonesia | http://www.proxsis.com/perundangan/LH/doc/uu/E00-1999-00019.pdf |
| 9 | PP 64 2010 Mitigasi bencana di wilayah pesisir dan pulau pulau kecil (Government Act on Disaster mitigation at coastal areas and small islands) | Signed by President of Indonesia | 2010 | National law | Disaster-risk reduction | Indonesia | http://dapp.bappenas.go.id/website/peraturan/file/pdf/PP_2010_064.pdf |
| 10 | PP 21 2010 Perlindungan lingkungan matitim (Government Act on maritime environmental protection) | Signed by President of Indonesia | 2010 | National law | Multiple | Indonesia | http://www.presidenri.go.id/DokumenUU.php/474.pdf |
| 11 | Peraturan Presiden 5 2010 Rencana Pembangunan Jangka Menengah Nasional tahun 2010 – 2014 (Medium term developmetn plan 2010 – 2014) | Signed by President of Indonesia | 2010 | National law | Development | Indonesia | http://www.deptan.go.id/pug/admin/satlak/perpres2010_5.pdf |

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|---|---|---|---|---|---|---|---|
| 12 | Peraturan presiden 73 2012 Strategi Nasional Pengelolaan Ekosistem Mangrove | Signed by President of Indonesia | 2012 | National law | Ecosystem/ resource management | Indonesia | http://bphn.go.id/data/documents/12pr073.pdf |
| 13 | Peraturan Presiden 121 2012 Rehabilitasi wilayah pesisir dan pulau pulau kecil (Rehabilitation of coastal areas and small islands) | Signed by President of Indonesia | 2012 | National law | Other | Indonesia | http://www.bphn.go.id/data/documents/12pr121.pdf |
| 14 | Permen LH 19 2012 Program kampung iklim (Minister of Env Act on climate friendly and proved village) | Signed by Ministry of Environment | 2012 | National law | Multiple | Village level | http://jdih.menlh.go.id/pdf/ind/IND-PUU-7-2012-Permen%20LH%2019%20th%202012%20Proklim.pdf |
| 15 | Permenhut P.03/Menhut–V/2004 Pedoman dan petunjuk pelaksanaan penyelenggaraan gerakan nasional rehabilitasi hutan dan lahan dengan lampiran tentang mangrove (Min of Forestry Act on Guidelines for the implementation of national action of forest and land rehabilitation with attachement on mangrove) | Signed by Ministry of Forestry | 2004 | National law | Other | Indonesia | http://www.kph.dephut.go.id/index.php?option=com_phocadownload&view=file&id=843:l110permenhut-p0304-ttg-pedoman-dan-juklak-penyelenggaraan-gn-rhl&Itemid=203 |
| 16 | Kepmenhut 20/Kpts–II/2001 Pola umum dan standar serta kriteria rehabilitasi hutan dan lahan (Min of Forestry Decree on The general system, standard and criteria for forest and land rehabilitation) | Signed by Ministry of Forestry | 2001 | National law | Other | Indonesia | http://www.dephut.go.id/index.php?q=id/node/107 |
| 17 | Kepmen LH 5 2000 Panduan penyusunan AMDAL kegiatan pembangunan di daerah lahan basah (Guidelines for environmental impact assessment activities in wetlands | Signed by Minister of Environment | 2000 | National law | Development | Indonesia | http://bplhd.jakarta.go.id/peraturan/kepmen/KEPMEN%20NO%2005%20TAHUN%202000.pdf |
| 18 | Permen KKP 17 2008 Kawasan Konservasi di wilayah pesisir dan pulau pulau kecil (Conservation areas at coastal areas and small islands) | Signed by Minister of Marine and Fisheries | 2008 | National law | Ecosystem/ resource management | Indonesia | http://www.bp2tponti-anak.com/uu/PERMEN%20No.%2017%20Thn%202008%20ttg%20Konservasi%20WP3K.pdf |
| 19 | Perda Kabupaten Parigi Moutong 6 2007 Pengleolaan wilayah pesisir dan pulau-pulau kecil (Coastal areas and small islands management) | Signed by Mayor | 2007 | Sub-national law | Ecosystem/ resource management | Parigi Moutong District, Central Sulawesi | http://ditjenpp.kemenkumham.go.id/files/ld/2007/KabupatenParigiMou-tong-2007-6.pdf |
| 20 | Perda Kabupaten Kepulauan Selayar 8 2010 Pengelolaan terumbu karang (Coral management) | Signed by Mayor | 2010 | Sub-national law | Ecosystem/ resource management | Selayar Isle District, South Sulawesi | http://bappeda.selayaronline.com/index.php?m=bWVudT0xMjMyNzAwODMzJmFpZD0xMjky-ODM3MTY5JnBh-Z2U9MQ== |
| 21 | Perbup Kaimana 04 2008 Pencadangan kawasan konservasi laut Kabupaten Kaimana (Assigning marine protected area at Kaimana District) | Signed by Mayor | 2008 | Sub-national law | Ecosystem/ resource management | Kaimana District, West Papua | http://www.kaimanakab.go.id/wp-content/uploads/2010/01/PERBUP-KKLD1.pdf |

