KAUST Beacon Development's Environmental Planning support to Vision 2030 and the Gigaprojects

Authors: Edwin Palmer, David McGrath, Andrew Booth, Fiona Symes, Ricardo O. Ramalho, David Wells

KBD provides strategic environmental support to Public Investment Fund companies including NEOM, Red Sea Global, ROSHN and Soudah. KBD has been instrumental in facilitating these nationally important strategic developments in line with the diversification of the national economy as per Vision 2030.
KBD has been supporting the gigaprojects since 2017, which first entailed the collection of environmental baseline information to support initial masterplanning. This has enabled them to understand environmental and social constraints and to design environmental and sustainable developments.
In particular, KBD has been supporting the gigaprojects with:

Baseline surveys to aid development.

Environmental and Social Impact Assessments.

Strategic advice on project design and on construction methodologies.

Baseline surveys to help conservation planning including long-term terrestrial and marine surveys, turtle tagging, dugong surveys, megafauna and seabird surveys (using observers as well as UAVs and AI).
KBD, As work has allowed for the protection of internationally important habitats and species while also supporting the gigaprojects to achieve positive environmental outcomes. For example, KBD has been instrumental in the restoration and regeneration of islands in NEOM by the removal of manmade causeways which aims to enable the return of species such as turtles and shorebirds to these islands. The causeways will also help to improve water quality, which in turn may enhancement marine habitats such as seagrass and corals, thereby, increasing carbon sequestration.
KBD is working in partnership with other parts of KAUST, including the Red Sea Research Centre and Reefscape, to deliver multiple projects supporting Vision 2030. KBD are instrumental in bringing innovative and ongoing research to the PIF companies through collaborative project delivery.

Integrated approach to coral protection and regeneration at the Red Sea Project

Authors: Jessica Bouwmeester, Carol Buitrago-Lopez, Rhonda Suka, Shaikha Al Saud, Naif Alzaben, Omar Al Attas, Ivor Williams

Coral reefs are sensitive ecosystems and are particularly vulnerable to climate change and local stressors. At the Red Sea Project we are using a range of strategies to preserve, restore and enhance reef-building corals, such as habitat management, monitoring, coral rescue, and coral growth enhancement. Additionally, we are expanding our strategies to include coral relocation, coral habitat enhancement, coral recruitment enhancement, higher-scale coral growth enhancement, and population resilience enhancement, starting with pilot projects before scaling up. We have started to fragment corals that are currently held in floating nurseries in preparation for relocation and we are in the process of testing a range of artificial substrates to relocate further adult coral colonies. Finally, we are developing land-based coral facilities from which we will have the ability to source coral larvae, coral recruits, and coral microfragments to supplement in situ efforts. Regenerative tourism development in coral reef ecosystems comes with many challenges but also offers a unique opportunity for scientists, managers and developers to collaborate and establish best practices as an example for other development project in the country and beyond.

Mapping coastal marine habitats using UAV and multispectral satellite imagery in the NEOM region, northern Red Sea, Saudi Arabia

Nikolaos Papagiannopoulos

The NEOM coastline includes complex reefs that form unique habitats, such as lagoons and islets, with high biodiversity. It also hosts eurythermal corals that may be the key to coral restoration in the future. Therefore, it is vital to ensure the preservation of the current marine biodiversity hot spots in the NEOM region, which ultimately translate into significant social and economic value.
In this study, we used a machine learning method on Sentinel-2 imagery to classify and map the benthic habitats in the NEOM region at 10 m resolution. Very high-resolution (3 cm) Unmanned Aerial Vehicle (UAV) imagery from 12 key sites in NEOM was also used to train and validate (50/50) the classification. We adopted a hierarchical approach, with level one being a geomorphological classification and level two a benthic habitat classification, since underwater geomorphological features are optically more distinguishable. The geomorphological classes include reef crest, outer reef flat, inner reef flat, shallow lagoon, sand/mud flats, and deep waters, which are beyond satellite remote sensing depth detection limits. The benthic habitat classes are comprised of coral, seagrass/algae, sand, rubble, rock and shallow mudflats. The resulting classification had an overall accuracy of 82% for the geomorphic, and 71% for the benthic habitat, both of which are satisfactory considering the difficulty of the task. The scale of the area was a key challenge when designing the classification scheme and refining the classification, as the region contains a diversity of marine environments and water conditions.
This regionally tuned benthic habitat classification provides, to our knowledge, the best assessment of the NEOM marine habitats. This dataset can be used by stakeholders to improve their decision making towards sustainable development in the NEOM project. It can also be used as a baseline to monitor changes in marine habitats in the future by applying the methodology on the latest available satellite imagery.

Environmental Sustainability Smart Network

Lina Eyouni

Red Sea Global is aiming to establish a long-term smart observational network that will provide key insights into the functioning of coral reef habitat and the coastal zones within the Red Sea Project and Amaala. The data will help us to protect and nurture the Red Sea's natural treasures through continuous monitoring and learning (historical and predictive) for decision makers.
Technology such as IoT, Artificial intelligence, and machine learning further underpins the destination,Äôs sustainability initiatives, with a suite of sensors and monitoring devices in place to track and measure variations in environmental factors. Variety of monitoring activities across landline stations, marine buoys, satellite, or drone imagery, and through integration with other services, collect data related to air quality, noise, marine water, soil quality, groundwater, domestic waste, or light emission. Regular monitoring activities can be extended with more sensitive on-demand measurements for key locations and when needed to manage specific events such as if there is a risk of marine or landline spill or leak.

Science-informed Marine Conservation of the Red Sea Zone

Ivor Williams

At the Red Sea project and Amaala, we are committed to achieving significant conservation gains for our marine habitats and species. To that end, we have dedicated substantial resources to building our capacity for science-led ecosystem management ‚Äì internally and through partnerships.

The starting point for these efforts involved comprehensive baseline assessments of all our key habitats and species. For example, we surveyed coral reef fish and habitat at 350 distinct sites. More than 100 of those are considered ‚Äòcore‚Äô sites that we re-survey annually. Our team has also mapped the location of colonies and counted number of nests of breeding birds on more than 90 islands. For several bird species we have also assessed baseline breeding success to allow us to track future changes to population wellbeing. Similar effort has been dedicated to assessing sea turtle nesting as well as distribution and composition of mangrove and seagrass habitats. More recent projects include focused survey efforts that will improve our data on marine mammals including dugong, and on reef sharks.

From that strong foundation, we use two main management approaches. These being: ‚Äòconservation‚Äô - wise management to remove or minimize threats and allow for natural regeneration - largely through spatial management; and ‚Äòenhancement and protection‚Äô - specific targeted interventions - including habitat improvement or addition, pest-species management, and animal rehabilitation.

Realizing the potential of our areas requires research partnerships that help us make science-based decisions and provide opportunities for impactful high-quality research. Build regional and national data sharing networks would enhance scope for larger-scale management and conservation. That will be best achieved with standardization of survey methods and data management, and a genuine commitment to transparent reporting of status and trends.

Embedding Environmental Planning and Ecosystem Services into the Masterplan Development Process at the Red Sea Project

David McGrath

Embedding Environmental Planning and Ecosystem Services into the Masterplan Development Process at the Red Sea Project

The Kingdom of Saudi Arabia (KSA) has embarked on an ambitious plan to diversify its economy through the development plans set out in Vision 2030. As part of the national strategy, The Red Sea Development Company (TRSDC), now Red Sea Global (RSG), was established by KSA‚Äôs Public Investment Fund (PIF) to develop the Red Sea Project (RSP) constituting high-quality tourism facilities and experiences based around the islands of the Al Wajh Bank on KSA‚Äôs Red Sea coast.

The RSP is being developed in a unique and sensitive area with a high-quality marine environment and complex marine and terrestrial ecosystems. In response to this, the project is taking care to understand the potential environmental issues associated with the development and seeking to mitigate and minimise environmental impacts, risks and effects.

KAUST ‚Äì Beacon Development has been instrumental in supporting the development of RSG good practices in environmental planning, design and impact assessment. KBD and RSG have developed an iterative approach to environmental planning that seeks to embed environmental considerations during the preliminary feasibility and concept phases of masterplan design. This provision of structured and on-going environmental support and guidance to planners and designers is unique in the region and aims to integrate environmental design solutions at the earliest stages of a project.

The approach to environmental design developed by KAUST ‚Äì Beacon Development includes collection and analysis of both primary and secondary environmental and ecological data, workshops with key stakeholders, regular review of designs, provision of feedback to design teams, production of mitigation measures and recording of alternatives considered. This is not a single study or action, but is instead an iterative process conducted as masterplan design progresses. Within this framework, KAUST-Beacon Developed have also pioneered the introduction of an Ecosystem Services Approach into RSG‚Äôs method of working and integration that employs an ecosystem approach to planning whilst also developing and enhancing priority ecosystem services that are important for the RSP.

Multi-tissue transcriptome analysis reveals new insights into the effects of UVB radiation exposure in aquaculture reared European seabass (Dicentrarchus labrax): a case study at the Red Sea

Ricardo Nuno Alves

Solar ultraviolet B radiation (UVB) has been underestimated as a stressor in fish species that grow in confined cages, especially in species cultured in oligotrophic waters that receive high levels of UVB, such as the European seabass (Dicentrarchus labrax). We recently reported that exposure to UVB daily doses from 3 to 12 kJ m,àí2 d,àí1 resulted in increased mortality, growth reduction, and induced changes in behavior, immune system, physiology, metabolism, and increased oxidative stress (Alves et al., 2021a, 2021b). With the aim to understand whether these findings are accompanied by overall transcriptional changes, the present study addressed the global gene expression profiles in multi-tissue after exposure to natural underwater UVB levels.

D. labrax juveniles were exposed for 43 days to several UVB daily doses (from 3 to 12 kJ m,àí2 d,àí1). An unirradiated treatment was used as a control. Fish were sampled after 3 (short-term) and 43 (long-term) days of exposure. Liver, skin, and immune organs were collected to evaluate differential gene expression between control and UVB treatments. Lists of differentially expressed genes (DEGs) were subsequently used to perform gene ontology and pathways enrichment analyses.

RNA-seq analyses revealed a high number of differentially expressed genes between control and UVB-exposed fish (e.g., short-term at 12 kJ m,àí2 d,àí1: liver - ,Üë 1,313, and ,Üì 871; skin - ,Üë 2,314, and ,Üì 2,259; long-term at 6 kJ m,àí2 d,àí1: skin - ,Üë 1,676, and ,Üì 2,218; immune organs - ,Üë 500, and ,Üì 112). Functional analysis revealed shared and tissue-enriched biological processes and pathways. Moreover, more than 220 differentially expressed long noncoding RNAs (lncRNAs) were identified after UVB exposure (skin > liver > immune organs). In addition, UVB-induced tissue damage was also confirmed through histopathological examination. This study provides noteworthy insights into the molecular changes in fish exposed to UVB.

Revealing the hidden biodiversity of NEOM waters using a combination of morphological and molecular approaches: Towards developing evidence-based management frameworks

Eva Aylagas Martinez

The NEOM region is characterized by areas of outstanding natural beauty, globally important heritage sites, vulnerable ecosystems and threatened species. All of these must be conserved and protected, as NEOM strives to fulfill its aspiration of being biodiversity net positive. To meet these goals, a deep understanding of the biodiversity present in NEOM is required. In the marine environment, there is an urgent need for a baseline assessment of the coral reef biodiversity to evaluate the current conditions and potential future changes due to coastal development and/or climate change. Given the scarce knowledge on reef-associated communities in NEOM, we have started a research project to assess the baseline status of coral reefs, while providing an inventory of the reef-associated biodiversity. In addition, as a response to the potential threat of the introduction of invasive species in NEOM, we aim to provide a baseline assessment of marine non-indigenous species. This project, therefore, has three components: i) to conduct benthic and fish biodiversity baseline surveys (morphology and molecular-based); ii) to conduct baseline assessments of non-indigenous species; and iii) to develop a curated collection and database of species based on vouchers, images, and DNA barcodes. This project will combine traditional taxonomic work based on in-kingdom and external collaborations with taxonomic experts and molecular-based tools. Here we will present an overview of the project and the preliminary results of the first surveys conducted. The outcomes of this project will be used by NEOM to inform management strategies, and evaluate effectiveness of marine protected areas, among others. Yet, the impact of the curated reference collection built based on morphological and molecular approaches will go beyond NEOM applications and will greatly improve our ability to document and monitor marine biodiversity with the use of diverse specimen-, image-, and DNA-based tools reliably in future environmental quality assessments.

Lithospheric inheritance controls on early sea-floor spreading: new insights from magmato-structural patterns along the Red Sea axis

Adrien Moulin, Sigurjon Jonsson

Plate divergence at oceanic ridges is accommodated by a combination of lithospheric stretching and the creation of new lithosphere, the balance being controlled by the shape of the underlying isotherms. Rate of opening and subsidiary heat supply (e.g., mantle plumes) are thus key factors that control the mode of sea-floor spreading, by setting the magmatic contribution to plate separation and in turn the pattern of normal faulting. The young (<13Ma) Red Sea ridge (RSR) represents a unique system to explore how secondary factors, notably the rifted margin inheritance, modulate the early evolution of spreading ridges.

We tracked the topographic and geomorphic signatures of the thermal regime along the RSR by extracting four metrics (axial depth, slope of the central-trough flanks, proportion of volcanic sea-floor, and distribution of normal-fault offsets) from Global Multiresolution Synthesis bathymetry, and compared their along-axis variations with the structure of the rifted margins. It shows that both ends of the Central RSR feature anomalously deep segments (i.e., Suakin and Nereus Deeps) bounded by steeper-than-average flanks. These segments occur where the structural pattern switches from regularly-spaced moderate-displacement (~400m) normal faults to one dominant large-displacement (~1200m) fault, and coincide with comparatively lower proportion of volcanic sea-floor (15-20% versus 70%).

This distinct signature is typical of a comparatively lower magmatic contribution, and is superposed to a northward gradient of decreasing magmatic contribution and crustal thickness that we link to the Afar plume. These two segments stand in the prolongation of Proterozoic suture zones within the Arabia-Nubia Shield, associated with local bulges of the lithosphere-asthenosphere boundary (LAB), and with the occurrence of onshore volcanic fields on the Arabian side. We propose that plume material drained from the Afar region is locally channeled beneath these LAB structures, resulting in the transfer of heat/magma from beneath the RSR to beneath the continental margin.

Title: Tectonostratigraphic latitudinal evolution of the eastern Red Sea rifted margin

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Since the 1960s, two end-member tectonic models have been debated about the nature of the crust below the Red Sea. The ‚Äúmainly rift‚Äù model specifies that thinned continental crust prevails throughout the Red Sea except for young oceanic crust (< 5 Ma) within a narrow central trough in the south. The ‚Äúmainly ocean‚Äù model suggests oceanic spreading has occurred throughout the Red Sea since the Middle Miocene.

To address these scenarios, this study presents a new tectonostratigraphic model along the eastern necking domain of the Red Sea based on the interpretation of well-calibrated industrial seismic data and a review of onshore geology.

We characterize for the first time the eastern Red Sea necking domain through its north-south structural and stratigraphic evolution. 1) Along-strike segmentation occurs during rifting (~28-16 Ma), with tilted blocks filled by siliciclastic sediments structuring the northern poor-magmatic segment (28N-21.5N), while clastic/volcanoclastic sediments and volcanic flows interpreted as SDRs characterize the southern magmatic segment (21.5N-13N). 2) It evolves in a passive margin-type basin controlled by thermal subsidence since Middle Miocene (~14 Ma), suggesting the Red Sea is mainly floored by oceanic crust. This work provides new insights to understand the Red Sea geology and the tectonostratigraphic evolution of rifted margins in magma-poor and magma-rich settings.

Along-strike variation in the crustal and uppermost mantle structure beneath the Red Sea as seen in seismic images

Ayoub Kaviani

Crustal and uppermost mantle structure beneath the Red Sea was imaged as a part of a broader seismic model obtained for the Middle East using surface-wave tomography (Kaviani et al., 2020).
According to our tomography model, it appears that the southern Red Sea exhibits higher shear-wave velocity than the northern Red Sea at shallow depths (10,Äì20 km).The shallow high-velocity layer in the southern Red Sea extends eastward beneath the Arabian Shield rather than along the Red Sea itself. At depths below 35 km, the situation reverses, with lower velocities observed beneath the southern Red Sea compared to the northern Red Sea. Our model indicates a transition from predominantly continental crust in the northern Red Sea to an oceanic crust in the southern Red Sea. These observations suggest that the crust beneath the northern Red Sea is likely undergoing the later stages of continental rifting, while the southern Red Sea is experiencing sea floor spreading.
At depths ,â•55 km, our mapping reveals a low-velocity anomaly beneath the southeastern Red Sea. This anomaly extends horizontally at a depth of 70 km, encompassing the Afar depression, Red Sea, and southern and southwestern regions of Arabia. At greater depths (90 km), this extensive low-velocity region extends northward. Our model also indicates a wide low-velocity region in the uppermost mantle beneath the southern Red Sea and the Arabian Shield, which could be linked to a broader mantle upwelling beneath Afar. Additionally, our model supports the hypothesis of a northward channeled flow in the uppermost mantle beneath the western Arabian Shield, which has also been proposed in previous studies.

Evolution of the post-rift evaporitic section in the Red Sea basin

Tihana Pensa

The sedimentary section in the Red Sea basin (RSB) consists of Oligocene,ÄìEarly Miocene rift sediments, overlain unconformably by post-rift Middle Miocene,ÄìPleistocene sediments, mainly evaporites. This study focuses on the post-rift sedimentary section, combining the interpretation of seismic surveys with biostratigraphic and Sr isotopic analysis of well samples.

The evaporite sequence consists of a mobile Middle Miocene salt layer overlain by syn-kinematic mini basins filled with layered evaporites (shale and anhydrite). Although micro- and nannofossils are generally absent, we report foraminiferal assemblages from shale layers within the salt. The presence of planktonic foraminifera Foshella fohsi constrains the end of the salt deposition to the Serravallian. Additionally, the 87Sr/86Sr isotope composition of anhydrite and limestone in the layered evaporites constrains the end of salt deposition at 13.2 ¬± 0.5 Ma. The age of the Middle Miocene salt is therefore constrained between 14 and 13.2 ¬± 0.5 Ma, coincident with the start of seafloor spreading.

The evaporitic phase throughout the Red Sea was terminated by an angular unconformity observed on seismic data. The age of this unconformity is constrained by our Sr isotopic dating of carbonates and anhydrite between 6.2 and 8.9 ¬± 0.5, which corresponds to the Messinian salinity crisis (MSC). Moreover, the observed age gap of 2.7 Ma between the evaporites and the oldest Pliocene limestone supports the theory that the Red Sea was entirely disconnected from the Mediterranean during the MSC and possibly desiccated.

At the start of the Pliocene, the RSB was flooded with seawater from the Gulf of Aden, and normal marine sedimentation resumed. Seismic data demonstrate that reef buildup was controlled by salt withdrawal from the margins. Keep-up reefs started growing along the shoreline, aggrading as they glided into deeper waters above the salt detachment. The oldest reef limestone from the base of a 700 m thick platform was dated by Sr isotopes at 5.5 ¬± 0.5 Ma.

This study calibrates the poorly dated post-rift stratigraphy of the RSB, indicating rapid deposition of salt coincident with oceanization, and the end of evaporitic deposition by the MSC. Finally, we dated the oldest carbonates pointing to the flooding of the previously desiccated basin with seawater from the Gulf of Aden.

