Cenozoic evolution of the Indonesian Throughflow and the origins of Indo-Pacific marine biodiversity: Mapping the biotic response to environmental change

The coral reefs and other shallow tropical marine ecosystems of Southeast Asia are the most diverse in the world and have been for at least the past 25 million years. Biologists have been working for two centuries to understand the origins and maintenance of this biodiversity maximum by studying the distribution and evolutionary history of extant taxa. But fossils can provide direct evidence of past diversity and, for coral reefs, a significant portion of the biota is preserved in the fossil record. To date this valuable resource remains underexploited. Southeast Asia contains the modern-day Indonesian Throughflow (ITF), the last remaining equatorial oceanic gateway and a major control on global climate. The long-term history of the ITF is controlled by the complex plate tectonic history of the region that had a strong impact on regional ecosystems by causing environmental changes that helped to shape the modern-day diversity. However the environmental and biotic history of the region remains obscure. In this project we examined the Miocene history preserved in the sediments of East Kalimantan (Indonesia) to understand how biota responded to past intervals of global and regional environmental change. The Miocene represents an ideal test case as it includes the middle Miocene Climatic Optimum, one of the warmest intervals in the past 50 million years. We think that this warm interval might be a useful analogue for future conditions resulting from accelerating anthropogenic climate change. When combined with increasing knowledge of other warm intervals in each of the three Cenozoic coral-reef provinces, new data from the SE Asian biodiversity maximum will allow a better understanding of the potential modes of change on extant coral reefs. Analysis of these long-term data from multiple regions with differing biotic and environmental histories are required to predict the "new normal" for modern tropical shallow marine ecosystems.

The THROUGHFLOW team includes earth systems modellers, geochemists, geologists, palaeoceanographers, palaeontologists,
Ecosystems.

biodiversity, habitat and age and allow increased understanding of the origins and maintenance of biodiversity in shallow marine reefs in Southeast Asia might require a step back into the past. We hope that our project will inspire future integrated studies of some researchers to be more resilient and thus more likely to persist in the face of ongoing anthropogenic change. The future of corals may well include a shift back into these dark, deep or turbid settings as biological communities in such settings are thought by monsoonal evolution in the densely populated East Asian region. We have discovered an apparent Late Miocene regional shift in coral particular habitats was explored through integrated studies that suggest a regional shift in habits from low-relief coral reefs in the Early Miocene towards coral carpets in the Middle-Late Miocene to more modern-looking high relief coral buildups in the Late Miocene. This habitat shift coincided with a major taxonomic turnover in benthic foraminifera but not in other benthic groups - although community changes in both the position of the Intertropical Convergence Zone (ITCZ) and strength of the Walker circulation. In addition, we completed new calibrations of foraminiferal Mg/Ca chemistry to sea-surface temperature in along the ITF pathway. These records suggest existing isotopic records of precipitation in the West Pacific may be driven to a large extent by atmospheric transport mechanisms, a result that agrees with land-based runoff records. Moreover, a benthic Mg/Ca temperature calibration proves that the relationship between Mg/Ca ratios and bottom water temperature is robust against potential bias owing to low carbonate saturation levels. Finally, we provide a ITF reconstruction from the lower thermocline (500 m) to surface spanning the last glacial cycle.

Biodiversity - Study of several benthic marine groups confirm high diversity in shallow marine habitats during early Miocene. We greatly expanded the known fossil record of Bryozoa, calcareous algae, and reef corals including the diverse extant genus Acropora. These data provide important new calibration points for molecular phylogenies of calcareous algae and corals. Biodiversity in particular habitats was explored through integrated studies that suggest a regional shift in habitats from low-relief coral reefs in the Early Miocene towards coral carpets in the Middle-Late Miocene to more modern-looking high relief coral buildups in the Late Miocene. This habitat shift coincided with a major taxonomic turnover in benthic foraminifera but not in other benthic groups - although community structure of corals was strongly altered. We discovered ancient highly diverse seagrass habitats and developed new protocols for identifying seagrass habitats from the fossil record.

A primary contribution of this project is the large new collections of fossils, sediments, imagery, and other data that are now accessioned into European natural history collections. These valuable new resources, are now part of the European research infrastructure, and will be available for future researchers working to understand the diverse marine ecosystems of Southeast Asia. Oceanographic results are likely to have significance for global climate studies including new insights on the past variability of climate and the ITF and its interconnection with large scale climatic features such as the Indian Ocean Monsoon systems, El Nino Southern Oscillation and the Indian Ocean Dipole. Species and region-specific calibrations of palaeoclimate proxies allow improved accuracy of future climate reconstructions from the ITF region. New palaeoclimate data will help improve models of future climates, especially monsoonal evolution in the densely populated East Asian region. We have discovered an apparent Late Miocene regional shift in coral reef ecosystems from turbid shallow mesophotic habitats to modern-style reefs living in the clear-water euphotic zone. This shift post-dates the origins of high biodiversity, showing that extant diversity originated in these so-called marginal settings. The future of corals reefs may well include a shift back into these dark, deep or turbid settings as biological communities in such settings are thought by some researchers to be more resilient and thus more likely to persist in the face of ongoing anthropogenic change. The future of corals reefs in Southeast Asia might require a step back into the past. We hope that our project will inspire future integrated studies of biodiversity, habitat and age and allow increased understanding of the origins and maintenance of biodiversity in shallow marine ecosystems.