# 3.2 Philippines

## Search terms and methods

As a first step, documents were searched using *Google advanced search* (www.google.com/advanced_search). Websites of important governmental and non-governmental organizations in the country, as well as adaptation programme and project databases were searched as a second step.

Google advanced search was performed in English using Google.com with the following keyword configurations:

- **All the words**: Philippine coast
- **Any of these words**: adaptation OR development OR law OR management OR policy OR project OR programme OR disaster risk reduction OR disaster management
- **None of these words**: -“Guard”, -earthquake, -ship

Wildcards are not supported in Google, but the search engine automatically finds variations of the keywords (e.g. the keyword Indonesia also triggers results with the keyword Indonesian, unless placed in quotation marks).

Relevant documents were also searched in the following websites:

1. weADAPT http://weadapt.org
2. Asia-Pacific Adapt www.asiapacificadapt.net
3. Websites of different ministries and local government agencies
4. Websites of research institutions and organizations such as Ecosystems Research and Development Bureau (ERDB) of the DENR (Department of Environment and Natural Resources), universities (e.g. Marine Science Institute – University of the Philippines), PAGASA, etc.
5. Websites of NGOs and programmes such as Conservation International, Wetlands International, Coral Triangle Initiative, etc.

## LIST OF DOCUMENTS REVIEWED

| No. | TITLE | NAME OF ORGANIZATION OR NETWORK | YEAR | DOCUMENT TYPE | MAIN FOCUS OF DOCUMENT | TARGET LOCATION(S) | DOWNLOAD LINK |
|---|---|---|---|---|---|---|---|
| 1 | Case study on the impacts of climate change on Milkfish pond production in the Municipalites of Borotok Nueva and Dumangas, Panay Island, Philippines | Network of Aquaculture Centers in Asia-Pacific (NACA) | | National project or programme | Adaptation | Municipalites of Borotok Nueva and Dumangas, Panay Island, Philippines | http://library.enaca.org/emerging_issues/climate_change/philippines-milkfish-climate-change-ebook.pdf |
| 2 | The Laguna de Bay watershed rehabilitation | UNFCCC | 2007 | National project or programme | Ecosystem/resource management | Laguna Bay on the island of Luzon, Philippines | http://cdm.unfccc.int/Projects/Validation/DB/DM117RRRIN1PZA7LWR-2L7ROBN82RM7/view.html |
| 3 | Center for empowerment and resource development | UNDP | 1996 | National project or programme | Multiple | Hinatuan Bay, Caraga region, Philippines. | http://www.equatorinitia-tive.org/images/stories/com_winners/casestudy/case_1348151407.pdf |
| 4 | Climate change vulnerability assessment of the Verde Island Passage | Conservation International | 2011 | Assessment/research only | Ecosystem/resource management | Verde Island Passage, Philippines | http://www.conservation.org/global/philippines/publications/Pages/Vulnerability-Assess-ment-of-the-Verde-Island-Passage.aspx |
| 5 | Transforming the manage-ment of marine and coastal resources in the Coral Triangle – A region-wide program to safeguard marine biological resources for future generations | WWF | 2010 | National project or programme | Ecosystem/resource management | Palawan Province, Tawi-Tawi Privince, and Verde Passage, Philippines | http://pdf.usaid.gov/pdf_docs/PDACQ544.pdf |
| 6 | The coastal resource management project – Philippines 1996 – 2004 | Department of Environment and Natural Resources | 2004 | National project or programme | Ecosystem/resource management | Philippines | http://oneocean.org/download/db_files/crmp_completion_report.pdf |
| 7 | Enhancing coastal and marine management through effective information management | Programme on Partnerships in Environmental management for the Seas of East Asia (PEMSEA/GEF/UNDP) | 2007 | Sub-national/local project or programme | Other | Bataan Province, Philippines | http://beta.pemsea.org/sites/default/files/ms200704-bataan-iims.pdf |
| 8 | The Integrated Population and Coastal Resource Management (IPOPCORM) – Fishing for families: Reproductive health and Integrated coastal manage-ment in the Philippines. | PATH foundation | 2008 | Sub-national/local project or programme | Ecosystem/resource management | Palawan Province, Philippines | http://www.isn.ethz.ch/isn/Digital-Library/Publications/Detail/?ots591=0c54e3b3-1e9c-be1e-2c24-a6a8c7060233&lng=en&size582=10&id=130889 |
| 9 | Western Mindanao Community Initiatives Project (WMCIP) | Department of Agrarian Reform | 2009 | Regional project or programme | Multiple | Western Mindanao, Philippines | http://www.ifad.org/evaluation/public_html/eksyst/doc/profile/pi/phl_65.htm |
| 10 | Integrated Coastal Resource Management in the Philippines | World Vision | 2009 | Sub-national/local project or programme | Ecosystem/resource management | Lamon Bay and Tabogan, Philippines | http://worldvision.org.ph/our-work/transforming-communities |
| 11 | Joint programme on strengthening the Philippines' institutional capacity to adapt to climate change – 2008 – 2010 | United Nations and Governement of the Philippines | 2010 | National project or programme | Adaptation | Philippines | http://www.philexport.ph/barterfli-philexport-file-portlet/download/G_meeting2011/2009/03/sandalo.pdf |