Surface expressions of rift-transform motion under salt deposits: analogue models application to the Zabargad Fracture Zone, northern Red Sea

Margherita Fittipaldi

The Red Sea rift is largely covered by Miocene evaporite deposits, that, flowing as glaciers into the rift, hide its main structure and geomorphology, especially in the northern Red Sea. This thick salt cover is made up mainly of halite and has led to contrasting interpretations of bathymetric, magnetic, and gravity data. The most recent studies suggest that the Red Sea is an oceanic ultra-slow spreading ridge composed of offset ridge segments separated by complex fault systems, interpreted as transform faults. One major 100 km offset, the Zabargad Fracture Zone (ZFZ), separates the northern Red Sea axis from the central one and is the location of the most intensive seismic activity in the north. Since the ZFZ is located near coastal communities, a possible large earthquake could cause harm. Consequently, knowing its structure and its related seismic hazard is important. New bathymetric data we collected show highly deformed salt deposits in the ZFZ with multiple curved and stretched salt lineaments. Considering the inability of the salt to erode underlying geology, pre-existing structures and rift movements probably control the salt flow pattern and lineaments direction. In this light, we built analogue models to simulate salt deformation in a strike-slip regime between two oceanic ridges. We use silica powder to simulate the brittle crust and transparent silicone to simulate salt deposits. Three different obliquities of the strike-slip fault between two ridges were tested. Preliminary results show that the salt acts as a filter of the sub-salt structures and movements and only the more prominent structures are replicated at the surface. Several modeled salt flows, especially in the center of grabens, form compressional ridges. Curved lineaments are present along the fault offsets. The scaled models will be compared with the ZFZ area, thus providing a better understanding and interpretation of the bathymetric data.

Seismic activity distributions study in Harrat Al-Ais and around, Saudi Arabia: compared to a similar area in the southeast of Egypt.

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Seismic activities of active areas, Harrat Al-Ais and North and South Umlujj located on the Red Sea coast, northwest of the Kingdom have been studied. Seismic activity occurs in these two areas as seismic swarms within a different period of time. In Harrat Al-Ais, seismic activity occurs with varying magnitudes and depths, as well as in the north and south of Umlujj. The local magnitudes of Harrat Al-Ais ranges from less than ML = 1.0 to less than 6.0, and at a depth range from 2 km to more than 40 km. As for the north and south of Umlujj, the depths ranged in between 2 to 25 km, with a local magnitude ranging from 0.2 to 3.9. In Harrat Al-Ais, seismic activity occurs in more than one location within varying depths and due to the magmatic activity beneath Al-Harrah. As for the north and south of Umljj, no magmatic activity is evident so far, unless it is proven in the future, and it may be attributed to the volcanic activity beneath Harrat Al-Ais. There is no relationship between the occurrence of seismic activity in the Harrat Al-Ais area and the seismic activities of north and south of Umlujj.
When comparison to a similar seismically active area located on the other side of the Red Sea, the Abu Dabab area, northeastern Egypt,. And to prove whether there is a tectonic link between them that causes the occurrence of that similar seismic activity. Based on this study, there may be more than one reason for the occurrence of this seismic activity, perhaps because of a tectonic link through the striking faults cut the main axis of the Red Sea, or due to the regional tectonic affecting the region represented by the tensile forces in the Red Sea region, and or because of the activity of a volcanic source links these areas. So, there is still a debate about whether there is a relationship, and thus more detailed seismic and geophysical studies are needed to examine the crust and upper mantle structures of this region using joint seismic data between the Saudi and Egyptian side.

KAUST Reefscape Restoration Initiative

Mark Gillan, Maram Abadi

The KAUST Reefscape Restoration Initiative is a large-scale coral reef restoration program in the Red Sea in the Kingdom of Saudi Arabia (KSA), begun in 2021 and funded by King Abdullah University of Science and Technology (KAUST), in partnership with NEOM. The initiative will begin with a 100-hectare reef restoration project at Shushah Island. This will be a global demonstration of coral restoration that integrates innovative, in-Kingdom, and internationally developed technologies, pioneering propagation, planting and monitoring approaches, and international expertise to accelerate solutions for reef ecosystems at a time of unprecedented environmental change. The program‚Äôs first reefscape restoration site is located near Shushah Island, approximately 20km off the shore of NEOM. Shushah Island. While the island itself is relatively small, it supports broad and diverse coral reef assemblage from mixed shallow reefs through mesophotic and deep reefs. Some of the shallow reefs directly adjacent to the island, from a depth range of ~1m to 5m, appear to be among the best in the Red Sea with nearly 100% coral cover in some locations along the crest while other reefs are heavily degraded and in need of restoration.

The effort will be a mix of coral conservation protection, enhancement, and restoration. Corals needed for outplanting at the site of restoration will be propagated primarily in an ex-situ coral nursery, which will be the world‚Äôs largest once completed. A further, in-situ coral nursery adjacent to the restoration site will be operational prior to the commissioning of the ex-situ nursery to support the restoration of priority sites within the 100-hectare area identified mutually between KAUST and NEOM. Both of these efforts will be augmented by a robust habitat enhancement program and by harnessing corals' natural sexual reproduction processes to support the restoration of a thriving reefscape.

Optimizing large-scale in situ propagation and outplanting methods for reef restoration at Shushah Island, Saudi Arabia

Elizabeth Goergen

In situ coral propagation practices are accelerating throughout the Red Sea to meet the regional demands of reef restoration. Whilst projects seek to rapidly scale, little information still exists for the region in locally tailoring methods and species selection to optimize production. Here we report how rapid trialing has been adopted and implemented to address this gap and initiate scaling for the world,Äôs largest reef restoration project ,Äì KAUST Reefscape Restoration Initiative (KRRI) at Shushah Island. Trials activity has met the goals for the first year of in situ propagation via installation of multiple nursery arrays ,Äì consisting of tree, platform, rope and line designs ,Äì across three environmentally diverse sites, collectively enabling propagation of >15,000 corals. Initial trials have focused on >5000 corals within these nurseries spanning diverse species and morphologies from the reefscape that are considered high priority taxa for local in situ propagation. We present the first data on propagation effectiveness (growth, survivorship, health; also nursery fouling and structural integrity) that are now being routinely generated using a suite of targeted versus high throughput imaging-based methods across these nursery designs. Outplant trials have also been established for early optimization of cost-effective techniques ,Äì spanning both chemical and physical attachment ,Äì across priority habitats in need of enhancement (e.g., reef walls, bommies); which, includes the same species used for nursery trials. Again, we present the first data on planting effectiveness using both targeted and broad scale imaging approaches. We discuss how acquiring such insights early ,Äì using a blend of highly resolved and high throughput monitoring approaches ,Äì can inform rapid tailoring of workflows (e.g., based on differences in species-method compatibility) for confidence in rapid scaling of activity.

The success of the RSG coral relocation project

Edwin Palmer

Saudi vision 2030 is a strategic framework to reduce Saudi Arabia's dependence on oil, diversify its economy, and develop public service sectors such as health, education, infrastructure, recreation, and tourism. Many of the developments are in offshore areas including pristine coral reef areas.
Given the highly sensitive features of the Red Sea environment, the project proponent i.e., Red Sea Global (RSG) has adopted strategies to mitigate the potential impacts, including the relocation of corals from within the development footprints.
Coral relocation typically incorporates best practice, local advice, and research recommendations to find the best coral relocation methodology. The coral relocation works should have clear goals and objectives.
The RSG coral relocation project was carried out from January 2021 to September 2023, in the Al Wajh Bank area, with the objective to relocate all healthy corals from the construction footprints and monitor their survivorship. The relocation project encompassed more than 3 hectares and close to 100,000 corals were relocated.
The coral relocation survivorship may depend on many variables including methodology applied (substrate and binding agent), environmental setting of donor and recipient site, and the corals genotype and phenotype to withstand stress and mechanical impact, among others.
This paper aims to evaluate the success of the RSG coral relocation project, including the methodologies used and the corals survivorship post relocation and additionally, describe the lesson learnt and shape the approach of future coral relocation works.

Keywords: Coral Relocation; RSG; gigaprojects.

Conservation and restoration of red mangroves (Rhizophora mucronata) in The Red Sea project

Cecilia Martin

Of the two species of mangroves inhabiting the Red Sea, the red mangrove (Rhizophora mucronata) is rarer, due to its sensitivity to high salinities and strong currents. Its abundance decreases towards the North of the Red Sea, where the northernmost limit of R. mucronata distribution is at the Al Wajh lagoon.

Following an extended ground truthing exercise, red mangrove forests were found at 3 sites in the Al Wajh lagoon. One of the forests lies along the mainland coastline and is impacted by camel grazing. Daily patrolling efforts from July to November 2022 showed that camels have visited the site at least once monthly, with up to 35 camels seen grazing there each time.

Given the rarity of the red mangroves in the Northern Red Sea and their vulnerability to grazing, efforts to conserve and restore the mainland red mangrove forest are underway. There, in 2022, growth of red mangrove seedlings starting from propagules was piloted at three 1 sq. m plots. Of the sowed propagules, 78 ¬±5% sprouted into seedlings, of which 82 ¬±4% reached maturity after 10 months and are ready to be out-planted. This confirms the site is suitable for red mangrove propagation. Hence, a 45 sq. m intertidal nursery of ~3,000 seedlings will be established there in September 2023, corresponding to the peak propagule production season for R. mucronata in the lagoon. Seedlings grown in the nursery will be out-planted into the adjacent forest to aid recovery. In addition, a fence will be installed later this year to release grazing pressure and allow natural recovery of grazed mangroves in the area.

Baseline multispectral and RGB drone imagery were acquired, and the areas will be resurveyed yearly to assess effectiveness of these enhancement efforts.

Coral spawning and large-scale recovery of coral populations

Eslam O. Osman

Coral spawning is a crucial process that contributes to the genetic diversity and large-scale recovery of coral populations. However, our understanding of coral spawning timing, particularly in regions with diverse thermal and environmental conditions across broad temporal gradients, including the Red Sea, remains patchy. To date, observations from the Red Sea have come from few sites and time periods limiting integration of data required to completely understanding spatial variation in spawning timings. To address this knowledge gap, three teams conducted extensive and parallel surveys during spring 2023 at diverse reef sites representing the central (Al-Fahal Reef - Saudi Arabia) as well as east (Shusha Island - Saudi Arabia) versus west (Hurghada ‚Äì Egypt) coast of the northern Red Sea. Surveys focused on Acropora spp., examining timing, and synchronization of coral spawning during the full moon nights of April and May - 2023, combined with gravidity check assessment during, but also before and after, this period. Our findings indicate that the examined Acropora species spawned predominantly in April in the central Red Sea and in May along the northern coast of the eastern Red Sea. Notably, these spawning events in the north and central Red Sea coincided with the night of the full moon of April and May, respectively, highlighting a multi-species synchronous reproductive phenomenon. Interestingly, corals in the west coast (Hurghada) spawned 2-3 nights before the full moon in May. Gravidity checks confirmed these timings for most species, with the exception for some digitate Acropora taxa. We analyze these patterns relative to differences in temperature regimes for these respective sites to understand whether and how temperature differences may enable wider forecasting of spawning timing across thermally variable sites. We highlight the importance of this parallel effort to confirm past observations of differences in spawning timing, and importantly provide crucial guidance for the development of management strategies aimed at conserving and restoring coral reefs in this ecologically diverse region.

Effects of long-term probiotic inoculation on coral reef holobionts

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Corals are currently threatened by climate change and actions to mitigate the decline of coral cover are urgently needed. The application of Beneficial Microbes for corals (BMCs) has been suggested as an important tool to boost coral health and restore the coral microbiome. Extensive research has revealed that the utilization of probiotics in aquariums can significantly reduce coral mortality and positively impact coral health, particularly during periods of thermal stress. Furthermore, it has been demonstrated that manipulating the coral microbiome in natural environments is achievable through consistent probiotic inoculation. However, how the application of BMCs to corals might affect their health and fitness over time in comparison to not treated corals and the potential of this application to maintain, restore and recover coral colonies in situ and how this could affect other reef members is still unknown. In this study, we introduce a comprehensive survey of the first long-term field experiment involving probiotic inoculation at Al Fahal reef, situated in the central Red Sea. Starting from August 2022, we have been applying two distinct consortia of probiotics, derived from the same species found in the Red Sea, to inoculate two coral species: Pocillopora verrucosa and Acropora spp. Our results show how the physiology, fitness, and health of the corals respond to the treatment over time in comparison with colonies inoculated with a placebo. We additionally tested the effect of probiotics on adjacent organisms such as two species of sponge and a macroalgae. Our work aims to contribute to the development of a holistic intervention framework and guide future efforts to rehabilitate coral reef ecosystems.

Title: Underwater robotic development initiatives for Red Sea coral survey and restoration.

Authors: Pablo Afman, Ibrahim Alsalamah, and Eric Feron

Abstract: The Red Sea conservation and development require realistic means to survey, estimate, maintain, develop or restore the numerous coral reefs that border much of the Red sea coastline. The large scale (thousands of miles) over which coral reefs are distributed provides the opportunity for world specialists to develop entirely autonomous, robotic solutions to perform these tasks, possibly hundreds of times faster than human operators and at an affordable cost.

Motivated by this opportunity, the Robotics, Intelligent Systems and Control (RISC) laboratory at KAUST has initiated an ambitious project aimed at developing robotic solutions specifically tailored to the foregoing tasks. Among projects currently under way, this presentation will focus on the development of a very agile, towed underwater platform operating in tandem with an autonomous surface vehicle. Specific attention will be spent on the towed platform and its maneuvering capabilities. Initial analytical and experimental results will be presented, along with a perspective on future developments and ongoing collaborations.

Detecting live coral cover from multispectral drone imagery

Brian Owain Nieuwenhuis

Coral reef flats are strongly influenced by climatic variation due to their shallow nature. The corals and other benthos inhabiting reef flats may therefore be particularly susceptible to the effects of climate change. Climate change induced changes in the ecosystem state and benthic communities of reef flats will impact the ecological services they provide. The Saudi Arabian Red Sea contains approximately 1400 km2 of reef flats. Thus, there is a need scale-up monitoring efforts in these areas. This cannot be achieved with traditional in-water monitoring. Unmanned Aerial Vehicles (or Drones) have tremendous potential to scale-up monitoring efforts, while also retaining enough spatial resolution to distinguish biologically meaningful entities. However, due to interference of the water column, it can be challenging to differentiate different benthic assemblages in standard RGB drone imagery. Recent advances in camera technology have opened up the possibility to capture multispectral imagery with drones. Here we explore the benefits of the increased spectral resolution offered by these cameras to differentiate live coral cover from other benthic assemblages including turf algae, seagrass, and macroalgae on a reef flat in the central Red Sea. By generating a robust understanding of the detectability of different benthic assemblages in drone imagery we hope to pave the way for efficient and accurate monitoring of reef flat communities throughout the Red Sea.

Title: SeaSonde HF radar facility: Operational met-ocean observing, new AI functionalities and cutting edge research.

Sending the communication: Andres Alonso-Martirena, Jorge Sanchez, Laura Pederson, Chad Whelan - CODAR Europe - Qualitas Remos SL

Due to HF radar,Äôs unique ability to map surface currents from shore with high temporal and spatial resolution and supplying useful wave data, it has become a key component of many coastal ocean observing systems worldwide. There exists plenty of evidence showing successful delivery of important societal benefits by HF radar networks which are part of some of the most advanced met-ocean services in the world such as the U.S. Integrated Ocean Observing System (IOOS) managed by NOAA. These HF radar networks provide critical information to support pollutant tracking, search and rescue operations, harmful algal bloom monitoring, navigation and a number of other applications which are critical for coastal managers, infrastructure operators, emergency responders and marine scientists to most effectively perform their tasks.

But there is opportunity to extract even greater value from HF radar. The Oceanic Platform of the Canary Islands (PLOCAN) is operating a SeaSonde¬Æ HF radar network delivering reliable real-time 2D currents and waves information to operational users such as the Spanish State Ports Agency Puertos del Estado. PLOCAN wants to expand beyond that and address some upcoming challenges towards smarter, safer, more sustainable ocean exploitation with a set of new disruptive HF radar technology enhancements. Their HF radar network not only uses the latest SeaSonde software and Marine AI platform, but it also integrates a new set of sensors (e.g. optical camera, wind anemometer) into each HF station and AI at the edge to deliver a unique picture of the coastal and marine environment including real-time information of winds, directional visibility range, vessel positions, etc. The new AI platform associated with SeaSonde has also the capability to analyze and control the activities and operations along the coastal strip and report and alert about its usage aligned with Marine Spatial Planning requirements.

Title : Sea Floor Characterization using Machine Learning and Multibeam Echosounder, A Case Study from Al Wajh Carbonate Platform, NE Saudi Arabia.

Authors : Indah Putri, Andika Perbawa, Manuel Ariza-Fuentes, Dea Oemaya, Fabio Marchese, Marta Watts, Alexander Petrovic, Volker Vahrenkamp.

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Seafloor sediment in shallow-water carbonate environments is naturally heterogeneous and complex. Understanding sediment distribution in this environment is essential as it provides insights into geological processes and supports the development of various infrastructure projects, including wind farm foundations, underwater fiber optics, and offshore platform construction. This study presents the initial results of investigating seafloor sediments in the Al-Wajh carbonate platform lagoon using Multibeam Echosounder (MBES), grab sampling, and machine learning clustering techniques.

We collected 4 km2 of high-resolution bathymetry and backscatter data in the Al Wajh lagoon, and 18 sediment grab samples for grain size, texture, and facies classification. To construct a carbonate fine distribution map, we correlated the backscattered intensity with the mud content of the collected samples using an asymptotic model. Moreover, we implemented k-Means clustering and k-Nearest Neighbor techniques, utilizing data from the grab samples, backscattered intensity, and rugosity of the seafloor topography. These methods were employed to classify sediment texture (according to Dunham classification) and to map this texture across the entire MBES survey area.

The confusion matrix shows a higher correlation (83%) for the k-nearest neighbor method compared to the unsupervised k-means method (56%). The results revealed a complex distribution of facies within the lagoon. A positive correlation was found between backscattered intensity and average sediment grain size. The carbonate fines distribution map effectively captured deposition trends, indicating water current directions. The sediment in the southern area, protected by the reef rim, predominantly comprises wackestone. The northern area, far from a protected zone, mainly comprises grainstone to packstone. This study successfully demonstrates that Multibeam Echosounder backscattered data and machine learning techniques can be used to generate a high-resolution map of sedimentary facies distribution in a carbonate platform lagoon. This approach reduces sampling requirements and processing efforts while enhancing the accuracy of sediment composition maps.

