Summary

Soil erosion resulting from land degradation and current climate change pose a mounting threat to coastal nations in the western Indian Ocean. However, vital long-term observational data are missing to properly assess and clarify the impact of a changing climate and land-use. Furthermore, environmental management strategies have been formulated on short-term instrumental records at best, as proper historical time-series data are rarely available, even for the most sensitive river catchments.

This thesis examines the spatial and temporal environmental changes that affect coral reef ecosystems in the western Indian Ocean using coral proxy archives combined with climate indices, as well as biological and ecological data. Coral archives offer continuous seasonally resolved data spanning multiple centuries, which faithfully record climate variability and the occurrence of events such as ENSO (El Niño Southern Oscillation) related floods, tropical cyclones and multidecadal precipitation and runoff changes.

This coral proxy based climate project (SINDOCOM) entailed the drilling of coral cores, with a diameter of 4 cm and more than 3 m in length, to reconstruct past environmental change for various reef complexes across northern and eastern Madagascar. Massive corals grow at an approximate rate of 1cm per year, archiving specific climate signals in their skeleton. In order to read these climate signals a novel scanning technique was devised that quantifies luminescence intensities of coral skeletons by splitting the total luminescence spectrum into three spectral domains (RGB; Chapter 2). By applying such a method, the amount of terrestrial humic acids could be determined that have been flushed into marine catchments at the time of skeletal precipitation (Chapter 2). As humic acids (green) have a slightly longer emission wavelength than the skeletal aragonite (blue), taking a Green/Blue (G/B) ratio provided a quantitative estimate of terrestrial erosion related to river runoff. The unprecedented sampling resolution of the luminescence device enabled weekly reconstructions of soil erosion and river discharge in northeast Madagascar over several decennia that resulted from natural rainfall cycles, intense cyclones and deforestation.

Combining the novel spectral luminescence approach with a proxy for sediment runoff (Ba/Ca), salinity ($\delta^{18}O_{sw}$) and turbidity/DIC ($\delta^{13}C$) it was

possible to identify the impact of runoff on individual corals associated with separate rivers in and around Antongil bay, the wettest region of Madagascar (Chapter 3). Moreover, three coral colonies were drilled close to individual rivers mouths, and proxies were combined with modelled data to identify the river runoff dynamics of the bay system. By modelling discharge and sediment yield for individual river catchments it was possible to recognise the river that experienced the highest rates of both sediment runoff and discharge, and compare the results with proxy data (Chapter 3). We relate differences to the distance between the coral and the river mouth, local physiochemical conditions and proxy behaviour. Our results provide information which will assist in future marine and terrestrial management programs (Chapter 3).

Long-term runoff patterns were assessed by using a longer core from the same region. Decoupling Madagascar's 20th century human deforestation from rainfall induced soil erosion using luminescence and geochemistry in the coral archives revealed a far-field precipitation link to the Pacific Ocean on multidecadal time-scales (Chapter 4). Indeed, the corals provide the first evidence for Pacific decadal modulation of rainfall over the western Indian Ocean. Positive phases of the Pacific Decadal Oscillation (PDO) are associated with increased Indian Ocean temperatures and rainfall across eastern Madagascar, while precipitation in southern Africa and eastern Australia decline. Consequently, the negative PDO phase that started in 1998 should lead to reduced rainfall over northeast Madagascar and increased precipitation in southern Africa and eastern Australia (Chapter 4). These results have important implications for future multidecadal variability of rainfall in Africa where water resource management is increasingly important under the warming climate.

To test whether coastal eastern Madagascar had warmed significantly over the past 43 years, sea surface temperatures (SST) were reconstructed from two coral skeletal Sr/Ca records (Chapter 5). Unfortunately, significant growth related influences on the skeletal precipitation of Sr/Ca were identified, hampering SST reconstructions. These are often referred to as vital effects. In both corals a positive correlation was observed between extension rate and Sr/Ca. Increasing extension rates in one coral were coupled with increasing Sr/Ca ratios, while decreasing extension rates in a different coral were coupled with decreasing Sr/Ca ratios. Further, during individual positive ENSO events, calcification rates in both corals were negatively correlated, causing a diverging Sr/Ca response. As both corals were of the same species (*Porites lutea*) and from the same environment (0.72 km apart), the reliability of Sr/Ca as a paleothermometer is comprimised. Accounting for these coral vital effects we estimate SST to have risen by 0.75°C – 1.07°C in eastern Madagascar over the past 43 years. This value is significantly higher than the range of 0.09°C – 0.44°C as given by gridded satellite data, suggesting gridded data may seriously underestimate trends at the reef scale.

The link between SST and rainfall is complicated and not always consistent. Identifying the ENSO-related precipitation response over NE Madagascar by applying coral cores as natural monitoring stations provides a greater insight into this complex connection (Synthesis). During La Niña events, when the southwest Indian Ocean cools, coral luminescence records indicate that precipitation over NE Madagascar increased. This is unexpected, however, and is likely due to the onset of an anomalous SST-gradient rather than the absolute SST in the southwest Indian Ocean. As the south-central Indian Ocean cools more than the south-west during La Niña events, convection is shifted towards the region of anomalously higher SST. This creates increased moisture transport towards Madagascar from the south-central Indian Ocean, and therefore more rainfall (Synthesis). However, the relationship between La Niña and precipitation broke down post 1976 when climate shifted to a new base level due to anthropogenic warming. This was probably caused by weakening of the SST-gradient between the south-west and the south-central Indian Ocean, as anthropogenic warming in the south-west increased at a faster rate than the south-central region. If anthropogenic warming continues, a reversal of the ENSO related precipitation response may occur, whereby El Niño events may lead to increased precipitation over NE Madagascar.

Another time interval where cooler SST triggered increased rainfall in parts of southern Africa was the Little Ice Age (LIA), between the 15^{th} and the mid-19^{th} century. The long coral luminescence record from north-east Madagascar provides evidence that conditions were significantly wetter during this period (Synthesis). This is in agreement with eastern African lake records, yet in contrast to central and southern African records. A stronger

monsoonal system in the Indian Ocean, related to a southern shift in Inter Tropical Convergence Zone (ITCZ), is likely responsible for this precipitation response. Again, this is probably linked to associated changes in SST-gradients. Indeed, there is much scope for future research in the SW Indian Ocean region to define the rainfall-drought cycles experienced over eastern and southern Africa during the LIA. This will be achieved by increasing the spatial and temporal resolution of coral cores in the region (CLIMATCH).