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|---|---|---|---|---|---|---|---|
| 12 | Mindanao rural development programme – Natural resource management project (Phase 2) | World Bank and Government of the Philippines | 2009 | Regional project or programme | Ecosystem/ resource management | Mindanao Island, the Philippines | http://www.worldbank.org/projects/P096836/mindanao-rural-development-program-mrdp-phase-ii-natural-resource-management-component?lang=en |
| 13 | PH – Climate change adaptation project | World Bank and Government of the Philippines | 2010 | Regional project or programme | Adaptation | Pantabangan-Carranglan Watershed, the Philippines | http://climatechange.denr.gov.ph/index.php?option=com_content&view=article&id=87%3Aphilippine-climate-change-adaptation-project-&catid=29%3Aclimate-change-programs&Itemid=41 |
| 14 | The Republic of th Philippines: Integrated Coastal Resource Management project | Asian Development Bank | 2006 | Regional project or programme | Ecosystem/ resource management | Provinces of Cagayan, Cebu, Davao Oriental, Masbate, Siquijor, and Zambales | http://www.adb.org/projects/documents/integrated-coastal-resources-management-project |
| 15 | Promoting sustainable mariculture | Coral Reef Targeted Research and Capacity Building for Management | 2010 | National project or programme | Ecosystem/ resource management | Philippines | http://www.gefcoral.org/LinkClick.aspx?fileticket=T79qyZpH-cs%3D&tabid=3260 |
| 16 | Reef rehabilitation project of the Central Philippines | University of Guam Marine Laboratory; Coastal Conserva-tion and Education Foundation, Inc.; Silliman University Marine Laboratory | 2006 | Regional project or programme | Ecosystem/ resource management | Calagcalag Marine Protected Area, Ayungon, Negros Oriental | http://www.guam-marinelab.com/publications/uogmltechrep120.pdf |
| 17 | Southern Leyte coral reef conservation project | Coral Cay Conservation, and, Philippines Reef and Rainforest Conservation Foundation | 2012 | Sub-national/ local project or programme | Ecosystem/ resource management | Palawan, Danjugan Island, Luzon and Negros. | http://www.coralcay.org/expedition-locations/the-philippines/ |
| 18 | Strengthening Capacities for Climate Risk Management and Disaster Preparedness in Selected Provinces of the Philippines | FAO | 2012 | Regional project or programme | Disaster-risk reduction | 6 provinces: Albay, Camarines Norte, Camarines Sur, Catanduanes, Masbate, and Sorsogon. | http://www.fao.org/docrep/field/009/aq197e/aq197e.pdf |
| 19 | Sustainable coastal resource management program – Sorsogon Bay, Philippines | Integrated Rural Development Foundation of the Philippines | 2002 | Sub-national/ local project or programme | Ecosystem/ resource management | Sorsogon Bay, Philippines | http://www.povertyenvironment.net/node/506 |
| 20 | Sustainable Coral Reef Ecosystems Management Program | Government of the Philippines | 2012 | National project or programme | Ecosystem/ resource management | Philippines | http://02cbb49.netsolhost.com/EARW/8th_EARW/6-1-9.8th_ICRI_EARW_2012_Korea.pdf |
| 21 | The rising tide of community-led conservation: Strengthening local fisheries management in the Coral Triangle | RARE | | Regional project or programme | Ecosystem/ resource management | Dauin, Philippines | http://www.rareconservation.org/sites/default/files/CoralTriangleBrochure_web.pdf |