Taking the temperature of coral reefs: An in-situ comparison of nine temperature loggers to inform best practices for future monitoring efforts

Walter Rich IV

Coral reefs are among the most sensitive ecosystems to anthropogenic warming. These habitats have continued to decline in recent years as heatwaves become more frequent and result in mass coral bleaching and mortality. Consequently, the number of in-situ temperature sensors deployed on reefs is rapidly increasing and these instruments are being used by a wide variety of stakeholders. With the advancement of sensing technology, new loggers are emerging on the market but their reliability and deployment requirements remain untested. To improve the future integration of diverse data sets it is crucial to evaluate sensor performance and ensure responsible application and reporting of reef temperature data. Here, we assess nine popular temperature loggers in a high-temperature coral reef in the central Red Sea and compare several deployment methods. Specifically, we deployed loggers in shallow (< 2 m) and deep (10 m) sites and incorporated a variety of shading methods to account for heating bias caused by solar radiation. We find a surprising degree of variability across the loggers, which in some cases are magnified by solar heating. In particular, unshaded Hobo pendant loggers, especially in shallow deployments (<2m depth) suffer deviations of up to 2.5¬ĴC compared to loggers deployed in shaded conditions; however, even unshaded Hobo pendant loggers in deep deployments overestimate temperatures by up to 0.5¬ĴC. The effect of solar heating was different across loggers, but in almost all cases shading improved accuracy. As research and monitoring efforts continue to increase in the Red Sea and on reefs globally, our results are crucial for informing the best practices to obtain accurate data that can be reliably combined across studies and regions to comprehensively monitor the rising temperatures on coral reefs.

Oxygen availability modulate clownfish larvae responses to acute thermal stress

Silvia Arossa

Ocean deoxygenation, mainly driven by warming and eutrophication, occurs globally and poses a significant threat to marine life. However, recent studies have revealed that seawater oxygenation substantially fluctuates daily and that nighttime anoxia (i.e., oxygen is removed by community respiration) is followed by daytime supersaturation (i.e., >100 mg/L; oxygen levels are restored by photosynthesis). In these dynamic coastal marine ecosystems, oxygen supersaturation also coincides with peak daytime temperatures. Recent advancements in understanding the interactions between oxygen and temperature on tropical species have demonstrated that supersaturation can potentially protect tropical organisms from warming by satisfying their oxygen requirements. Based on this premise, we investigated whether oxygen supersaturation could mitigate the adverse effects of high temperatures on demersal fish larvae. To address this hypothesis, we exposed newly born Amphiprion bicinctus larvae to three different oxygen treatments: deoxygenation (~4 mg L-1), 100% air saturation (~6 mg L-1), and oxygen supersaturation (~12 mg L-1). Subsequently, we examined their responses under thermal stress (+0.5 ¬∫C hour-1). The larvae subjected to the deoxygenation treatment exhibited the lowest lethal temperature (LT50) at 30.15 ¬∫C (¬± 0.12 SD), followed by 31.26 ¬∫C (¬± 0.08 SD) for the 100% air saturation treatment and 31.54 ¬∫C (¬± 0.08 SD) for the oxygen supersaturation treatment. Although a trend was observed, with the oxygen supersaturation treatment demonstrating the highest LT50, no statistically significant difference was detected between the 100% air saturation and oxygen supersaturation treatments. Despite the modest effects observed, the findings indicate that oxygen surplus has the potential to enhance the thermal stress resistance of clownfish larvae. This information is pertinent not only to nurseries impacted by climate change, but also to fisheries and aquaculture, to design effective management, conservation, and rearing strategies.

Detection of change in Red Sea shallow water coral reef communities following the 2020 bleaching event

Natalie Dunn

In the Red Sea, moderately warm intervals of sea surface temperature were first recorded in the 1930s and 1970s. More recently, extreme warm pulses occurred in 1998, 2010, 2015, and 2020, suggesting that these events are becoming more frequent and severe. Major coral bleaching events coincided with temperature anomalies since 1998, during which branching corals and shallow inshore reefs were most susceptible. While many studies globally have quantified bleaching prevalence, few studies evaluated long-term impacts to community composition and reef structural complexity, and these effects are largely unknown in the Red Sea. This study investigated the long-term consequences of the 2020 bleaching event on shallow water coral-dominated communities in the central Red Sea, using Structure-from-Motion photogrammetry. This methodology uses overlapping images to generate a three-dimensional reconstruction of the reef, from which high-resolution structural complexity and community composition may be extracted. Between KAUST and Yanbu, seven transects were surveyed in October 2020 during the bleaching event, and re-surveyed two years later in October 2022. Temperature and salinity were recorded at each site for both time points. Using ArcGIS, coral colonies in each transect were identified to the lowest possible taxonomic level, and growth form and condition were recorded. Preliminary data support common patterns linking bleaching susceptibility with growth form. High mortality was recorded among branching Acropora, while massive Porites exhibited high recovery rates, and Goniastrea survival appeared to vary with species. However, branching Pocillopora were surprisingly resistant to bleaching, and some soft corals exhibited high mortality rates. This presentation will discuss how resistance and resilience across some of the most thermally-tolerant corals influence overall impact to reef communities and structure. This research comes at an important time for the Kingdom of Saudi Arabia, as major sustainability goals are being introduced to combat increasing local and global threats.

WARMING ADAPTATION TRADE-OFFS IN CORAL SYMBIONT SYMBIODINIUM ADRIATICUM FROM THE RED SEA

Isabel Armelles Vicent

Coral reefs are threatened by ocean warming which leads to the death of the endosymbiotic Symbiodinium and subsequent bleaching. Several experiments have shown that Symbiodinium has the ability to adapt to higher temperatures. We evaluated the cost of adaptation to warmer conditions in Symbiodinium microadriaticum, which was isolated from the Red Sea and long-term adapted to ambient (26 ¬∫C) and warming (32 ¬∫C) temperatures. Trade-offs associated with temperature adaptation were assessed on population growth, photosynthetic performance, and oxidative stress. Cultures adapted to ambient temperatures exhibited higher growth rates, although warming adaptation did not increase the optimum growth temperature. Production of reactive oxygen species (ROS) was similar for both strains at lower and medium temperatures. However, at 32 ¬∫C, warming adapted strain maintained the same ROS levels as in the lower temperature treatments, indicating a better ability to withstand thermal stress. Photosynthetic performance was measured using the maximum photochemical quantum yield (Fv/Fm). Ambient adapted strain showed a significant decline in photosynthetic performance at temperatures above 26 ¬∫C throughout the experiment, whereas the Fv/Fm values were more stable for warming adapted strain. Our findings suggest that warming adapted strain has a greater ability to cope with thermal stress and its associated ROS production by either maintaining similar production levels or not affecting its removal capacity, albeit with a reduced maximum growth rate. Additionally, we exposed both strains to UVB radiation to examine whether warming adaptation incurs costs when facing multiple stressors.

Erik Krieger

Calcifying macroalgae are crucial for the healthy functioning and growth of coral reefs. Algal carbonate production can equal and even surpass that of reef-building corals, particularly after disturbances that result in coral mass mortality. Increased temperatures from ocean warming and marine heatwaves (MHWs) are principal drivers of the global decline in coral cover. Despite their importance in maintaining reefs, however, the responses of reef algae to these drivers, and the role of temperature variability in modulating responses, are poorly known. To this end, we conducted an experiment evaluating the role of diurnal temperature variability in influencing responses of different calcifying reef algae to normal and anomalous summer temperature regimes. For two and a half months, our four study species (Lithophyllum kaiseri and Neogoniolithon sp. and Halimeda tuna and H. discoidea) were exposed to six different temperature regimes: ‚ÄúA‚Äù = 31¬∞ constant, ‚ÄúB‚Äù = 31¬∞C + 1.5¬∞C diurnal variability with the peak during the day, ‚ÄúC‚Äù = 31¬∞C + 1.5¬∞C diurnal variability with the peak during the night; ‚ÄúD‚Äù = 31¬∞C + a symmetric six-week heatwave with a intensity of 34¬∞C and no variability, ‚ÄúE‚Äù = 31¬∞C + the simulated MHW and a diurnal variability of 1.5¬∞C peaking during the day and ‚ÄúF‚Äù = 31¬∞C + the simulated MHW and a diurnal variability of 1.5¬∞C peaking during the night. During the experiment several metrics related to photo- and calcification physiology were monitored to assess species-specific responses to diurnal temperature changes in isolation and in interaction with a discrete extreme temperature event. Preliminary results indicate a generally negative impact on growth and photophysiology from nighttime peaks in temperature and no or positive effects when these occurred during the day. Drops in temperature at night are thus likely crucial in alleviating heat stress from marine heatwaves.

Effects of Temperature Stress on Central Red Sea Crustose Coralline Algae

Huajing Yan, Steve S. Doo, Lauren A. Tisdale, Maggie D. Johnson

Crustose coralline algae (CCA) are an essential component of coral reef ecosystems where they provide important ecological services. Red Sea coral reefs have abundant CCA communities and the warmest sea temperatures in the world. Yet, a large gap still exists in our understanding of CCA responses to warming ocean temperatures. To evaluate temperature effects on coralline biological functions, we conducted an aquarium experiment with different warming treatments. Two species of crustose coralline algae, Lithophyllum kaiseri, a free-living CCA (rhodolith), and Neogoniolithon sp. an encrusting CCA, were exposed to 6 temperature levels for two months (26¬∞C, 29¬∞C, 32¬∞C, 35¬∞C, 38¬∞C, and 41¬∞C). At the start, middle, and end of the experiment, samples were buoyant weighed, photosynthetic efficiency was determined with a diving PAM, and light and dark metabolic rates were measured using the alkalinity anomaly method. All samples were stained with calcein at the start of the experiment for linear extension visualization. Preliminary buoyant weighing results suggests that Lithophyllum kaiseri continued to grow in the 26 ¬∞C, 29 ¬∞C, and 32 ¬∞C treatments, while Neogoniolithon sp. grew only in the 26 ¬∞C and 29 ¬∞C treatments. Photosynthetic efficiency of both CCA species in the 35 ¬∞C was lower than other temperature treatments (excluding 38¬∞C and 41¬∞C samples). Our results shed light on the potential impacts of warming temperatures on physiology and growth rates of two important coralline species. Elucidating the relationships between temperature and ecological function of key algal taxa is becoming increasingly important as coral reefs shift towards dominance by fleshy and calcifying algae as ocean warming continues to intensify.

Decadal Variations in Sea Surface Temperature and Biological Parameters in the Red Sea: Implications for Climate Change

Irfan Mahmood

Understanding the impacts of climate change on marine ecosystems requires monitoring of key physical and biological parameters. The current study involves analyzing the fluctuations in sea surface temperature (SST) and key biological parameters: chlorophyll-a concentration and particulate organic carbon (POC) for Red Sea from 2003 to 2022. The analysis revealed an upward trend in both day and night SST, with an increase of approximately 0.69¬∞C and 0.84¬∞C respectively, possibly hinting towards the pervasive effects of global warming. Concurrently, the biological markers exhibited noticeable cyclical patterns, suggesting a correlation with seasonal biological activities. This correlation between rising temperatures and biological parameters signifies potential alterations in the marine ecosystem. Elevated SST can increase the stratification of the water column, potentially reducing nutrient mixing, thereby impacting phytoplankton productivity, which is reflected in chlorophyll-a concentrations. Furthermore, the changes in SST might influence the quantity and composition of POC, an integral part of the carbon cycle. The findings contribute to the recent evidence on the potential impacts of climate change on marine ecosystems and emphasize the need for continued monitoring and adaptive management strategies. This analysis underscores the complexity of climate change impacts on marine ecosystems and suggests a potentially significant transformation of the Red Sea's ecosystem in response to rising temperatures. The insights from this study will contribute to our understanding of the complex dynamics between physical and biological parameters in the marine environment under the influence of climate change.

Bio mineralization and ocean acidification of bryozoans with the status of bryozoan research in Saudi Arabian EEZ of Red Sea

Authors: Mohammed Naufal, Jayaraj Kadeparambil Arjunan

Abstract: Declining pH levels in the global oceans are extensively documented as a threat to marine biota. Bryozoans are among the major phyla which are made up of calcium carbonate skeletons, potentially affected by ocean acidiÔ¨Åcation. Depending up on the species, bryozoan skeletons may consist of aragonite, calcite or have a bimineralic combination of both the minerals. Calcite is generally less soluble in seawater than Aragonite. All though, the mineralogy of the bryozoan skeleton is under a high degree of organismal control, bimineralic species shows an apparent ecophenotypic variability in the proportions of aragonite and calcite in their skeletons. Based on biomineralogy alone, compared to the higher latitudes, ocean acidiÔ¨Åcation can be likely affect bryozoan species of tropical regions to a larger extent. The effects of global climatic changes, including and global warming etc are well studied with Bryozoans species, as they are one of the major bio-constructional and bio-indicator organisms. Several studies have been also carried out regarding the potential vulnerability of bryozoans to ocean acidification.
The bryozoan wealth of the EEZ of Saudi Arabia (the Red Sea and Arabian Gulf) is still unexplored. The exclusive bryozoan reporting of Phylum Bryozoa from the Red Sea coast of Saudi Arabia was Soule & Soule 1985. Considering the Bryozoology of Saudi Arabia, the significance of Bryozoan research starts from its role in Paleobiologic study, followed by a filling aspect of the lacunae of the marine biodiversity of the Kingdom. Going further, Bryozoa as an indicator species for the ongoing global ocean acidification is a matter for research. Considering the exclusive reef habitat ecosystem of the Red Sea, identifying a bryozoan reef from the Red Sea waters has a good chance of occurring and if identified, it will become an interesting among 65 bryozoon reefs around the globe.

Declining Nutrient Availability and Element Pollution in the Red Sea: Indicators of a Global Oceanic Trend

Chunzhi Cai

Reconstructing element concentrations in sediment cores helps identify historical natural or human-induced environmental changes. This study investigates variations in 15 element concentrations in Red Sea (a hot spot for biodiversity) sediment cores over the past five centuries. The findings reveal a significant change in sediment element accumulation rates (EAR) following the Second Industrial Revolution (~1870) and the opening of the Suez Canal. In the North, where industrial activities become prevalent, we observe an increase in the mean EAR of Fe, Cd, V, Zn, Cu, and Cr from 4.56% to 17.6%, with positive slope change rates ranging from 332% (Fe) to 1003% (Cu). Conversely, in the South, we observe a decline in the mean EAR of Mg, total N, total organic C, and Ca from -8.5% to -17.8%, with negative slope change rates ranging from -83% (Ca) to -13980% (Mg). The results reveal the increasing accumulation of trace metals from human activities in recent decades in the North, whereas the South is experiencing a decline in nutrient input from the Indian Ocean associated with ocean warming. These two challenges may be synergistic and have a detrimental effect on the Red Sea ecosystems.

Burst-overlap interferometric time-series analysis of satellite radar images of the southern Gulf of Aqaba

Xing Li

Earthquakes on the Dead Sea fault pose a significant seismic risk, primarily due to high population density and aging building infrastructure. Of particular concern is the Gulf of Aqaba, situated at the southernmost segment of the Dead Sea fault, where the notable 1995 Mw 7.3 Nuweiba earthquake occurred. Accurate mapping of the interseismic deformation is important input for seismic hazard assessments. However, due to a lack of seismic and geodetic data, observations along the southern Dead Sea fault have been limited. Here we use burst-overlap interferometric time-series analysis of satellite radar images spanning from 2014 to 2021, a novel method, to provide new independent evidence for the slip rate as well as locking depth along the entire fault system. The estimated slip rates for the Gulf of Aqaba and Wadi Arabah are ~5 mm/yr but then decrease to 3.8 mm/yr, 3.4 mm/yr and to 2.8 mm/yr for the Jordan valley, Yammouneh fault, and northern DSF, respectively, aligning well with observations from GPS measurements. We find the locking depths in the gulf significantly lower than north of it in Wadi Arabah (~16km), that is ~6 km in the northern gulf and only ~4 km in the southern gulf. The result indicates a lower moment accumulation rate on this portion of the fault system and thus lower earthquake hazard as compared to the fault north of the gulf.

Uplifted Marine Terraces due to Normal Faulting along the Gulf of Aqaba and on Tiran Island

Ribot Matthieu

Approaching its southern end, the Dead Sea strike-slip fault (DSF) becomes trans-tensional in the Gulf of Aqaba and where it connects to the Red Sea rift. The details of this transition, however, has remained difficult to unravel as most of the active tectonic structures are located off-shore. Here we focus on uplifted marine terraces located in the Gulf of Aqaba and on Tiran Island. Using high-resolution tri-stereo Pleiades satellite imagery, we build a Digital Surface Model (DSM) at a 0.5-meter resolution of the eastern coast of the gulf and Tiran Island to map 19 levels of marine terraces. The terraces are preserved at elevations from 1 m to almost 500 m above the current sea level. Correlating laterally U-Th ages obtained along the Gulf of Aqaba with the lower levels found on Tiran Island, we build an age model to estimate the ages of the upper terraces on the island. Combining this with the terrace heights from our DSM, we derive the uplift rate affecting the terraces. The geographic extent of the terraces along the gulf suggests that the DSF is responsible for uplift along the entire eastern coastline of the gulf at a rate of about 0.14 ¬± 0.03 mm/yr. The uplift rate of Tiran Island, located closer to the Red Sea rift, is faster at 0.21 ¬± 0.02 mm/yr. This faster uplift rate suggests a combined tectonic uplift related to both the DSF system and the Red Sea rift. Using that measured uplift rates represent 1/3 of offshore normal faulting slip rates, we estimate the slip rate of the normal faults along the eastern coast of the gulf and south of Tiran Island as 0.42 mm/yr and 0.63 mm/yr, respectively. This shows that these faults need to be included in seismic hazard assessments for NEOM and neighboring areas.

Zeynep Bektas

The Gulf of Aqaba is located at the southern end of the 1000 km-long Dead Sea Fault. The last major earthquake in this area occurred in 1995, causing significant damage in neighboring towns and villages. In contrast to the wealth of information on historical earthquakes along most of the Dead Sea Fault, relatively little is known about past major earthquakes in Gulf of Aqaba. To address this issue, we carried out a seismo-turbidite investigation on 18 sediment cores (26.8 to 107.3 cm in length) we acquired during a research cruise to the gulf in 2018. Our core analysis included ¬µ-XRF scanning, grain size analysis, and magnetic susceptibility measurements, as well as radiographic imaging, which we used to detect turbidites intercalated within the background sediments. The results reveal coevality of numerous turbidites in different cores, even in different basins of the gulf, which we utilized as a criterion to ascribe seismic origin to turbidites. Seismo-turbidites generated by earthquakes in 1068, 1212, 1588, 1839, and 1995 CE are visible in a stratigraphically well-correlated sedimentary sequence dating back approximately 1000 years. Seismo-turbidites caused by the 1995 earthquake were not found in the southern gulf, implying that only the northern part of the fault system ruptured in 1995. Seismo-turbidites triggered by the 1068 and 1588 earthquakes, on the other hand, were identified in cores from throughout the gulf, showing that the entire fault system in the gulf was likely activated during these significant earthquakes. Unlike the 1068 and 1588 earthquakes, seismo-turbidites caused by the 1212 and 1839 earthquakes were only found locally, implying that these were smaller earthquakes in the northern and southern parts of the gulf, respectively. In addition, seismo-turbidites were identified around 363 CE, 280 BCE, 890 BCE, and 1490 BCE in one core comprising a sedimentary sequence dating back to 1800 BCE. These older probable seismo-turbidites, together with the 1588 and 1068 earthquakes, may offer a 400-700 (average = 580) year recurrence interval for large earthquakes in the gulf. Because there have been no substantial turbidites in the southern gulf since 1588 CE, this area of the fault system may be a candidate for a large earthquake in the near future.

Relocation of seismicity around the northern Red Sea region: Contribution of regional seismic networks in improving locations

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In this study, for a period from 1997 to 2014 seismic activity for a number of 1445 earthquakes were relocated in the northern Red Sea region, such as seismicity of the Gulf of Aqaba, Gulf of Suez seismic data, as well as seismicity data of the northern part of the Red Sea. Th aim was to improve the locations of this seismicity data by using seismic phases of more than one seismic monitoring network around the study area, such as the Egyptian network monitoring stations from the western side, and the Saudi network monitoring stations from the eastern side, in addition to international monitoring stations surrounding the study area from the northern side, with a total number of 176 seismic stations. More than one technique was applied during seismic data analysis.