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|---|---|---|---|---|---|---|---|
| 22 | Trowell Development Foundation | Equator Initiative | 2012 | Sub-national/ local project or programme | Ecosystem/ resource management | Nothern Samar province, Philippines | http://www.equatorinitiative.org/images/stories/com_winners/casestudy/case_1348261106.pdf |
| 23 | Do marine protected areas work? A case study from the Philippines | Economy and Environment Programme for Southeast Asia | 2004 | Sub-national/ local policy | Ecosystem/ resource management | Northern Mindanao and Danao Bay | http://econpapers.repec.org/paper/eeppbrief/pb2004092.htm |
| 24 | Forging alliance toward better coastal resource management in the Philippines: A case study of Banate Bay | The Southeast Asian Regional Center for Graduate Study and Research in Agriculture | 2010 | Sub-national/ local policy | Ecosystem/ resource management | Anilao, Barotac Nuevo, Barotac Viejo, and Banate in Iloilo province | http://searca.org/index.php/knowledge-management/knowledge-resources/policy-brief-series/230-forging-alliances-toward-better-coastal-resource-management-in-the-philippines-the-case-of-banate-bay |
| 25 | Integrated Coastal Management (ICM): Revitalising the coasts and oceans program in the Philippines | Programme on Partnerships in Environmental management for the Seas of East Asia (PEMSEA) | 2006 | Sub-national/ local project or programme | Ecosystem/ resource management | Batangas Bay, Philippines | http://iwlearn.net/publications/misc/presentation/integrated-coastal-management-icm-revitalizing-the-coasts-and-oceans-program-in-the-philippines |
| 26 | Reef rescue: Financing marine conservation in the Philippines | Economy and Environment Programme for Southeast Asia (EEPSEA) | 2005 | Assessment/ research only | Ecosystem/ resource management | Quezon City, Cebu City, and Puerta Princesa, Philippines | http://econpapers.repec.org/paper/eeppbrief/pb2005064.htm |
| 27 | Responding to sea-level-rise: A study of options to combat coastal erosion in the Philippines | Economy and Environment Programme for Southeast Asia (EEPSEA) | 2009 | Assessment/ research only | Adaptation | San Fernando Bay in the La Union region, Philippines. | http://www.eepsea.net/index.php?option=com_k2&view=item&id=133:responding-to-sea-level-rise-a-study-of-options-to-combat-coastal-erosion-in-the-philippines&Itemid=193 |
| 28 | Saving fisher and fish: An assessment of fishery assessment options for the Visayan sea in the Philippines | Economy and Environment Programme for Southeast Asia (EEPSEA) | 2009 | Assessment/ research only | Ecosystem/ resource management | Nothern Iloilo in the Visayan Sea, Philippines | http://idl-bnc.idrc.ca/dspace/bitstream/10625/46142/1/132632.pdf |
| 29 | Sustainable development and management of Manila Bay – focus on water quality | Program on building partnerships in Environmental Management in the Seas of East Asia (PEMSEA) | 2006 | Assessment/ research only | Ecosystem/ resource management | Manila Bay, Philippines | http://beta.pemsea.org/publications/sustainable-development-and-management-manila-bay-focus-water-quality |
| 30 | Philippine integrated coastal management: The need for improved accountability and local ownership | Stockholm Environment Institute (SEI) | 2010 | | Ecosystem/ resource management | Babuyan Islands, Philippines | http://www.sei-international.org/mediamanager/documents/Publications/SEI-Policy-Brief-Larsen-PhilippineIntegratedCoastalManagement-2010.pdf |