The results demonstrated a clear improvement in locating seismic data with a very small percentage of errors (horizontally and vertically) compared to locating these data previously using the Egyptian and Saudi seismic network only. The seismic activity became clustered around the active faults present in the region, i.e., around the active faults within the Gulf of Aqaba, the Gulf of Suez, and the northern part of the Red Sea. The results of this study are considered a new contribution to reconsidering the location of seismic activity in an important and active seismic area in the northern Red Sea region, and may be used for any other seismological studies, including updating seismic hazard and the Saudi Building code.

The current seismic activity in the Gulf of Aqaba

Laura Parisi

Faults in the Gulf of Aqaba (GoA) represent the southernmost part of the Dead Sea transform plate boundary and generate hazardous earthquakes. The last earthquake of magnitude Mw 7.2-7.3 occurred in 1995 and caused significant damage in coastal communities in Egypt and Saudi Arabia. The last moderate earthquakes (Mw>5) occurred in 2015 and 2016. The development of NEOM in the proximity of the GoA fault system dramatically increases the vulnerability, and thus the seismic risk in the region.

Whilst recent multibeam bathymetric data reveal the details of a complex network of strike-slip and normal faults in the GoA, they do not provide information about the sub-surface geometry and depth extent of the mapped faults. However, the precise 3D fault geometry is critical to understand fault interaction and seismotectonics and hence feeds into seismic hazard assessments. To fill this gap, we here present the first high-resolution analysis of the GoA seismicity. For this purpose, we use three datasets: 1) A 12-year-long earthquake catalog from the Saudi Geological Survey, 2) a 3-year-long earthquake catalog (2019-2022) we built by using continuous seismic waveforms from our temporary broadband seismic network and the SGS network, and 3) focal mechanisms calculated for the best-located events.

We find that the northern GoA is currently less seismically active than its center part within the Aragonese deep (where the 1995 and 2015 events occurred) and the southern part of the gulf (where the 2016 event occurred). While in the north and center, earthquakes align with the main known strike-slip fault (Aragonese fault) and some minor normal faults, seismicity in the south does not fit with the previously mapped Arnona fault, but instead, it clusters obliquely to the main plate boundary. Most of the faults are steep and extend to depths of 30 km in the north and 25 km in the center. The seismogenic depth appears to abruptly decrease to 15-18 km south of the 2016 seismic sequence (located in the southern gulf).

Our preliminary findings are promising for a better understanding of the seismotectonics and deformation patterns for the southernmost part Dead Sea Transform and will constitute a fundamental piece of information for the seismic hazard estimations in the NEOM region.

A Physics-based PSHA study for the Gulf of Aqaba

Theodoros Aspiotis, Olaf Zielke, P. Martin Mai
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The mid-ocean ridge of the Red Sea is a seismically active zone, with moderate-size earthquakes at far off-shore distances from population centers. The seismically most active region in Saudi Arabia is the narrow Gulf of Aqaba (GoA) at the northern end of the Red Sea. The fault system identified in the Gulf of Aqaba forms the southern extension of the Dead Sea Fault Zone; these faults have produced large earthquakes of magnitude M>7 in the past (e.g., 1995 M7.3 Nuwaiba earthquake), and continue to be active as shown by the observed seismicity. However, the resulting earthquake hazard in the GoA has received limited attention in past decades because of the sparsity of data and the absence of large population centers and infrastructure.
With the giga-project NEOM, part of the Kingdom's Vision 2030, in northwestern Saudi Arabia, the earthquake activity in the Gulf of Aqaba receives increased scientific attention. However, a detailed regional comprehensive seismic hazard assessment (SHA) following modern standards is still missing.

Under this scope, we employ earthquake multi-cycle simulations to generate long-term physics-based earthquake catalogs. Our simulations incorporate the geometric complexities of the fault system and consider various sources of uncertainty. Through the analysis of numerous catalogues spanning tens-of-thousands of years, we identify the recurrence rates and possible complex patterns of multi-fault ruptures for large-magnitude earthquake events.
The results of our research yield a comprehensive set of multi-cycle earthquake catalogs that form the basis of a physics-based probabilistic seismic hazard assessment (PSHA) model for the GoA fault system. Our physics-based framework acknowledges and quantifies uncertainties due to the limited instrumental period. Using this model, we derive probabilities of exceedance of different intensity measures at specific locations of interest, providing valuable insights of the seismic hazard levels.
The findings of this study, aim to contribute to risk-mitigation strategies as well as to the long-term sustainability of the city.

Dynamic Earthquake Rupture and Ground Motion Simulations for the Gulf of Aqaba Fault System

Bo Li

The ~180 km long Gulf of Aqaba (GoA) fault system, southern part of the Dead Sea Transform Fault, is a left-lateral strike-slip plate boundary separating the Arabian plate from the Sinai micro-plate. With the potential to produce Mw 7.3 and larger earthquakes, the GoA fault system poses a high seismic hazard for the rapidly developing NEOM and nearby coastal communities. However, the offshore fault system and limited data availability make reliable seismic hazard assessment (SHA) challenging.

In this study, we conduct 3-D spontaneous dynamic rupture simulations of mechanically plausible earthquake scenarios in GoA and investigate the resulting local ground motions. Using recently-mapped bathymetry and seismic data, we construct various fault geometries to represent alternative possibilities of the GoA fault system. For validation purposes, we first simulate the 1995 Mw 7.3 Nuweiba rupture with observation-constrained regional prestress. Our results show that the fault system‚Äôs geometric complexity, hypocenter location, and prestress affect rupture propagation across the multi-segment GoA fault system and thus lead to varying slip distributions and magnitudes. An Mw 7.4 scenario occurs if entire main fault segments break, which results in up to ~ 1m seafloor displacements and may even trigger local tsunami in the coastal area. All simulations yield heterogeneous ground motion distributions, with strong shaking at fault geometric complexities and in the forward rupture direction. Notably, potential supershear rupture may further intensify ground shaking ~10-20 km away from the faults. In addition, local topography either amplifies or diminishes ground shakings. Such local ground motion characteristics captured in dynamic simulations are important to improve the site-specific hazard assessment. The ensemble of physics based and observationally informed earthquake scenarios and the resulting ground motions can complement empirical SHA methods in the data-scarce GoA region.

New Geological Concepts for Unlocking the Potential of Red Sea Hydrocarbon Exploration

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The Gulf of Suez-ancestral Red Sea rift basin was opened in the late Oligocene-Early Miocene time. Activity of the Dead Sea transform at 14 Ma aborted extension in the Gulf of Suez in contrast to the Red Sea which continued extension and seafloor spreading. Hydrocarbon exploration in the Gulf of Suez rift started with the discovery of Gemsa oil field in 1886 and was followed by discovery of many major oil/gas fields including Gharib, Bakr, Belayim Land and Marine, Morgan, Ras Budran, October, July, and Ramadan fields (among others). The total discovered hydrocarbons in the Gulf of Suez basin is about 13 billion barrels of oil. The Red Sea extends for over 2000 km and is shared by several countries. Hydrocarbon exploration in this large basin gained increasing attention in recent years but did not lead to potential discoveries relative to the Gulf of Suez basin. The challenge of subsurface imaging, the larger water depth, seafloor spreading, and volcanicity are among the main reasons that probably led to unsatisfactory hydrocarbon exploration results. New exploration concepts are also essential for Red Sea hydrocarbon exploration due to the different stages of geological evolution of both basins.

The small number of wells drilled for hydrocarbon exploration in the Egyptian part of the Red Sea has given negative results including the absence of the pre-rift sedimentary section that includes main reservoir and source rocks. New geological concepts are given in this study to help successful hydrocarbon exploration in this part of the Red Sea and may also be applicable in the other parts of the basin. By considering similarities in tectonic history, sedimentary fill, and basin architecture, oil and gas companies operating in different parts of the Red Sea can benefit from these concepts to enhance their exploration efforts.

Success carries many forms for meaningful reef restoration in the Red Sea

David Suggett

Coral reef restoration has now become a global movement, including the Red Sea, via motivation to improve reef health condition alongside new socio-economic opportunity. However, this movement is at a pivotal crossroads ‚Äì despite the increasing scale of activity, innovation, and economic opportunity ‚Äì reef restoration outcomes continue to convey practices as expensive, unscalable, and with low effectiveness. Such perceptions likely stem from uncertainty in how reef restoration is deemed successful, which in turn confounds resolving what is considered meaningful reef restoration ‚Äì how much, when and where. Here we propose a time-critical change in perspective in how reef restoration success is gauged to avoid misconceptions in the utility and feasibility as activity and investment continues to accelerate; specifically, we unpack four key factors central to our view, giving examples applied to the growing activity throughout the Red Sea: (i) Inherent benefits must be clear measurable goals ‚Äì projects often have inherent indirect outcomes, e.g. socio-economics benefits, that are not identified as goals and hence not recognized as success; (ii) Goals require robust metrics ‚Äì activity is not a replacement for effectiveness, and success (or failure) becomes attributed to indirect forecasts of project outcomes; (iii) The need to differentiate research and development (R&D) from practice ‚Äì many critiques of ineffective or unsuccessful restoration focus on what are restoration ecology experiments as opposed to real reef restoration outcomes; (iv) Cost-effectiveness should not be confused with cost-benefit ‚Äì where success does not always mean ‚Äúcheap‚Äù but rather reflects whether the benefits (e.g. retained or improved service value costs) outweigh the cost. Ensuring restoration programs rapidly consider such factors in how they operate and hence communicate their success is critical to ensuring more objective appraisals of when and where reef restoration is meaningful.

3D Printing Innovations Enhancing Coral Growth and Microbiome Development with High-Resolution Designs

Thomas Ressa

Coral reefs are one of the most abundant and biodiverse ecosystems on the planet - providing food security in the form of healthy proteins, coastal protection from the increasing frequency and strength of storms through wave energy dissipation, and a phenomenal opportunity for education through ecotourism. Unfortunately, coral reefs are in steep decline due to a myriad of compounding issues. Local stressors such as overfishing, high nutrient input from agricultural runoff, and pollution from coastal development contribute to decreased water quality. Global stressors like ocean acidification and thermal events due to increased carbon in our atmosphere reduce coral‚Äôs ability to create strong skeletal structures that form the foundation of coral reefs. Coral restoration methodologies and applications have continued to grow in complexity, but scaling these interventions is typically hindered by cost. To keep costs down, many of the materials being used are readily available but not ideal for the environment ‚Äì PVC, plastics such as zip ties and mesh, fiberglass, rebar, and fishing line to name a few. This presents a significant opportunity for eco-friendly, nature-based, and natural materials that mimic the innately available properties of the ecosystem. Innovations in 3D printing are producing higher resolution and more complex designs tailored to meet practitioners' needs, positively impacting coral growth, and inducing healthy microbiome development. Innovative solutions that improve the efficiency of restoration projects are essential to maintaining and enhancing coral reef ecosystems and the communities that rely on them.

Vertical transmission of coral probiotics and their effect on coral larvae heat-stress performance

Marco Casartelli, Erika P. Santoro, Megan Dear, Sebastian Schmidt-Roach, Carlos Duarte, Raquel Peixoto

Microbes living in association with corals are known to establish positive interaction with their host. In this sense, coral probiotics focus on identifying native beneficial microorganisms (BMCs) that could be cultivated and administered to corals, with the aim of increasing their ability to cope with environmental stressors. The experimental evidence of the effectiveness of the method in aquarium systems have now posed the challenge of upscaling this practice to in-situ applications. However, in order to move in this direction, two critical aspects that still require investigation are 1) the degree of vertical transferability of probiotics in sexual reproduction events, and 2) the effect of BMCs inoculation during the early stages of coral development. To address these questions, we collected gametes from 10-months BMC- and placebo-treated colonies of Acropora sp. during the mass spawning event of April 2023, in Al Fahal Reef, the central Saudi Arabian Red Sea. Coral fragments and their respective gametes were used to sequence the 16S rRNA gene and evaluate the vertical transmission of the administered probiotics. Additionally, larvae obtained from multiple cross-fertilizations were used in a 5-days heat-stress experiment, upon treatment with either probiotics or placebo, and their mortality rate was evaluated. The results of this study shed light on the vertical heritability of coral probiotics over generations and the effect of their inoculations on larvae fitness under increased water temperature, giving us further insight into the long-term applicability of such practice in a coral reef system.

Probiotics do accelerate coral growth and support coral reef restoration efforts

Barbara Ribeiro

Use of Beneficial Microorganisms for Corals (BMCs) can be an important ally of coral reef restoration, where targeted beneficial traits may include accelerated coral growth. However, how such BMCs applications can specifically enhance restoration activities in the Red Sea are untested. We therefore developed an experimental approach (1) to improve coral growth by using BMCs and heterotrophic feeding to support a large-scale coral reef restoration project at Shushah Island (Saudi Arabia); and (2) to evaluate and compare different ways to deliver the probiotics into coral nurseries, either by application in isolation or when combined with heterotrophic feeding (i.e., rotifer-encapsulated BMCs). A 12-month fully replicated experiment using an open aquaria system is underway assessing four conditions: Placebo, BMCs, Rotifers, and BMCs-rotifers . A total of 24 colonies of the coral species Acropora cf. hyacinthus, Stylophora pistillata and Porites cf. lutea were selected and fragmented into ~830 coral nubbins. Coral health and physiology were evaluated based on a multi-metric approach of coral color pigmentation, lipids, fatty acids, proteins and carbohydrates contents, chlorophyll fluorescence, zooxanthellae density, rapid light curve, and photosynthetic efficiency of the Symbiodiniaceae (FvFm). Coral effective growth was assessed by calcification, linear extension, weight, and photogrammetry. The microbiome will be evaluated to identify the potential acquisition of BMCs and microbiome restructuring. At T0, all baseline samples and data were collected, and where - for example - FvFm of the three coral species was consistent, with a mean of 0.608 (¬± 0.031) for A. cf. hyacinthus, and 0.607 (¬± 0.032) for both S. pistillata and P. cf. lutea, indicating competent coral nubbins (post-fragmentation) at the beginning of the experiment. Whilst data collection for this experiment remains on-going, we will present the preliminary insight and discuss how the findings will enable wider and directed application of BMCs for restoration and conservation of coral reefs.

Moving Towards Sustainability of Red Sea Coral Reef Saudi Fisheries: a case study from a traditional setting to certification

Mark Dimech

Red Sea is home to diverse coral reef fisheries, targeted by small-scale fishermen using vessels from 7-9 m. As part of the development of the Saudi Coast, a project was initiated to transition a traditional fishery (coastline of 468 Km), towards Marine Stewardship Council (MSC) certification. The use of market-based instruments is seen as a promising approach to supporting sustainable fisheries such as MSC. An intensive sampling program was launched that covers all the fishery dependent data collection; catch and effort, stock parameters, habitats, and socio-economics. The information was used to develop the high-level policy document that sets out the scope of the fishery with specific clear guidance on the strategic direction. A process was initiated to develop a Fisheries Management Plan (FMP) which seeks to ensure that fishery management decisions do not adversely affect the ecosystem structure, and that the harvest of target stocks (and related economic benefits) is sustainable in the long-term. The FMP was developed using EAF, which is risk-based management planning process, by taking into account the knowledge and uncertainties about biotic, abiotic and human components and their interactions and applying an integrated approach within ecologically meaningful boundaries. A stakeholder analysis was conducted, followed by several stakeholder workshops to run the issue identification, risk assessment, and development of the management system. Stakeholder involvement in the management process from the start was a must; in turn, this lead to an increase in its legitimacy and therefore compliance. Based on the data gathered, the Strategy, the FMP and implementation, the process started to obtain the certification, under the MSC,Äôs Risk-Based Framework (RBF) to assess data-limited fisheries against different performance indicators across the MSC Fisheries Standard. The ultimate goal is to achieve sustainable fisheries in the medium-long term by using EAF and the MSC standard as an operational target.

NEOM Sustainable Fisheries Programme: Towards Fisheries Management within a Nature Reserve covering 95% of NEOM

Presenters:

- Winston Cowie, NEOM, Senior Manager – Marine Policy and Fisheries
- KAUST Fisheries Team

NEOM Nature Reserve covers 95% of the marine area of NEOM. Within this unique context NEOM is implementing a sustainable fisheries programme with a vision of ‘Global leadership in fisheries science, management and rewilding as a core component of the Nature Reserve value proposition.’ The 20 project programme has commenced in collaboration with KAUST and spans the next three years. In the upcoming period we will gather critical inputs to gain an understanding on the state of the fishery; its socioeconomics; commercial and recreational fishing pressure; and traditional ecological knowledge; all of which will inform the development of the NEOM Fisheries Policy, Plan, and Regulation.

Socio-economic aspects of small-scale fisheries and contribution to the management process in the Northern Red Sea, KSA

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The social and economic aspects of fisheries are among the components the management process. This study presents the socio-economic characteristics of small-scale fishing in the NEOM region, the Northern Red Sea, KSA. We obtained the list of fishing from the Ministry of Environment, Water and Agriculture office in Duba determined number of fishermen actively engaged in fishing during 2022. A semi-structured questionnaire was prepared to understand the social and economic aspects of fisheries for 2022. The themes addressed by the questionnaire encompass characteristics of sociodemographic, household, fishing boat and gears, effort, marketing, and economic aspects. Actively working fishermen were targeted to interview. Interviews were done face-to-face with a response rate of 72% in 2023. Results indicate that fishing has a considerable past and cultural root in this region and plays an essential role in the livelihood of coastal communities, mainly fishing families. 70% of the fishermen came from a fishing family and 91% of fishermen were born in the region where they were fishing for generations. While 84% of fishermen defined fishing as their main income source of livelihood, 61%, fishing was the only source of income. More importantly, fishing was the main source of income for the households of 70% of the respondents. The fact that 76% of the fishermen consume fish at least 3 days a week or more in their households was an indication that fishing is important also for nutrition besides income. It was determined that 34% of the responses received financial support from the government. This rate rises to 43% among households. The results may make a significant contribution to decision-makers for a comprehensive understanding of the socioeconomic context of the small-scale fishing community and contribute to the preparation of the fisheries management plan for sustainable fisheries in the northern Red Sea.

Prevention and response to marine pollution from sea-based sources in the Red Sea and Gulf of Aden− Challenges and Achievements in the PERSGA region

Mahmoud Ahmed Mohamed

The Red Sea and Gulf of Aden holds strategic and economic significance. Since marine pollution from various sea-based sources, including ship generated wastes, invasive aquatic species (IAS) introduced via ships,Äô ballast, biofouling, accidental and illicit dumping of wastes by transiting ships poses a serious threat to the marine and coastal environment in the region, due to its trans-boundary nature, and marine pollution prevention necessitates regional cooperation and a coordinated response.

To address these multiple challenges, the Regional Organization for the conservation of the Red Sea and Gulf of Aden (PERSGA) devised a Regional Program for Reduction of Navigation Risk and Marine Pollution which provides operational base for effective implementation of the Jeddah Convention (1982) and associated protocols, particularly the Protocol Concerning Regional Cooperation in Combating Pollution by Oil and Other Harmful Substances in Cases of Emergency. This program undertakes regular capacity building and regional coordination activities to capacitate Contracting Parties to the Jeddah Convention which are Djibouti, Egypt, Jordan, Saudi Arabia, Somalia, Sudan, and Yemen, to prevent and combat marine pollution in the region.