## LAWS AND REGULATIONS

| No. | TITLE | NAME OF ORGANIZATION OR NETWORK | YEAR | DOCUMENT TYPE | MAIN FOCUS OF DOCUMENT | TARGET LOCATION(S) | DOWNLOAD LINK |
|---|---|---|---|---|---|---|---|
| 1 | Republic Act No. 9729: An act mainstreaming climate change into government policy formulations, establishing the framework strategy and program on climate change, and creating for this pupose the climate change commission, and for other purposes. | The Senate and House of Representatives of the Philippines in Congress | 2009 | National law | Multiple | Philippines | http://www.lawphil.net/statutes/repacts/ra2009/ra_9729_2009.html |
| 2 | Republic Act No. 101211: An act strengthening the Philippine disaster risk reduction and management system, providing for the national disaster risk reduction and management framework and institutionalizing the national risk reduction and management plan, appropriate funds therefor and for other purposes | The Senate and House of Representatives of the Philippines in Congress | 2010 | National policy | Disaster-risk reduction | Philippines | http://download-88flood.www.gov.tw/otherReC/file/045_RA%2010121.pdf |
| 3 | The National Disaster Risk Reduction and Management Plan 2011–2028 | The Philippines Office of Civil Defense | 2011 | National policy | Disaster-risk reduction | Philippines | http://www.who.int/hac/crises/phl/philippines_ndrrmp_2011_2028.pdf |
| 4 | National Framework Strategy on Climate Change 2010 – 2022 | Office of the President of the Philippines, Climate Change Commission | 2010 | National policy | Adaptation | Philippines | http://www.neda.gov.ph/references/Guidelines/DRR/nfscc_sgd.pdf |
| 5 | National Climate Change Action Plan 2011 – 2028 | Climate Change Commission | 2011 | National policy | Adaptation | Philippines | http://www.lccad.org/nccap.php |
| 6 | The Philippines Strategy on Climate Change Adaptation 2010 – 2022 | Department of Environment and Natural Resources | 2010 | National policy | Adaptation | Philippines | http://www.neda.gov.ph/references/Guidelines/DRR/nfscc_sgd.pdf |

# ANNEX 4

# EXPERT INTERVIEW METHODS & RESPONDENTS

# 4.1
# Expert interview guide

## Introduction of the interviewer and purpose

**Introduction:** My name is__________, and I work with the Center for International Forestry Research (CIFOR), based in Bogor. CIFOR is a non-profit, global research organization dedicated to advancing human wellbeing, environmental conservation and equity. We conduct research that enables more informed and equitable decision making about the use and management of forests.

I have contacted you to discuss issues related to climate hazards in coastal areas (for example, storms and floods and their impact on people and economic activities), and the potential use of coastal ecosystems (e. g. mangroves, corals) to help people address/deal with these hazards, and adapt, through ecosystem-based strategies. Ecosystem-based strategies focus on the use of ecosystem services (i.e. the services that ecosystems provide to humans) to help solve different problems and address risks to people, e.g. like the ones coming from climate change. Ecosystem-based strategies are employed through the sustainable management, conservation or restoration of ecosystems.

Since you have experience in, or influence activities in, coastal areas in Indonesia/Philippines (or province/district) in your capacity as ____(e.g. chief of XXXXX in XXXXX)___, we believe that you will provide valuable insights to our study.

Our discussion today forms part of a study entitled "Climate Change Impact Chains in Coastal Areas" which CIFOR is conducting together with the BMU-IKI (the International Climate Initiative of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)-funded IMACC (Inventory of Methods for Climate Change Adaptation Project of GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). The study encompasses a literature review on climate change, analysis of project and policy documents related to climate change and coastal areas in two country case studies: Indonesia and Philippines, and expert interviews with stakeholders in these two countries.

Your expert opinion will be very valuable for assessing the potential and challenges associated with ecosystem-based strategies in coastal areas and we highly appreciate your time and consideration.

**During the interview, I would like to discuss the following topics:**

- The most important climate hazards in coastal areas and their impacts
- Strategies currently employed to address these hazards and other challenges
- Current coastal management and management of ecosystems and resources (e.g. mangrove/coral)
- Current adaptation strategies, if any
- Potential and challenges of employing ecosystem-based strategies versus other strategies (e.g. infrastructure)
- Policy frameworks and institutional cooperation/coordination that facilitate or inhibit the implementation of ecosystem-based strategies
- Additional important issues/recommendations

We will also provide you with a comprehensive report once this study is completed.