In addition, the Red Sea and Gulf of Aden areas were recognized as the IMO special areas under Annex I and Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL). Since all PERSGA States are parties to the MARPOL Convention, they have been taking concrete measures to ensure that their ports have adequate reception facilities to meet the requirements of MARPOL.

This presentation provides an overview of the challenges and achievements in the PERSGA region in the field of marine pollution prevention and reduction as well as highlighting some of the key breakthrough outcomes that includes the designation of the Red Sea as Special area for the protection of the environment in the region, the development of oil spill modeling tools.

Electronic and electrical waste management in PERSGA region

Bashar Albataineh

e-waste can be a source of highly toxic substances, such as heavy metals, and POPs, such as polychlorinated biphenyls (PCBs), brominated flame retardants (BFRs), Dioxins and Furans. poses a considerable risk to the human health and environment.

Over the last decade, the world witnessed rapid growth in e-waste due to the improvement in technologies, increased demand for electronics, and shorter product life spans. This trend has made e-waste one of the fastest-growing waste streams globally. the lack of awareness and appropriate skills has led to further increase in the amount of e-waste, deepening the issue, and made it crucial to take vigorous steps to prevent and properly manage e-waste in order to minimize its negative impact on the environment and human health.

The present paper focuses on the efforts undertaken by the regional organization for the conservation of the environment of the Red Sea and Gulf of Aden (PERSGA) to tackle this issue, raising awareness about the risks of e-waste to human health and the environment and promoting sound management of e-waste in RSGA region, building capacities in dealing with e-waste and handling them in an environmentally sound manner, and encouraging sharing of experience among member states, building on the outcomes of the on-ground project implemented in collaboration between PERSGA and Aqaba Special Economic Zone Authority for the management of e-waste in the Jordanian coast of the Gulf of Aqaba, as the first initiative of its kind in the coastal cities of the region.

PERSGA Marine Litter Programme

Zaher Al Agwan

The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA) has developed and conducted many activities in relation to the marine litter management. The main aim of such activities is to protect the marine environment and organisms from effects of litter and plastics in the Red Sea and Gulf of Aden region. supporting PERSGA Member Countries (MCs) (Djibouti, Egypt, Jordan, Saudi Arabia, Somalia, Sudan and Yemen) for this purpose at national levels as well. These activities include training workshops, beach clean-up campaigns, awareness,Äìraising programs, coastal marine litter assessment along the Red Sea and Gulf of Aden. Such workshops and programs are implemented at the regional level and national levels to raise level of awareness and train national specialists on methods used for this assessment. Many different locations along the mainland coastline of the PERSGA region, including towns, villages, boat anchoring sites and remote areas, were surveys for assessment of litter and plastics. Clean,Äîup campaigns were also undertaken during this assessment for a regional marine litter monitoring purpose. Different stakeholders and communities, including school students and fishers, were involved in such campaigns and in the workshops/programs. Other activities include development of a Regional Action Plan (RAP) for marine litter management in the region. National Action Plans (NAPs) for marine litter management have also been developed for MCs within the framework of this RAP. PERSGA continues implementing the activities to mitigate impacts of litter and plastics on the marine environment in the region and to support MCs to tackle problems of these pollutants.

Tracing 13 million years of ocean spreading and recent volcanic activity under the salt and sediment in the Red Sea

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The Red Sea is a comparably young ocean basin filled with Miocene salt and younger sediments. Spreading rates increase from North to South from <10mm/yr to 16mm/yr and accordingly, the Red Sea Rift is an ultra-slow spreading rift. Its spreading center is, however, not entirely exposed along the basin but buried in large proportions by glacier-like salt flows and overlying sediments. In the central and southern Red Sea, axial volcanism can be directly observed in the exposed areas. These windows to the underlying oceanic crust through the salt and sediment blankets become sparse towards the northern Red Sea, where the oceanic crust is almost entirely hidden. Therefore, direct observation of the oceanic crust, the mid-ocean ridge, and the neovolcanic zone in the blanketed areas is impossible, leading to large uncertainties regarding the crustal structure under the salt. We will present our compilation of earthquake and vertical gravity gradient data and bathymetric mapping, showing the hidden off-axis traces of oceanic crust accretion for at least 13 million years along the Red Sea basin. Furthermore, we present our latest data and seafloor observations (e.g., sparker seismics, AUV bathymetry, and ROV footage) from the blanketed areas along the neo-volcanic zone, revealing abundant (mid-ocean-ridge-related) volcanic activity in the sediment covered areas. Our data provide valuable insights into the various traces of volcanic activity throughout the sediment-covered areas, including in the highly debated northern Red Sea.

Neo-formed oceanic crust and salt basin splitting in the Red Sea and the South Atlantic

Webster Ueipass Mohriak

Limited drilling and a lack of deep seismic reflection profiles in the Egyptian and Saudi Arabian conjugate margins have resulted in several unconstrained hypotheses for the Red Sea development, such as the presence of rifted continental crust, an exhumed mantle, or oceanic crust under the thickly layered evaporite sequences in the axial trough. The South Atlantic hosts extremely prolific hydrocarbon provinces in the deep-water region. The interpretation of the transition from continental to oceanic crust has been a matter of intense debate due to the discovery of microbialite reservoir rocks below the layered evaporite sequences in the distal margins, resulting in the discovery of the largest oil fields worldwide in the 21st century. The major tectonic domains in the southern South Atlantic correspond to the salt basin in southern Brazil, which is separated from the southernmost segment, offshore southern Brazil, Uruguay, and Argentina, by the Florian√≥polis Fracture Zone,ÄìWalvis Ridge. In the Red Sea, the most important transform fault zone is the Zabargad Fracture Zone, extending from offshore Egypt to northwest Saudi Arabia. Both transform fault zones exhibit some characteristics of an early phase of oceanization north of the transform fault. The embryonic oceanic rifts in the Red Sea and the South Atlantic show evidence of salt flow from the continental shelf to the axial trough. The comparison of the Abimael Ridge in the southern Santos Basin with the Mabahiss Deep in the northern Red Sea indicates that oceanic propagation is hindered by major fracture zones. The spreading ridge offset is associated with a delay in the oceanization process that has split the salt basins, developing a swath of neo-formed volcanic crust. The volcanic basement is characterized by the absence of autochthonous salt deposits on the floor of an abyss surrounded by allochthonous salt fronts.

Fluctuation of the magmatic activity recorded in the seafloor morphology at Hadarba Deep, Red Sea

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The Red Sea Rift is an ultra-slow spreading ridge of great interest due to its young character, representative of the start of oceanic crust-forming processes, but so far has been vastly understudied. Recent surveys (Spring 2022) in the central Red Sea using an autonomous underwater vehicle acquired multibeam bathymetry, backscatter, sub-bottom profile, and water column data over a 9 km long ridge segment in the Hadarba Deep. The high-resolution hydroacoustic data combined with the geochemistry of few glass samples was used to investigate the fluctuation of the magmatic activity over the last 15 ka. The segment displays an overall low tectonic extension (<10% of the total extension) and low vertical offset that imply a relatively high magmatic activity for an ultra-slow spreading segment, at least during its recent history. This is in adequation with the volcanic activity. About 90 eruptive units with varying stages of sedimentation have been delineated within the 43 km^2 mapped region. Within the axial valley, the oldest lava flows are buried under 2.1 m of sediment, indicating ages of up to ~15 ka based on the average sedimentation rate estimates (~14 cm/ka), while the youngest eruptions are covered by <10 cm of sediment, and are thus younger than 700 years. Three volcanic phases have been identified based on changes in flow morphology and distribution, and tectonic pattern. All three axial phases have an average eruptive frequency of ~100-250 years. All these observations provide valuable implications for the formation history of the Red Sea Rift and the formation of ultra-slow spreading crust.

Sulfides chimneys from Kebrit Deep, Red Sea , an insights into hydrothermal circulation of a young, sedimented ocean basin

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Understanding hydrothermal circulation in the Red Sea provides insights into crustal cooling processes, ore deposit, and chemosynthetic habitat formation in a young oceanic basin. Furthermore, the Red Sea allows the study of hydrothermal circulation in an ocean basin with large evaporite sequences, similar to e.g., the South Atlantic or Gulf of Mexico. However, hydrothermal activity in the Red Sea is yet mostly inferred by and associated with high-temperature brine pools and the occurrence of metalliferous sediments. An exception is inactive sulfide chimneys at Kebrit Deep (northern Red Sea), as the only trace of high-temperature hydrothermal mineralization outside the (hot) brine pools.
Only a few studies are available on sulfides from this location. Kebrit Deep sulfides show significant Fe, Zn, and Pb enrichment due to their emplacement in a sediment-hosted environment. Pb-isotopes show a certain degree of periodicity in hydrothermal activity. However, the limited geochemical data lack a detailed geological context. The nature of the crust below Kebrit Deep and the physicochemical properties of the fluids still needs to be better constrained.
We will present our results from the first systematic ROV mapping and sampling of inactive chimneys from the Kebrit Deep. The sulfide petrography and geochemistry shed light on the elemental budget of ore-forming minerals and the debated nature of the crust below Kebrit Deep. Together with ROV video and AUV bathymetry, we can connect our geochemical findings of the Kebrit sulfides to the local geological context.

Red Sea hydrothermal vent fields: discovery of low-temperature venting and microbial Fe-deposit formation

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Hydrothermal circulation of seawater through the crust occurs along all mid-ocean ridges and forms habitats for chemosynthetic life at hydrothermal vents. Studies of active vents worldwide have increased our understanding of marine biodiversity and early life under extreme conditions. The evolution and colonization of hydrothermal vents are, however, still poorly understood. Particularly interesting in that respect are young, semi-enclosed oceans like the Red Sea. However, active hydrothermal vents have never been observed in one of Earth's youngest ocean basins, despite ample evidence for hydrothermal activity based on rock chemistry, extinct chimney fields, metalliferous sediments, and few high-temperature brine pools that are difficult to access.
Here, we present data on the first active hydrothermal vent fields and associated microbial communities discovered in the Red Sea Rift. High-resolution AUV hydroacoustic data and ROV observations revealed one of the largest active low-temperature hydrothermal areas worldwide, consisting of 43 fields. The vent fields consist of numerous Fe-Mn-oxyhydroxide mounds venting shimmering fluids with temperatures of at least 40¬∞C. Thriving microbial communities dominate the mound fields instead of specialized macrofauna. The composition and microtextures of Fe-Mn crusts emphasize the importance of the microbes in forming these mounds. The Red Sea's high saline and warm bottom water conditions, together with the lack of specialized vent-fauna, create a unique environment for the microbes, potentially analog to conditions during the early history of Earth, which opens new frontiers in understanding Earth‚Äôs early life and the role of microbes in large Precambrian Fe-deposit formation.

Microbial diversity and metabolism in Red Sea hydrothermal vent fields and their potential impact on the mitigation of the greenhouse gas nitrous oxide

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The microbial diversity and metabolism of the prokaryotes inhabiting hydrothermal fields in the Red Sea and their ecosystem-level functions remain unknown. Specifically, the capability of microbes to produce and consume greenhouse gasses such as N2O has yet to be investigated. The ocean is a primary source of N2O, which can drive global warming. To shed light on this, we sequenced 26 metagenomes from seven cores and three microbial mats from hydrothermal fields in the Red Sea. We used shotgun metagenomics to retrieve metagenome-assembled genomes (MAGs) and the METABOLIC pipeline to quantitatively characterize the functional abundance at a community level. We recovered a total of 765 MAGs. Of these, 553 MAGs were assigned to Bacteria, while 109 MAGs were assigned to Archaea. The bacterial MAGs spanned 32 phyla, including Proteobacteria and Chloroflexota, and 52 bacterial classes. The archaeal MAGs represented nine phyla, including Thermoproteota and Hydrothermarchaeota, along with 11 archaeal classes. Notably, 196 unique MAGs were of medium (‚â• 50% complete, ‚â§ 10% contaminated) to high (> 90% complete, < 5% contaminated) quality. The most abundant metabolic functions included amino acid utilization, fermentation, fatty acid degradation, and formate oxidation. Regarding sulfur metabolism, thiosulfate disproportionation, sulfur and sulfite oxidation, and sulfate reduction were the most abundant processes. Iron oxidation and arsenate and iron reduction functions were highly represented. Although ammonia oxidation showed lower abundance, the reduction of nitric oxide to nitrous oxide was identified as the predominant nitrogen function. Interestingly, N2O reduction to nitrogen was mainly limited to classes of Gemmatimonadetes and Anaerolineae (abundant in microbial mat). Our findings suggest that microbial mats in hydrothermal vents may act as N2O sinks in hydrothermal environments. Furthermore, our metabolic analysis showed that the microbial classes lacked complete pathways for nitrogen and sulfur metabolisms, suggesting a dependence of the microbes on each other for these metabolic processes.

Unveiling Antibiotic Resistance Genes in Red Sea Brine Pools

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Antibiotic resistance (AR) has emerged as a major global health concern, resulting in a significant threat and recently reported to have caused 1.27 million deaths worldwide. While AR has been observed in various pristine environments, our study focused on identifying AR in the extreme and pristine Red Sea Brine Pools. Using an environmental metagenomics approach, we identified antimicrobial resistance genes (ARGs) associated with multiple drug classes, with tetracycline and macrolide resistance being particularly prevalent in the pools. We showed that the abundance of ARGs correlated with the level of human impact on the environment. Pristine Red Sea samples exhibited the lowest average ARG levels, followed by estuary samples, while activated sludge samples showed the highest levels of ARGs. Hierarchical clustering analysis revealed that drug classes associated with resistance in the Atlantis II Deep brine pool formed a distinct group separate from other samples. Additionally, the Discovery Deep brine pool exhibited significantly lower ARG abundance. We observed a correlation between integrons and ARG abundance in the Red Sea brine samples, whereas insertion sequences and plasmids showed a correlation with ARG abundance in human-impacted samples but not in pristine brine samples. These findings suggest that different types of mobile genetic elements (MGEs) play varying roles in the distribution of ARGs in pristine versus human-impacted environments. Furthermore, our study uncovered the presence of mobile antibiotic-resistance genes in the Atlantis II brine pool. We observed the coexistence of integrases and plasmid replication proteins on the same contigs containing predicted multidrug-resistant efflux pump genes, providing evidence for potential horizontal gene transfer (HGT) mechanisms facilitating ARG acquisition. Overall, this study highlights the significance of non-pathogenic environmental bacteria as silent reservoirs for ARGs and sheds light on the mechanisms of HGT involved in the transfer of antibiotic resistance genes.

Tracking hydrodynamic connectivity between coastal habitats with UAVs and dye tracers

Aislinn Dunne

Coral reefs often exist in nutrient-poor coastal waters but can receive nutrition from external sources. Water flow can facilitate connectivity and transport of such nutrients between coastal habitats, and tracking water movement around reefs can inform our understanding of the flux of materials reaching coral habitats. However, shallow coastal water movement can be difficult to track or predict due to complex tidal and shallow water dynamics. In this study, we demonstrate an unmanned aerial vehicle (UAV)-based approach for monitoring water flows through shallow coastal habitats. We used UAVs to record dye tracing experiments carried out on several days during ebb tides, and used the imagery to track water movement between mangroves, seagrasses, and coral reefs in the central Red Sea. We found a good correlation between dye concentration of in situ water samples and the interaction term of two UAV‚Äëderived indices, showing that UAV imagery can be used to map dye concentrations and characterize water velocity and dispersion during dye tracer studies. We used UAV imagery to estimate rates of material transfer between habitats, showing the spatial scale at which vegetated habitats influence the water quality of downstream ecosystem. Here we provide an application of UAV technology for marine connectivity studies, which can be used to describe fine-scale movements of water between tropical coastal habitats as well as the potential for current-driven organic carbon exchange across ecosystems.

Title: Detection of thermal and color fronts using remote sensing data and its preliminary results in the Red Sea

Radharani Sen

Relatively few studies have explored the spatio-temporal variability of oceanic frontal systems in the Red Sea (RS). Using a gradient-based frontal detection method (the Canny algorithm) and high-resolution daily aqua Moderate Resolution Imaging Spectroradiometer (MODIS) observations of sea surface temperature (SST) and chlorophyll (Chl-a) spanning 19 years (2003‚Äì2021), this study examines the climatology of thermal and ocean color frontal location and seasonal change in the region. The RS was divided into two regions: the northern Red Sea (NRS), defined as the area north of 23¬∞N latitude, and the central and southern Red Sea (CSRS), south of this boundary. The analysis reveals that the NRS thermal front was less frequent throughout the year due to consistent surface cooling. However, SST and Chl-a fronts in the NRS were most strongly correlated between February and April. During the summer, SST fronts were observed in the NRS, but there were no significant color fronts. In the CSRS, Chl-a showed a robust increase in the winter despite warm surface water and high SSH, owing to the inflow of Gulf of Aden surface water into the southern RS during the Northeast Monsoon and the vertical mixing of the highest chlorophyll-concentrated water column in the central RS's productive zone. While the number of Chl-a fronts in the CSRS was low in the summer, the number of color fronts remained significant. These fronts appear to be associated with eddy dynamics. The findings contribute to a better understanding of the Red Sea's complex dynamics, which impact global ocean circulation and influence biogeochemical cycles.

Does eddy-driven subduction matter for carbon export in tropical seas?

Malika Kheireddine

We investigated the export of the organic carbon driven by mesoscale features (i.e., fronts and eddies) in the Red Sea waters, one of the warmest sea of the global ocean, to evaluate the contribution of the eddy subduction pump in such ecosystem. We mainly focused on eddies and fronts, identified from satellite, cruise data and Seaglider survey. The physical and biogeochemical structure of the front was characterized using a bio-optical profiler equipped with a CTD and bio-optical sensors revealing a subducted filament with biological tracers reaching up to 330 m depth. In parallel, water sampling within and outside of the subducted filament were taken. Measurements from these water samples include the biogeochemical composition of the subducted water, allowing us to better understand and characterize the export potential of the subducted filament. Intrusion of particulate organic carbon was ranging from 12 to 50 mg C m-3, and was approximately found within the isopycnal layer 28 ‚Äì 28.35 kg m-3. The concomitant high values in chlorophyll a suggest subduction of viable phytoplankton within this isopycnal layer. Based on HPLC measurements, we observed the presence of pico-phytoplankton within the subducted area, which confirm that a parcel of surface water has been subducted below the base of the productive zone. AOU values associated to the subduction of POC suggest high rates of particles remineralization by bacteria reflective of the presence of fresh and labile carbon material. Characterizing the properties of the subducted filament in such ecosystem (i.e., low oxygen and high temperature) will contribute to our understanding of such event in the context of climate change.