Thank you once again for your time and valuable insights!

| MAIN QUESTIONS | ADDITIONAL QUESTIONS & PROBES | CLARIFYING QUESTIONS |
|---|---|---|
| Can you tell me briefly about the most important climate hazards affecting the coastal areas that you work in/ are familiar with? | • What impacts do these hazards cause?<br>• Which places are most affected and when?<br>• Who is affected most and why?<br>• Under what circumstances do serious problems arise?<br>• Have you noticed any changes in the situation over the years? | |
| In your experience, what type of strategies are mostly employed in coastal areas to tackle with these issues?<br>OR<br>In your opinion, what are the strategies most frequently employed to address these and other problems in coastal areas? | • Who decides/plans and implements the strategies that you mention?<br>• Are these strategies effective?<br>• Why/why not?<br>• Have you/your organization been involved in planning/implementing such strategies? | |
| What about coastal and ecosystem management? How are resources and ecosystems currently managed? | • Are resources and ecosystems degrading? Why/ why not?<br>• What are the effects of current ecosystem management practices? Who is affected (positively or negatively) and why?<br>• Have you noticed any changes in the situation over the years? | • Can you expand a little on this?<br>• Can you tell me anything else?<br>• Can you give me some examples? |
| And what about adaptation strategies? Are they employed and if yes, what type of strategies?<br>Who are the main adaptation actors/ decision-makers/practitioners? | • Are these strategies effective?<br>• Why/ why not?<br>• Have you/ your organization been involved in planning/ implementing adaptation strategies?<br>• Why/ why not? | |
| Are you aware of/involved in any past or current ecosystem-based strategies in coastal areas?<br>In your opinion, what other ecosystem-based strategies can be employed? | • What are the activities of these strategies?<br>• Which problems do/ will they help to address?<br>• What results (if implemented)?<br>• What are the benefits?<br>• What are the challenges?<br>• How can these challenges be addressed? | |
| What are the advantages and disadvantages of employing ecosystem-based strategies for adaptation in comparison to other strategies (e.g. infrastructure)? | • What are the main costs and benefits of each?<br>• What are the trade-offs between the different types of strategies? | |
| Is the policy framework and cooperation between institutions adequate for promoting ecosystem-based adaptation strategies? | • What needs to be improved and how? | |
| What else (e.g. knowledge, capacity) is needed to foster ecosystem-based adaptation strategies in coastal areas? | • What kind of knowledge/capacity?<br>• To whom?<br>• Who should deliver it?<br>• In what form should it be delivered? | |

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|---|---|---|
| With regards to adaptation in general, do you think there are information, data, and knowledge gaps that impede action at the national and local level?<br><br>What are the needs that need to be addressed for more effective adaptation? | • What kind of gaps/needs?<br>• How can they best be addressed?<br>• Who should be responsible? | |
| Do you have any additional recommendations/issues that you would like to raise or discuss? | | |

# 4.2 List of interviewees – Indonesia

| | NAME | ORGANIZATION | CONTACT |
|---|---|---|---|
| 1 | Dr. Edvin Aldrian | Meteorology, Climatology, and Geo-physic Agency | |
| 2 | Ms. A. Rachmi Yulianti | Climate Change National Council | |
| 3 | Mr. Syofyan Hasan | Ministry of Marine Resources and Fishery | |
| 4 | Ms. Ita Sualia | Wetlands-Indonesia | |
| 5 | Ms. Cherryta Yunia | Ministry of Forestry | |
| 6 | Dr. Bambang Suprayogi | Yayasan Gajah Sumatera | |
| 7 | Mr. Nyoman Iswarayoga | WWF-Indonesia | |
| 8 | Dr. Endah Murniningtyas | Ministry of National Planning and Development | |
| 9 | Dr. Joko Purbopuspito | University of Sam Ratulangi | |
| 10 | Dr. Heru Santoso | Indonesian Institute of Science | |

# 4.3
# List of interviewees – Philippines

| | NAME | ORGANIZATION | CONTACT |
|---|---|---|---|
| 1 | Porfirio M. Aliño | Marine Science Institute - University of the Philippines | Quezon City<br>CP No. 09178387042<br>pmalino@upmsi.ph |
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