Observations and biogeochemical modeling reveal chlorophyll diel cycle with near-sunset maxima in the Red Sea

Yixin Wang

Connectivity, the exchange of individuals and genes among geographically separated marine populations, plays a key role in coral reef biodiversity and resilience. The Red Sea is a semi-enclosed basin with dynamic circulation and abundant coral reefs, making it a natural laboratory for coral reef connectivity research. Previous studies broadly investigated Red Sea connectivity, but were spatially restricted to regional or sparsely-distributed reef sites. Here, using hydrodynamic and particle tracking models, a high-resolution circulation- driven physical connectivity atlas covering every Red Sea coral reef, including seasonality, was simulated and further validated against available in-situ genetic datasets. The simulation was conducted without incorporating larval traits to isolate and quantify the connectivity contributed by circulation. Our validation experiment suggests the importance of circulation in shaping the genetic structure of Red Sea reef species, supporting the Isolation By Circulation (IBC) theory in the Red Sea seascape genetics. The simulated atlas reveals that reefs in the northern Red Sea are better sources and destinations than those in the southern basin, regardless of season. The east-west connections between the southern reefs are identified to be weak. Complex circulation dynamics drive a regional-specific seasonality, e.g., the Farasan Islands reefs are better sources during summer while the nearby Bab-Al-Mandeb strait reefs are better sources during winter. The west-coast reefs are generally winter-intensified sources whereas the east-coast reefs are generally summer-intensified sources. The revealed seasonality of physical connectivity is important for larval dispersal processes as reef species may spawn in different seasons. This physical connectivity atlas provides a reference for designing marine conservation strategies from a circulation perspective and easy-to-access physical connectivity datasets for the future Red Sea seascape genetic studies.

Surya Prakash Tiwari

The spatial and temporal variations of Chloropyll-a (Chl-a) in clear and coastal waters are critical for understanding the health of marine environment. To estimate Chl-a from oceanic and coastal waters, several empirical and semi-empirical models based on reflectance are available. However, machine learning models have been used to simulate multiple environmental parameters over the past few decades, and their applications to water quality parameters have recently gained traction. This study proposes a novel approach to modeling Chl-a by using Fuzzy C-Means clustering based Neural Network (NN) which is optimized through Bayesian Optimization (BO) based on the band configuration of the Moderate Resolution Spectroradiometer Aqua with a wide range of variations . The training data were initially grouped into three clusters based on remote sensing reflectance values, and separate NN models were created for each cluster. Subsequently the hyperparameters of the NN models were optimized. The dataset includes (i) global in-situ measurements of NASA Bio-Optical Marine Algorithm Dataset, (ii) validation data of SeaWifs satellite matchups, and (iii) simulated dataset for the Red Sea. It exhibited significant variations in Chl-a levels under both oligotrophic and eutrophic conditions. Accuracy assessment of the present study is performed by comparing the modeled and observed values of the Chl-a in the Red Sea. The performance matrices computed of the developed model were promising. Therefore, this study provides a potential approach for the retrieval of Chl-a in the Red Sea oligotrophic waters, where the performance of existing algorithms is deteriorating to estimate precise values of Chl-a. The findings of this research have the ability to advance our understanding of biogeochemical cycles and processes in marine and open ocean waters.

Heterotrophic bacterial production and contribution to the trophic carbon flow in oligotrophic waters

Afrah Alothman

In oligotrophic ecosystems, heterotrophic bacterial production role through the microbial loop and grazing processes may represent the most important path of carbon transport into higher trophic levels. However, there are few studies on quantifying the carbon transfer from bacteria to the food web in the ocean. Here we used 13C-isotope tracers and Cavity-Ring Down Spectroscopy (CRDS), to measure bacterial production (BP), bacterial respiration (BR), primary production (PP) and carbon transfer from bacteria via the microbial loop into higher trophic level (CTB). Our results showed that BP rate (0.07 ¬± 0.02 ¬µg C L-1 d-1) was significantly lower than PP (6.50 ¬± 1.17 ¬µg C L-1 d-1). However, removing grazers by pre-filtration increased the BP rate more than ten times (3.52 ¬± 1.41 ¬µg C L-1 d-1). We found that large proportion of the carbon assimilated by bacteria is used for respiration (1.37 ¬± 0.54 ¬µg C L-1 d-1), and this high respiratory demand of bacteria cells in such oligotrophic waters could explain the low growth efficiency (0.05 ¬± 0.01 %), observed in our study. Notably, the CTB to the microbial food web, as measured in the fraction above picoplankton (> 1.2/3 ¬µm), exceeded daily BP by an average of 73.31 ¬± 0.05%. This transfer was found to significantly increase with increasing temperatures, highlighting the enhanced role of CTB when warming increase. ¬±The carbon transfer efficiency (CTE) from the bacterial and phytoplankton pathways into higher trophic levels showed that bacteria (51 ¬± 14%) can transfer the carbon in a similar magnitude of efficiency to phytoplankton (46 ¬± 10 %) in oligotrophic waters such as the Red Sea.

Trends in commercially important fish resources in Sudan's coral reefs: results from BRUV monitoring from 2015-2022

Portia Joy Nillos-Kleiven

The western coast of the Red Sea has an extensive and thriving coral reef ecosystem, but data from this area is relatively scarce, more so with data that has been replicated over a period of time. In this paper, we report on the state of the coral reef in Sudan from 2015-2022 looking specifically at the fish and coral community.

We take a closer look at the fishery-independent pattern of abundance for heavily fished carnivores, as well as the live hard coral cover for the same reefs in the same time period. The data that we present is based on stereo measurements and analysis of video recordings from baited remote underwater video rigs (BRUVs) that were deployed in 34 stations located in shallow (3-20 m) coral reef areas along the entire coastline of the country from 2015, 2016, 2017 and 2022. Data obtained from these recordings were used to determine species composition, diversity, and abundance for fish, and substrate composition for corals.

A specific question we want to answer is whether the abundance of commercially important species in different fishery management areas are correlated with the location of the reef (near shore, off shore), and how the abundance of these heavily fished species have changed over time. For the coral data, we are looking as to whether the reefs that were reported as bleached in 2015-2016 have shown some recovery after 6 years.

To conclude, we hope that these results will be used to inform and provide good advice on the development of a national policy and strategy on ecosystems-based fisheries management that will include marine protected areas as a key component. Such national policy is important to ensure that the reefs of Sudan will be sustainably managed while aiding in the rebuilding process that the country will have to go through soon.

Unexpectedly dynamic coral-dwelling gall crab communities on central Red Sea reefs

Susanne Bahr

Most coral reef biodiversity comprises cryptic invertebrate taxa, many of which exhibit close relationships with scleractinian corals. Symbiotic decapods represent a particularly abundant group of coral associates, yet fundamental aspects of their ecology, such as occurrence and distribution, remain undisclosed. These knowledge gaps are particularly evident in coral-dwelling gall crabs (Cryptochiridae), obligate symbionts of scleractinians that induce skeletal modifications in their hosts in which they permanently reside. To study their prevalence, distribution and community dynamics in the Red Sea, we established permanent transects (n=12) on four Thuwal reefs at depths between 5 and 9 m. All potential gall crab host colonies within belt transects (0.5 m x 20 m) were surveyed, measured, photographed and examined for dwellings. Cryptochirid communities were recorded during a baseline (T0) and a follow-up survey (T1) eight months apart. A total of 942 colonies were surveyed, 262 of which were matched between T0 and T1. We observed 35 host genera, and the overall cryptochirid prevalence rate across all available hosts was 28.5%. Gall crab occurrence was significantly correlated with host genus, site and sampling time. Furthermore, we observed unexpectedly high turnover rates (frequency of colonization and extinction events) in the resurveyed colonies. The host genera Echinopora, Platygyra and Pavona showed particularly high fluctuations in their associated cryptochirid community, especially considering the short period between sampling efforts. Lastly, cryptochirid abundance decreased from T0 to T1, likely due to high coral mortality on one of the reefs. Our findings revealed previously unknown relatively rapid temporal dynamics in cryptochirid communities and increased extinction rates caused by the loss of host colonies. As obligate coral associates, gall crabs are particularly vulnerable to habitat degradation. Investigating their occurrence, distribution, and drivers of community dynamics is thus crucial to understanding the detrimental effects environmental change may have on reef-associated communities.

The Mediterranean and Red Seas as cryptic hotspots: the striking cases of the Perinereis cultrifera and P. nuntia (Annelida, Nereididae) species complexes

Marcos Teixeira

Molecular data have been unraveling the existence of a cryptic species complex within the Perinereis cultrifera taxon, which has not been fully explored yet. In this study, morphological and DNA analyses (COI, 16S rRNA and 28S rRNA) of Perinereis specimens from several different locations, including marine intertidal and brackish European localities and the northern region of the Saudi Arabian Red Sea (NEOM area) were performed. The phylogeny revealed at least 18 divergent and completely sorted lineages, 12 of which occurred solely in the Mediterranean Sea, and 6 of those unique to Italian brackish waters. One lineage is also apparently unique to the northern Red Sea and was only present in the rocky beaches of the Gulf of Aqaba. In the remaining sampling sites along the northern Saudi coast the P. cultrifera species group was replaced by Perinereis cf. nuntia, which seems to be the dominant coastal annelid in the region. The latter is also a known species complex with several recently described species for the neighboring Egyptian coast. Our P. cf. nuntia samples revealed at least two different morphotypes, one from the lagoons in Duba and Aqaba, and another from the marine sites of Shusha Island. These may be undescribed species and further molecular analysis is being conducted to confirm it. Unlike in Europe, the Red Sea annelid barcode reference library is still very incipient, with almost no matches at the taxonomic species level, undermining large-scale biomonitoring projects using metabarcoding. Currently, within and project funded by NEOM, we aim to contribute to the discovery of unknown cryptic annelid lineages and a better knowledge of the Red Sea biodiversity in general. Unveiling and formally describing cryptic complexes will further enhance our ability to use molecular-based tools in biomonitoring and assessment of distribution patterns in space and time.

The unknown diversity of the family Agariciidae from the Saudi Arabian Red Sea: a phylogenomic approach

Silvia Vimercati

The stony coral family Agariciidae currently comprises 49 accepted nominal species occurring across the tropical belt, many of which are ecologically important reef ecosystem components in shallow to deep waters. However, little information is available regarding the actual species diversity of this morphologically diverse and species-rich family. The Red Sea is a young semi-enclosed body of water that has long been recognized as a marine biodiversity hotspot for scleractinian corals. There, 4 Agariciidae genera, Dactylotrochus, Gardineroseris, Leptoseris, and Pavona have been recorded from 1 to 166 m depth. Previous molecular phylogenetic analyses from the basin based on traditional markers have revealed 19 shallow-water agariciid nominal species of which some were polyphyletic, highlighting that mitochondrial genes and nuclear rRNA are not informative enough to resolve the family evolutionary history. Here, we used target-capture of ultraconserved elements (UCEs) and exon loci to reconstruct the phylogenomic relationships among more than¬†140 Red Sea agariciid specimens collected between 1 and 500 m depth and representing all the four currently recognized genera in the region. The overall morphology of the examined material was used to identify the specimens based on traditional taxonomic descriptions and type materials. We recovered 10 highly supported species level molecular clades and revealed that species-level relationships for most of the Red Sea Agariciidae are incongruent with traditional morphological and single-locus genetic groupings. Our results revealed a highly diversified Agariciidae fauna in the Red Sea, with several new species-level lineages, some of which likely endemic, and some occurring both in the shallow-water and mesophotic reefs. Our results show for the first time that a genomic approach is highly informative to resolve the Agariciidae family evolutionary history, and highlight the need for a more in-depth investigation of the family diversity outside of the Red Sea.

A multi-species genomic assessment of coral population connectivity around the Arabian Peninsula

Nicolas Oury

Knowledge of seascape and population connectivity ideally provides the basis for the definition of effective management and conservation units. This is particularly relevant for scleractinian corals, key components of coral reefs, which are experiencing critical declines due to both global and local factors. Yet, their connectivity remains insufficiently documented, especially around the Arabian Peninsula, surrounded by different water masses, each with unique oceanographic conditions providing potential barriers or corridors for marine organisms. Here, in order to better understand the role of these conditions in shaping the diversity, distribution and connectivity of scleractinian corals, we assessed for the first time ever the population genomic connectivity of different non-model coral species with different life history traits and distribution around the Arabian Peninsula. We used target-enrichment of ultraconserved elements (UCEs) and exon loci from hundreds of colonies collected from the Gulf of Aqaba to the Arabian Gulf, including the Saudi Red Sea coast, to collect single-nucleotide polymorphisms (SNPs) for each species separately. From the ca. 1,200 SNPs retained per species, Bayesian clustering methods and demographic inferences were applied to first infer the population genetic structure of each species, then the demographic history of each population. We revealed distinct genetic structuring patterns among species, probably related to different reproductive timings coupled with the strong seasonality of currents in this region. All species, however, exhibit a mutual isolation of the populations from the Red Sea, supporting the uniqueness of its coral communities, although occasional gene flow with the Gulfs of Tadjoura and, to a lesser extent, of Aden seems to occur. In addition to providing valuable guidelines for the efficient conservation of the species studied, these results give new insights into the role that abiotic parameters play in the progressive isolation and then speciation of Red Sea populations.

The Cryptobiome Relativity: Investigating the Relationships Between Habitat Heterogeneity and the Diversity of Cryptobenthic Assemblages Over Time and Space

Joao Duarte-Rosado

Reefs have an extraordinary tridimensional complexity and coupled with biophysicochemical factors that characterize it, they harbor a diverse heterogeneity in habitat types composing its landscape, being considered the rainforests of the sea. However, a comprehensive assessment of one of the major components of its biodiversity, the cryptobenthos, remains limited due to intrinsic challenges associated with their small-size and their common nocturnal behavior. To overcome this, Autonomous Reef Monitoring Structures (ARMS) were developed. We deployed ARMS to assess cryptobenthic biodiversity over two distinct submerged time periods, 7 months and 2-years to compare short-term (pioneer) and long-term (established) communities in four distinct habitat types within a reef,Äôs ecosystem. Two of these habitats were characterized as transitioning hard coral habitats, each displaying their own unique features on their coral communities, whereas the other two habitats were non-coral dominated and were classified based on their dominant benthic features, namely turf algae (biotic) and coral rubble (abiotic). This study built upon the first assessment of the pioneer communities within these reef habitats, aiming to complement the first assessment with data that allows for understanding the long-term colonization and succession of cryptobenthic communities within reef ecosystems, critical for unraveling the dynamics of these organisms. Findings from this comparative study revealed that habitat dominance type might be a major player in shaping reef,Äôs cryptobenthic diversity as it significantly influenced the diversity and composition of cryptobenthic assemblages during both pioneer and established stages. Therefore, these results underscore the relevance of habitat heterogeneity in shaping the diversity of pioneer cryptobenthic assemblages within the reef and highlight the critical importance of preserving reef heterogeneity to maintain biodiversity and long-term reef health. Such insights are essential for the effective implementation of reef rehabilitation and restoration strategies for reefs throughout the globe.

Reef Monitoring in the Red Sea: Insights from long-term observations in the central Saudi Arabian coast.

Gloria Gil, Rodrigo Villalobos, Darren Coker, Karla Gonzalez, Diego Lozano-Cort√©s, Michael Berumen, Susana Carvalho

The Red Sea is renowned for its exceptional biodiversity and ecological significance, making it a crucial area for conservation efforts. Our research focuses on conducting long-term observations of reefs located along the eastern coast of the Red Sea, employing a multidisciplinary approach that integrates an array of field surveys and techniques in order to gain comprehensive insights into the dynamics of these important ecosystems. Through continuous monitoring efforts, we have been able to capture key aspects of reef ecosystem dynamics, including species‚Äô abundance and composition, as well as community structure. Furthermore, our research has been able to reveal both spatial and temporal variations, which sheds light on the complex interactions among physical, chemical, and biological factors in the Red Sea. In this study, we present the preliminary results of the monitoring efforts for the year 2023 in reefs located in the Thuwal area. We aim to demonstrate the importance of long-term monitoring in understanding the patterns of diversity of Red Sea reefs. Overall, this research contributes to the broader scientific understanding of the Red Sea's marine environment and the understanding of reef dynamics in the region, that ultimately, can provide valuable information for effective conservation and management strategies. Furthermore, this research emphasizes the urgency of early warning systems and the implementation of standardized national monitoring programs in the kingdom that preserve the remarkable biodiversity of the Red Sea. By presenting our findings at ICMERS, we aim to foster knowledge exchange, collaboration, and discussions among scientists, policymakers, and stakeholders interested in the conservation of the Red Sea's marine ecosystems.

Adam R. Barno

Corals maintain relationships with their associated microorganisms in what is together termed a holobiont. Environmental pressures can trigger changes in coral holobiont assemblages as well as changes to the host epigenome, which may be transferred intergenerationally. Here, we are testing if the in-situ application of probiotics induces heritable changes to both the coral epigenome and the coral-associated microbiome. To accomplish this, Acropora sp. colonies were inoculated with either a placebo treatment or a probiotic consortium consisting of four isolated beneficial microorganisms for corals (BMCs; Halomonas piezotolerans, Cobetia sp., Pseudomonas sp., Pseudoalteromonas lipolytica) three days per week for over one year. In April 2023, during spawning, gametes from eight of the inoculated colonies (three placebo and three BMC-treated corals) were collected from the water column using 150 ¬µm pore size collection nets. The microbiome and epigenome of both the parent and released gametes were analyzed to compare BMC- and placebo-treated corals. The results of this¬†study will determine if the probiotic inoculation was able to modify the coral microbiome in situ, whether these microbiome differences were associated with an epigenome change, and if the modifications to the coral epigenome were vertically transmitted to the released gametes. The research presented here aims to further our knowledge of how changes to the coral-associated microbiome via probiotic inoculations affect other components of the coral holobiont, providing insights into the transferability and longevity of these effects.

Red Sea Living Resources: Lessons learned and Challenges for sustainable uses, Egypt as a case study

Mahmoud Hanafy

Egypt has paid special attention, over the past years, to issues of natural resources protection. It has established institutional and legislation system for conservation of natural heritage under directives and support of the political leadership. This includes the issuing of five national environmental laws and numerous ministerial decrees, as well as the ratification of at least 17 international and regional agreements and conventions. It also includes the establishment of a network of national protected areas.
Although the biodiversity-based tourism raised the value of the biodiversity and encouraged the Egyptian government to took several actions toward conservation and sustainable uses, Egyptian marine resources of the Red Sea have been significantly impacted, in some cases to critical levels, due to over and miss-uses of biodiversity, including over-uses of diving coral reefs, and harvesting for the curio trade, recreational activities, infilling and excavation of coral reefs before 1994, irrational coastal development, over-fishing, mis-management of solid waste and marine lettering and more recently climate change (i.e coral bleaching due to heat stress). At the same time, although, the activities of tourism and oil production represent high valuable sources of national income and the monetary value of these resources has increased sharply; the challenge for Egypt is to continue such activities, which generates considerable economic benefits and job opportunities, while maintaining the living marine resources of the Red Sea. In the presentation, I will review the current status, threats and drivers to threats to the Egyptian living marine resources of the Red Sea, challenges and opportunities for sustainable use of biodiversity, lessons learned, the role of civil society (the NGO HEPCA as co-management success story) and Egyptian development and conservation processes as a case study.

Maritime Waste White Paper

Alexander R.D. Shepherd

The National Center for Environmental Compliance (NCEC)/KAUST Marine and Coastal Environmental Protection Initiative (MCEPI) produced a draft Maritime Waste Management Action Plan in July 2021. The Action Plan provided a road map to deliver the circular economy principles of Vision 2030 and KSA national, regional, and international, commitments to Maritime Waste Management. The Action Plan was presented at a workshop at KAUST in October 2021.

Progress in reviewing, approving, and delivering, the Action Plan has been limited to date. No Competent Authority has taken ownership for coordinating the management of maritime waste. The National Center for Waste Management (NCWM) has a mandate to facilitate investment in terrestrial waste management but not in maritime waste management. The NCEC has a mandate to set and monitor environmental standards for waste management but not to implement waste management. Other Authorities have sectoral, rather than inter-sectoral responsibilities with respect to maritime waste management.

Accordingly, KAUST has recommended the preparation of a Maritime Waste Management White Paper to facilitate the mandating of a Competent Authority to: (1) manage the effective cross-sector national, and transboundary, management of Maritime Waste; (2) review the MCEPI draft Action Plan, facilitate revision, and seek approval for implementation from the higher Authority; (3) manage delivery of, any approved Action Plan.

The key proposed elements of the white paper will be presented.

Next steps: Government should commission the further development of a white paper to be presented to the higher authority.

STRATEGIC ACTION PLAN AND CONSERVATION AGENDA FOR MARINE BIODIVERSITY IN SAUDI ARABIA

Nicolas Pilcher, Lotfi Rabaoui, Carlos García-Saez, Abdulnaser Qutob & Mohamed Ali Qurban

National Center for Wildlife, Riyadh, Saudi Arabia

The Kingdom of Saudi Arabia plays host to a vast wealth of marine biodiversity, among which are many endemic species, spread across major taxa groups and key habitats. The conservation and management of these habitats lies squarely on the shoulders of the National Center for Wildlife under the Environmental Law issued by Royal Decree No. (m/165), dated 19/11/1441 Hijri.

Until recently there haD been no cohesive approach to marine species and ecosystem conservation and management in the Kingdom, but today the National Center for Wildlife (NCW) has established and commenced implementation of a Strategic Action Plan (SAP) that addresses, in an ongoing and systematic manner, the assessment of conservation status, designs responsive and targeted management interventions, and evaluates the resulting conservation impact. The SAP addresses 11 key focal areas broken down by major species groups and major habitats, along with several overlapping agendas, such as public awareness, habitat restoration and impact assessments. Each focal area is backed by an Action Plan that contains actions, targets, timeframes and management interventions. These are envisioned to be living documents that can be updated as new data are available, or when new challenges present themselves.

NCW recognises that the implementation of the SAP will take time, will need to be underpinned by rigorous scientific data and management responses grounded in global best practices. NCW also recognises the magnitude of the challenges established by the SAP, and calls on key academic, development, government and public sectors to collaborate in the study, long-term preservation, and wise management of the Kingdom’s unique marine biodiversity assets.

EMERGENCY RESPONSE PLANS TO PROTECT MARINE WILDLIFE AND HABITATS IN SAUDI ARABIA

Mohamed Ali Qurban, Abdulsalam Ardan, Hamad Alnasri, Racheal Thomson, Lotfi Rabaoui, Abdulnaser Alqutob & Nicolas Pilcher

National Center for Wildlife, Riyadh, Saudi Arabia

The mandate of the National Center for Wildlife (NCW) specifically addresses the conservation and management of marine biodiversity in the Kingdom of Saudi Arabia. Management interventions call for understanding of species and habitat status, designing and implementing management interventions, and assessing the efficacy and status responses to these interventions. In addition to these key processes, NCW believes in being prepared for potential emergencies and catastrophes which might impact the marine environment, and has commenced a process of developing emergency response plans to deal with unexpected challenges.

Among these are the development of an Emergency Response Plan (ERP) for Crown of Thorns (COTs) Outbreaks, and Emergency Response Plan for Oil Spill Impacts to Marine Wildlife and Habitats. The COT Plan was first presented in draft form to stakeholders in October 2022 and was finalised in July 2023 after gathering feedback from across the country. The oil spill response plan was presented to stakeholders in September 2023. NCW's roles in these processes include planning, response, damage assessment, and as needed, restoration. The COT response plan specifically addresses how to determine when a COT outbreak is significant, and how to respond. The pil spill response plan specifically addresses oiled wildlife (e.g. sea turtles and seabirds) and the use of chemicals in the treatment of the spill itself on marine habitats and species.

Through the ERPs, NCW provides responders with a set of measured responses based on the severity of the threats, and describes specific actions that can be escalated from minor to catastrophic all within the same plan.

NCW relies on valuable scientific information from multiple sources and partners, and uses this information to provide timely assessments of potential impacts, determine best response strategies, and minimise ecological damage and monetary losses. We acknowledge that our role is that of overall coordinator in these events, and call on the support of our partners, academic institutions, other government agencies, NGOs, civil society groups and the general public in responding cohesively and collectively to threats to marine species and the environment when emergencies such as these arise.

EMERGENCY RESPONSE PLANS TO PROTECT MARINE WILDLIFE AND HABITATS IN SAUDI ARABIA

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On 24 May 2023 at approximately 8:00pm the international news outlet Reuters reported a deadly epidemic of sea urchins in the Gulf of Aqaba. Researchers at the University of Tel Aviv reported mass mortality in sea urchins *Diadema setosum* which became skeletons with massive tissue loss over a few days. These die-offs were also being reported in Oman, and the culprit looked likely to be ciliate parasite.

This phenomenon was not new nor restricted to the Red Sea: In early 2023 there was mass mortality of the Diadema urchins reported in the Mediterranean, and a mass die-off occurred in the Caribbean in the 1980s and then more recently in 2022. In that study the team reported that a ciliate most similar to *Philaster apodigitiformis* was consistently associated with abnormal urchins at affected sites but was absent from unaffected sites.

The news of the potential die-off of urchins in the Red Sea sparked concern in the Kingdom, and the National Center for Wildlife (NCW) developed a response plan to immediately address the potential threat. The response plan called for a phased approach to the threat, starting with assessment of the current situation alongside enhanced control of ballast water in commercial shipping, then investigation of diseased individuals, followed by possible removal of infected urchins, culture of healthy urchins, and potentially other response actions.

Following extensive surveys by NCW and partner agencies and academic institutions (KAUST, KFUPS, Red Sea Global, NEOM) no infected urchins were found, although there were anecdotal comments on diseased urchins having been seen in previous months, and of ‘reduced numbers of urchins’ on the reefs during the surveys. However, there was no baseline information with which to compare these claims. NCW and partners have remained vigilant subsequent to the initial surveys.

Dynamics of reef platforms in the Red Sea

Abdulkader Al Afifi

The coast of the Red Sea, north of the 20th parallel, is rimmed by numerous shallow, steep-sided carbonate platforms and platform fragments that extend as far as 25 kms offshore. On bathymetric maps, these platforms have curvilinear coast-parallel shapes that resemble a jigsaw puzzle, and those near the shoreline are capped by modern reefs. Reflection seismic data show that these platforms consist of Plio-Pleistocene reef buildups which nucleated along the coast, then split apart into rafts which glided offshore above the Middle Miocene salt detachment. In areas of gentle bathymetric slopes, reef growth in these rafts kept up with subsidence caused by seaward translation and salt expulsion. This resulted in ~ 1 km thick keep-up reef platforms, which aggraded as they glided seawards above the salt. Large reef rafts may be grounded over salt welds, resulting in splitting and fragmentation. Splits between the rafts are occupied by reactive salt diapirs and flows. In areas of steeper bathymetric slopes, reef growth did not keep up with subsidence and Pliocene reefs back-stepped towards the shoreline as they sank and were buried by sediments to depths of 2 kilometers, and are classified as give-up reefs. The post-rift salt sedimentary section in the Red Sea provides a unique view on the dynamic life cycle of reefs in a post-rift salt basin, from birth along the shore to a seaward journey ending in fragmentation, drowning, and burial.

Late Cenozoic foraminifers of the Red Sea: archives to learn from the past, tools to monitor the present and protect the future

Nazik Ogretmen

Foraminifers are direct tools to monitor environmental changes in any vulnerable marine settings both shallow and deep parts throughout the geological time scales and the present day. Corals, as the gems of the marine realm, are among the most affected organisms by changing climate, and foraminifers can be used to assess coral health. The Red Sea, to that extent, is a unique environment with remarkable endemism of its marine fauna representing a natural laboratory to observe and record any shift in climate conditions and the response of corals by utilizing foraminifers as bioindicators. With this present study, we review all the studies performed in the Red Sea that dealt with its foraminifers to document its past climate conditions and sea-level variations since the Pliocene-onwards and with a micropaleontological point of view we examine the so-called normal open marine conditions restored during the Pliocene. We emphasize the necessity of documenting past climate extremes in the Red Sea and the response of its foraminifers and corals. We focus on benthic foraminifers and associated coral communities of the Red Sea to evaluate their intersection towards monitoring and protecting healthy coral reefs in the changing climate condition of the present day and future by learning from millions of years of geological archives until today.

Microbial community of the first living stromatolites discovered in the Red Sea

Elisa Garuglieri

Stromatolites are laminated bio-sedimentary deposits formed by sessile bacterial communities thriving at the fringe between the land and the sea. They represent the first records of life on Earth, having dominated the planet‚Äôs surface for three billion years, and have been proposed to be responsible for critical biogeochemical processes such as early atmosphere oxygenation and the first massive biological carbon production. After a distribution decline started in the early Neoproterozoic, rare living stromatolites remain today in extreme environmental niches, including hypersaline lagoons, soda lakes, hot springs, and intense streaming waters. Their study is of profound geological, biological and ecological significance, helping us to better understand the geobiology of their ancient counterparts and opening new scenarios in extreme microbiology and exobiology. Furthermore, these unique microbial ecosystems hold potential implications for biotechnology (e.g., novel bacterial species and metabolic functions) and represent valuable resources in terms of environmental heritage awareness and high-profile sustainable tourism.
Recently (2021), the first known field of living stromatolites was discovered in the Red Sea by Prof. Vahrenkamp and team (ANPERC, KAUST) on the south coast of Sheybarah Island, Al Wajh Platform Lagoon, NE Red Sea. The new stromatolite field, located in an intertidal, open-marine setting, exhibits three distinct architectural types varying along the sea-land transition. By employing electron microscopy imaging and molecular ecology techniques (16S rRNA gene and metagenomic analysis), we explored the stromatolite structures, revealing the presence of different bacterial communities specific to each architectural type and separated from those populating the surrounding environment (water and loose sediments). The alpha diversity of the microbial assemblages decreases along the sea-land transition as stromatolites are enriched with specific endolithic bacteria. The microbial composition at Phylum and Class levels aligns with data obtained from the Bahamian analogues, the only other known modern stromatolites found in open marine settings.

Assessing In-Situ Coral Reef Calcification Rates in the Red Sea Using Standardized Sampling Tools

Matthew Tietbohl

Assessing In-Situ Coral Reef Calcification Rates in the Red Sea Using Standardized Sampling Tools: Coral reef ecosystems rely on calcareous accretion for growth, playing a fundamental role in coral reef geomorphology. The Red Sea offers a unique opportunity to study these processes in the absence of a number of important stressors, such as massive storms and river discharge, which are known to influence these processes. However, a basin-scale understanding of calcification rates in Red Sea coral reefs is lacking, hindering our ability to determine how this functional process may be altered in the face of climate change and other stressors. Here, we introduce a standardized approach using calcification accretion units (CAUs) to quantify in-situ calcification rates on Red Sea coral reefs. Preliminary results from short-term deployments indicate significant variability among sites, highlighting the need for further sampling efforts. We propose expanding the CAU network across the Red Sea, fostering collaboration among institutions. By deploying CAUs extensively in a standardized way, we aim to generate a comprehensive dataset to identify hotspots of early reef growth and regions with limited calcification. This data will allow unprecedented insight into drivers of reef calcification processes throughout the Red Sea, and further, offers opportunities to inform possible intervention strategies in locations with low calcification. By building a collaborative network we can addresses the critical knowledge gap in Red Sea coral reef accretion processes. Collaborative efforts and standardized sampling will enable the utilization of big data to guide conservation strategies and management efforts for the preservation and restoration of reefs throughout the Red Sea. Further, we provide fundamental knowledge about calcification rates and drives that can be used to test hypotheses of reef growth and its relationship to community composition and diversity.

Plastic particles can be mistaken as a food source and incorporated into benthic foraminifera tests

Marleen Stuhr

Large benthic foraminifera (LBF) are essential components of tropical coral reef communities and key carbonate-producing organisms. Among other applications, LBF can be utilised as indicators of pollution and environmental change. Marine litter, particularly plastic debris, presents a novel, yet largely unquantified, stress on foraminifera. While the effects of plastic pollution are increasingly being documented, most studies have focused on physiological responses of few organism groups (e.g., fishes, corals). Many previous studies showed negative effects of microplastics and nanoplastics on organismal physiology and ecosystem functioning, but potential responses of foraminifera remain widely unknown. We here present some of the first feeding choice experiments on LBF, comparing plastics with common food choices. Initially, we document the impact of microplastics (150-300 Œºm) on the heterotrophic feeding behaviour of Amphistegina gibbosa incubated with Artemia sp. nauplii only, with pristine microplastic particles only, or with a choice of nauplii and pristine microplastic. In a duplicate experiment, we compared the effect of pristine microplastic vs. microplastic that was pre-conditioned in artificial seawater. Feeding responses in both cases were evaluated a day later.
Our results indicate a strong feeding selection against pristine microplastic, suggesting a selective ability of the foraminifera to discern between potential food sources. However, the presence of pre-conditioned microplastic caused similar feeding interaction rates as with the natural food source Artemia. This suggests that feeding behaviour (and subsequently energy resources) of LBF may be more severely impacted by microplastics with longer residence times in marine environments. In a subsequent long-term study, we exposed foraminifera to nanoplastic particles (~1 Œºm) and sterilized Nannochloropsis algae cells as a natural food source within the same size range. Here, we did not only observe the uptake of polymer nanoparticles deep into the foraminiferal test, but also the incorporation of plastic particles into the outer calcite walls of the tests. Despite the high degree of specialisation regarding the skeletal formation of LBF, abundant cases of nanoplastic encrustation in the calcite tests were observed. Nanoplastic incorporation into the test was associated with LBF growth by formation of new chambers, in conjunction with continuous nanoplastic ingestion and subsequent incomplete egestion. Microalgae

presence in nanoplastic treatments significantly increased the initial feeding response after 1 day, but regardless of microalgae presence, nanoplastic ingestion was similar after 6 weeks of chronic exposure. While ~40% of ingesting LBF expelled all nanoplastics fromtheir cytoplasm, the nanoplastic was still attached to the outer surface of the test and was later encrusted with calcite. These findings highlight the need for further investigation of the impacts of plastic pollution on foraminifera, such as their function as potential plastic sinks or plastic pollution indicators, as well as the effects of alterations in the structural integrity of foraminiferal tests. The large-scale incorporation of nanoplastic into LBF tests as well as potential consequences (e.g., test instability, toxicity) could impact ecosystem functions related to LBF, such as carbonate sediment generation on coral reefs.

Brine-pool sediments as high-resolution archive for Holocene climate variations in the African-Arabian dessert belt (Red Sea, Saudi Arabia)

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During the Middle Miocene some 15 to 10 million years ago, the Red Sea rift basin became isolated from the Mediterranean Sea resulting in the deposition of thick salt deposits exceeding in places 1.5km in thickness. Subsequently buried by thick clastic and carbonate marine sediments salt layers became plastic forming spectacular salt flows protruding from the subsurface along faults and nowadays covering large extends of the modern sea floor mainly towards the rift axis. In front of some of these salt-flows brine pools developed much like ablation lakes in front of glaciers. In these deep marine highly saline extreme environments layers a steady trickle of pelagic sediments were deposited over time and remained largely undisturbed by burrowing organisms thereby preserving a high resolution time record of oceanic conditions. We present results from a newly discovered 20m deep brine pool to the south of the Al Wajh platform that formed at the relatively shallow depth of 630 m in front of a spectacular submarine salt-flow protruding from underneath the Al Wajh platform through a fault zone. Multibeam and CDT data, water samples, and the analysis of a 2.5m sediment core (Œ¥14C radiocarbon dating, TOC, Œ¥18O & Œ¥13C stable isotopes, XRF, magnetic susceptibility & spectophotrometric reflectance) reveal the temperature and salinity profiles of the brine pool and provide based on C14 dating of planktonic foraminifera a detailed record of the oceanic conditions over the past 6500 years before present (BP).
Over the 20m brine water column temperature increases from 21.5 C to 23 C and salinity 40 to 190 PSU. The core reveals significant changes over depth in its elemental and isotopic composition. These changes can be correlated to important climate events during the Holocene which also impacted Human civilizations, such as the Copper Age 4700 year PB, the 4200 ka event associated with the collapse of the Akkadian Empire and the Bronze Age 4000-3000 years PB.
The results of this study highlight the importance of near shelf brine pools as climate archives in the Red Sea. In addition the outcomes help to improve our understanding of the magnitudes of climate events (regional to global) and their impact on human civilizations around the Red Sea.

Hydrographic variability of the upper layer from high-resolution glider and remote sensing observations in the Central Red Sea

Z. Kokkini, N. Zarokanellos, A. Kalampokis, B. H. Jones

The CentralRed Sea (CRS) lies between two distinct hydrographic regimes of the Red Sea (RS). The northern RS is the region where the intermediate and deep water formation occurs during the winter, and the southern RS is where the intrusion of low salinity surface and intermediate Gulf of Aden Water takes place. The CRS is a region with high (sub)/mesoscale activity throughout the year. In situ, glider observations have been used to understand the seasonal variability from October 2017 to October 2018. Here, the key seasonal characteristics have been described during that year. The winter reveals the weakening of the stratification, where strong cooling and wind enhance the deepening of the MLD up to 120m. During the winter-to-spring transition period, the Eastern Boundary Current (EBC) presence was up to 100m of the water column with salinity <39.5 and restricted nearshore,as captured in our observation. However, the EBC was present in all the glider transects between April to May. During summer, the remote sensing and glider observations show evidence of an eddy dipole, where a cyclonic eddy (CE) takes place in the north and an anticyclonic eddy (AE) in the south. The CE decay and disappear at the end of August. On the other hand, the southern AE has been intensified, reaching its peak in the second week of August. The presence of the AE in the study area restricts the EBC nearshore. During the summer-to-fall transition period, the AE has decayed, allowing now the lateral advection of the EBC along with the presence of the Gulf of Aden Intermediate Water between 50 to 75m depth. The CRS is a unique region where mesoscale activity plays an important role in the ecosystem, and our findings help to identify the local physical and biological processes.

Lateral, temporal and compositional wind-blown dust supply to Al Wajh lagoon islands, Northern Red Sea

Manuel Ariza-Fuentes

Windblown dust is the most uncertain component in climate studies. It has a marked influence on cloud properties, solar radiation and it provides essential nutrients such as iron to oligotrophic water bodies. Atmospheric dust is mainly sourced from hot deserts, such as the Saharo-Arabian belt which emits up to 1700 Tg/yr. The Red Sea, an oligotrophic sea without active river drainage, is located in the middle of the Saharo-Arabian belt; modelling and remote sensing studies estimate the Red Sea receives about 8.6 Mt/yr of dust. We provide the first spatial and temporal study over an annual cycle of dust input into the Al Wajh lagoon, NE Red Sea. Ten dust traps were installed on nine different carbonate islands following the coastline and from nearshore to farthest seaward. Of the 140 samples collected over a fourteen months period, 94 provided usable material from which organic matter and calcium carbonate were removed to analyze the windblown silica-mineral dust. Gravimetry analysis was performed. Satellite data from PlanetScope and MODIS were analyzed to determine the source of dust and seasonal and spatial changes. Our estimates indicate that more than 2700 t/yr of silica-mineral dust are entering the Al Wajh lagoonal waters. Driven by persistent easterly winds (max reaching 12 m/s), the coastal Arabian plain is identified as the main source of dust, with an important contribution from Sinai Peninsula by NW winds. Highest dust input occurs during April and August. Lowest dust input occurs during winter. Dust ribbons perpendicular to the easterly winds during dust storms, clearly seen in the satellite images as narrow as ~20m can explain the observed spatial heterogeneities in dust deposition. No clear land-sea or NW-SE trends are reported. Research is continuing on the dust mineralogy, size and shape to determine its impact on Red Sea lagoons.

Summertime Appearance of Gulf of Aden Water in the Northern Red Sea

Lina Eyouni

The Northern Red Sea (NRS) is an energetic, dynamic system that can be affected by heat flux, mesoscale eddies, and northward flow. Wintertime in the NRS is characterized by heat loss from the upper layers to the atmosphere, whereas lateral advection is dominant in summer. The arrival time of the water advection from the southern Red Sea to the NRS is highly spatially variable and falls under the influence of atmospheric forcing during its movement. In this study, we show the influence of atmospheric effects and horizontal advection of Gulf of Aden Water on the upper layer of the NRS. Using in-situ temperature and salinity observations collected in the NRS in the winter and summer of 2019 along with satellite imagery, we document the advection of warmer and less salty water at the surface in both winter and summer and an additional subsurface layer of fresher water in summer. This advected water is modified by heating and shoaling of the mixed layer in summer. Simulation of the mixed layer using the Price-Weller-Pinkel (PWP) vertical mixing model showed that advection of heat and buoyancy was important for maintaining stratification in the NRS during the summer. In contrast, in winter, the timing of the water mass formation due to evaporation, significant cooling, and the presence of advection add complexity to the region. The PWP model is unable to reproduce the mixed layer, and the difference in the heat content compared with observations was large except during the absence of the mesoscale eddy and when advection was minimal. Overall, this study suggests that there is no direct relationship between either atmospheric forcing or advection and the mixed layer depth, except during specific events in summer and winter.

Tidal influence on the general circulation in the Red Sea

Daquan Guo

Tides play an important role in modulating the ocean circulation and water transformations, especially in the coastal oceans and gulfs, through tide-induced residual currents and tidal mixing processes. The Red Sea is a semi-enclosed marginal sea with its southern end connecting to the open ocean through the narrow Bab-al-Mandeb (BAM) strait. The Red Sea has a relatively independent circulation system, making it an ideal basin for investigating the influence of tidal mixing on the basin‚Äôs general circulations. Using a high-resolution regional ocean model, the impact of tidal mixing on water mass transformation and general circulation in the Red Sea is investigated through a set of numerical experiments with different configurations of tide-induced diapycnal diffusivity based on conversion of the energetic analysis. 20 years continuously runs with different tidal mixing schemes shows that the tidal-inducing mixing plays a crucial role in maintaining the deep cell circulation in the Red Sea, as well as affecting eddy activities, water transport at the BAM strait and the deep-water formation processes.

Extreme freshening event of the Red Sea caused by the 2015/16 Super El Niño

Junchuan Sun

Salinity plays a crucial role in characterizing the ocean's density and determining circulation patterns both on global and regional scales. Salinity fluctuation is also a principal environmental factor affecting the distribution of marine and estuarine species. Furthermore, higher salinity contributes to the increased thermotolerance of corals via osmoadaptation. The Red Sea is one of the saltiest seas (up to 40.5 PSU) in the world, owing to high evaporation, sparse precipitation, absence of river discharge and restricted water exchange with the Indian Ocean through the narrow Bab-El-Mandeb strait. Based on the remotely sensed Sea Surface Salinity (SSS) dataset, in-situ profiles data (Argo and Glider), and our high-resolution Mitgcm ocean model, an extreme freshening event in the 2015/2016 winter was identified and carefully investigated. The distribution of SSS and ocean particle tracking modeling indicated that the hyposaline Gulf of Aden Surface Water had reached the northernmost Red Sea in May 2016, resulting in an average 0.5 decrease in the northern Red Sea's SSS compared to the climatology mean. Diagnostic analysis revealed that the early onset of the inflow of GASW was driven by the easterly wind intensification over the Gulf of Aden in September 2015, while the rapid propagation of GASW into the northern Red Sea was attributed to the unusual weakness of southerly wind over the north Red Sea and the intensification of northerly wind over the south Red Sea. The wind anomalies were triggered by the unprecedented Super-El Ni√±o 2015/16. The freshening event may have profound impacts on stratification and ventilation in the northern Red Sea, as well as on the ecosystem. It can be inferred that the extreme freshening events are becoming increasingly frequent for the El Nino events are increasing in frequency and intensity under global warming.

Unveiling the Annual Physical and Biogeochemical Variability of Red Sea: Insights from High-Resolution Glider and Remote Sensing Observations

Nikolaos Zarokanellos, Zoi Kokkini and Burt Jones

The significant latitudinal span of the Red Sea from 12 N to 30 N provides a thermohaline circulation that promotes a northward-flowing eastern boundary current (EBC). Both numerical calculations and observations show that the basin's ubiquitous mesoscale and submesoscale characteristics influence the EBC's northward pathway. To evaluate the physical and biogeochemical variability of this complex regime, a sustained glider study was initiated in the Central Red Sea (CRS). Combining glider observations with remote sensing data, reanalysis outputs, and a 1-D mixing model, we characterized the mesoscale processes over the course of an annual cycle (2014-2015). The degree of restratification of the mixed layer (ML) is partially explained by heat, freshwater, and momentum fluxes, according to a comparison of glider data with 1-D mixing model results. The goals of this study were to 1) analyze seasonal physical and biogeochemical variability and 2) determine where and when lateral advection affects mixed layer evolution. The link between the horizontal and vertical temperature and salinity distributions shows that EBC contributes to the slumping of the horizontal density gradient, causing stratification. There was clear evidence of the EBC in early spring, as evidenced by the transport of warm, low-salinity water into the CRS The stratification induced by the EBC was found to restrict the coexistence of sharp lateral gradients, winter mixing, and mesoscale activity. The influx of Gulf of Aden water varies with season. Glider observations reveal the seasonal contrasts in the water masses characteristics and their transition between summer stratification and winter mixing. Changes in the water masses have a significant impact on the distribution and dispersal biogeochemical properties, with the deep chlorophyll maximum and phytoplankton population. This study advances our understanding of the Red Sea's dynamic physical and biogeochemical processes, providing valuable insights for future research and management efforts.

A decade of observations of fish and benthic communities in Saudi Arabian Red Sea

Milica Predragovic

Long-term monitoring of ecosystems plays a crucial role in understanding the impacts of environmental changes and implementing effective conservation strategies. This is especially important for sensitive ecosystems such as coral reefs, which are facing escalating threats from climate change, including frequent and severe coral bleaching events. Over the past years, numerous severe bleaching incidents have led to a global decline in coral cover, including Saudi Arabian Red Sea reefs. Our study investigates the temporal and spatial patterns of coral reef communities, based on periodic in-situ survey data from 2008 to 2019, a period that coincided with two major bleaching events in the Red Sea. We explore fish abundance and benthic cover on 22 reefs (10 nearshore and 12 offshore) across two distinct locations, Thuwal and Al Lith, presenting the first detailed study of temporal and spatial patterns of reef fish and benthic communities over a decade in these areas. Our findings revealed consistent differences in communities along an inshore to offshore gradient highlighting distinctiveness between reef types. We identified a decrease in coral cover, especially on nearshore reefs, in both regions and a shift towards communities with decreases in overall fish abundance through time. This decline of fish abundance was attributed to several key families including Carangidae, Chaetodontidae, Lutjanidae, and Serranidae. We found no correlation between fish and benthic data, suggesting that additional factors may be contributing to the observed changes in fish abundance, emphasizing the need for further investigation into the underlying causes of these observed community shifts. While these findings provide valuable insight into the temporal trends of fish and benthic communities, there is a pressing need for more structured and systematic long-term surveys to ensure effective management of Saudi Arabian coral reefs. This becomes even more critical considering the numerous coastal development projects along the Saudi Arabian coast committed to preserving and enhancing coral reef communities.

Challenges and opportunities in evaluating fish community composition for reefs under restoration at unprecedented scales

Pedro Pereira

Coral restoration is accelerating worldwide in efforts to stem ever-deteriorating reef health. However, despite recent growth towards more standardized and networked restoration activity, a step-change in scale is needed to reach ambitious global targets in extent of restored ecosystem targets by 2030. A recent project initiated in the northern Red Sea ‚Äì KAUST‚Äôs Reefscape Restoration Initiative (KRRI) represents the largest restoration footprint to date, providing opportunity to develop and implement complex monitoring protocols. Across the 100 ha reefscape area, restoration activity spans rehabilitating existing reef, introduction of new substrates, and large-scale coral propagation nurseries. Within the monitoring program, fish community diversity not only represents outcomes of the reefscape but potentially underpins activity success; for example, where fish are a key performance indicator of site health and aesthetics for ecosystem service values, but fundamentally critical to reduce coral space competitors such as algae that regulate restored coral survivorship. We present the framework for monitoring fish communities over space and time across this ambitious project, through the initial baseline data from across the reefscape. We identify how critical interdependencies with operations ‚Äì including site zonation ‚Äì potentially govern development of fish communities over time, and this add further complexities to monitoring. We discuss how fish community monitoring contributes to cost-(in)efficiencies of restoration, and outline steps needed to move activity towards more autonomous practices spanning data collection, processing and curation that are central to decision making. In doing so, we provide a roadmap that restoration projects will likely need in place as they continue to scale.

Seasonality of methane and carbon dioxide emissions in tropical seagrass and unvegetated ecosystems

Vincent Saderne, Aislinn Francesca Dunne, Walter Ambrose Rich, Ronald Cadiz, Susana Carvalho, Joao C√∫rdia & Alexander Kattan

Seagrass ecosystems are important carbon dioxide sinks that can sequester carbon for centuries as organic matter in sediment. They are also a major source of methane, a potent greenhouse gas, which limits their carbon sink capacity. However, data are lacking on their methane emission dynamics. Here, we conduct a one-year survey of carbon dioxide and methane concentrations and air-sea fluxes in Red Sea seagrass, mudflat, and coral backreef ecosystems. All ecosystems were sources of methane and carbon dioxide. Methane concentrations were lowest in the reef lagoon. We suggest that lagoons may be a globally important source of greenhouse gases. Methane concentrations were lower in seagrass than mudflat ecosystems at temperatures below 29.2,Äâ¬∞C. Seagrass had the highest annual methane air-sea fluxes but the lowest global warming potential in carbon dioxide equivalent due to a decrease in its flux. Hence, seagrasses can help climate change mitigation compared to bare sediments.

Taxonomic diversity of benthic dinoflagellates in the Red Sea

Igor Polikarpov

Benthic dinoflagellate assemblages in sub-tropical and tropical areas have recently been a subject of great attention in response to their capability to produce toxins and cause toxic blooms in the coastal areas. Pilot taxonomic surveys of the benthic dinoflagellates in the northern Red Sea were performed for the first time along the Jordanian coast in the Gulf of Aqaba (October 2009, 2011, and 2022) and the Egyptian Red Sea coast at Hurghada (July 2018 and January 2022) based on opportunity sampling from the shallow slope of the inshore coral reefs. The coastal area of the northern Red Sea was inhabited by taxonomically diverse and abundant assemblages of sand-dwelling and epiphytic dinoflagellates. A total of 63 dinoflagellate taxa belonging to six orders were recorded in this study. The records of Dinophyceae insertae sedis included rarely encountered taxa belonging to Amphidiniella, Cabra, Coutea, Laciniporus, Madanidinium, Plagiodinium, and Pileidinium. More than half of the identified benthic dinoflagellates were recorded for the first time in the Red Sea. Based on the obtained material, a new sand-dwelling dinoflagellate Ailadinium reticulatum gen et sp. nov. has been described from the Jordanian coast. The high diversity of sand-dwelling dinoflagellates in the northern Red Sea was supported mainly by gymnodinioid, amphidinioid, and prorocentroid taxa. The epiphytic dinoflagellate assemblages were dominated by Prorocentrum, Coolia, Ostreopsis, Gambierdiscus, and Fukuyoa species. A wide range of known toxin producers were observed including the ichthyotoxic dinoflagellates of the genus Amphidinium, okadaic acid producing Prorocentrum species, cooliatoxin producing Coolia, palytoxin producer Ostreopsis, and ciguatera-related Fukuyoa and Gambierdiscus species. The presence of known toxic dinoflagellate species indicates a potential risk to marine food webs and human health in the northern Red Sea, and underscores the need for further studies on taxonomy, ecology and toxicology of benthic dinoflagellates in this region.

HIGH FREQUENCY COASTAL PHYTOPLANKTON MONITORING IN THE RED SEA

Eva Aloufont

The Red Sea is warming at a faster rate than the global ocean (average), its oligotrophic surface coastal waters are characterized by high salinities (up to 40) and high temperatures (up to 33C). These conditions result in low phytoplankton biomass and a community dominated by small cells, however bigger cells can be important specially in the winter. As the Red Sea environment warms, the impacts of the increasing temperatures in this high saline high temperature and low nutrient environment on the phytoplankton community remains an important unanswered question. Long term studies are limited and represent a key to understand how the ecosystem will cope with these changes. We present a first observational high resolution monitoring program that started in 2018, on environmental parameters and a remotely controlled automated flow cytometer (CytoSub) fitted in a buoy at a mooring coastal station in the Red Sea. Plankton automated sampling is performed every hour for the small classes and every 6 h for the bigger cells. Focusing on the analyses of the sum of particles, the obtained high frequency data will enable us to understand the contribution of the various size classes to the total concentration of particles and the influence of temperature in the phytoplankton community and the ecosystem capacity responses.

An overview of phytoplankton blooms in the Arabian Gulf and the Red Sea: what are the differences and wherefore?

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Extending along both sides of the Arabian Peninsula, the Arabian Gulf, and the Red Sea are semi-enclosed with a limited oceanic exchange, linked to the northern Indian Ocean through narrow, shallow straits. Both are characterized by highly diverse microalgal assemblages, with some species blooming during the year, occasionally releasing toxins and causing harmful algal blooms (HABs) under certain environmental conditions. Historical accounts of the phytoplankton blooms were summarized and analyzed for the northwestern and north-eastern parts of the Arabian Gulf and across the Red Sea over the past three decades. Based on these datasets, the different areas of the Arabian Gulf and the Red Sea were compared in order to provide a present-day pattern of phytoplankton blooms diversity, spatial distribution, seasonality, and long-term trends. The most ecologically relevant species of microalgae were identified, which may impact coastal areas, fishery resources, and public health along geographically distant and environmentally distinct regions. The revealed regional differences in the occurrence of phytoplankton blooms reflected local meteorological and oceanographic conditions governing the frequency, severity, composition, and seasonality of the phytoplankton outbreaks in the different parts of the Arabian Gulf and the Red Sea. A wide range of potentially harmful species encountered within local phytoplankton assemblages across these marginal seas responded differently to local environmental settings and constituted unique HAB complexes that differed numerically and in composition and shaped the characteristic HAB status of each sub-basin considered. The presence of the bloom-forming and toxigenic microalgae in a great variety in both basins requires large-scale phytoplankton monitoring programs in the coastal waters of all countries bordering the Arabian Gulf and the Red Sea, with a focus on harmful microalgae and the relevant algal phycotoxins for comprehensive regional-based assessments of HABs risk and their expected impacts on the marine environment, public health, and human coastal activities.

Exploring the Influence of Environmental Changes on Phytoplankton Dynamics in the Western Coast of Arabian Gulf

Sdena Nunes, Mohammed Qurban, Carlos Duarte, Susana Agusti

The Arabian Gulf is known for its unique ecology, which includes a diverse array of phytoplankton species. In our study, we examined the relationship between natural and anthropogenic conditions and their impact on phytoplankton communities in the Arabian Gulf. Our objective was to uncover the underlying factors driving the fluctuations in phytoplankton dynamics over time. To achieve this, we conducted an analysis of phytoplankton pigments in sediment cores collected from three locations within the western coast of the Arabian Gulf. Employing a chromatography approach and applying the CHEMTAX algorithm, we successfully identified 18 distinct pigments and categorized them into 7 phytoplankton groups (cyanobacteria, prasinophytes, haptophytes, cryptophytes, pelagophytes, diatoms, and dinoflagellates). During the 1990s, a noteworthy decline in cyanobacteria concentration occurred, which coincided with the historical period of the Gulf War. All the CHEMTAX groups exhibited an overall increase in concentration (in ng cm-2 yr-1) from older to more recent sediments. Nevertheless, certain groups, such as cyanobacteria and cryptophytes, have shown a decreasing trend in their relative abundance compared to total chlorophyll a (T_Chla) over time. Alternatively, diatoms appear to be experiencing a rise in relative abundance. By elucidating the responses of phytoplankton over time, our research sheds light on the interaction between anthropogenic changes in the western Arabin Gulf coast and phytoplankton dynamics in their natural habitat.

Keywords: Arabian Gulf, phytoplankton dynamics, environmental changes, sediment cores, anthropogenic influences.

Egg development and hatching in Red Sea damselfishes

He Song

Damselfishes (family Pomacentridae) are widely distributed reef-associated marine fishes. The family,Äôs diversity, iconic nesting behaviors, and high environmental adaptability contribute to the popularity of damselfishes as aquarium species, tourist attractions, and model scientific study organisms. In the proposed presentation, we will report the survey results from a series of in situ underwater observations on two Red Sea damselfishes: the Red Sea anemonefish (Amphiprion bicinctus) and the Maldives damselfish (Amblyglyphidodon indicus). We followed the egg development processes and provide an in-situ photo time series for both species. The Red Sea anemonefish eggs were hatching in 144-168 hours after egg laying while Maldives damselfish eggs were hatching in 120 to 144 hours after egg laying. By referencing the time scale provided herein, observation by the naked eye could roughly indicate the developmental stage of the eggs in the nest and how much time is remaining before hatching. This would also help to decrease the underwater observation time of divers and minimize interference to nesting damselfishes but still enables the back-calculation of spawning times. The incorporation of this information with longer-term environmental data can provide important insight into factors driving reproductive cycles.

Alan Barozzi

The Atlantis II Deep, located in the Red Sea, is a deep hypersaline anoxic basin (DHAB) that stands out for its polyextreme conditions. This basin presents high temperatures, reaching up to 69¬∞C, and exhibits challenging characteristics such as high salinity (up to six times that of regular seawater), high pressure (depth of 2190 m), low pH (5.0), oxygen depletion, and the input of hydrothermal metal-rich fluids from the opening oceanic crust. Hydrothermal activities determine the formation of three distinct stratified convective layers within the basin.
Despite the inhospitable nature, the Atlantis II Deep sustains a diverse microbial community that exhibits variations across different compartments along the DHAB vertical profile. The presence of multiple convective layers, each exposed to progressively increasing temperature and salinity stresses, provides a unique opportunity to study the changes occurring within the microbial community and the metabolic strategies adopted by specialized microorganisms to cope with thermal stress in anoxic hypersaline conditions.
In our study, we reconstructed a total of 333 prokaryotic metagenomic-assembled genomes (MAGs) derived from 15 fractions encompassing the overlaying seawater, the three brine bodies, and their respective transition zones. This analysis revealed a gradual increase in the abundance of archaea toward the hottest and saltiest brine body, in contrast to the bacterial-dominated community found at the brine-seawater interface. Furthermore, among the MAGs assembled in the most extreme layer, we identified the presence of metabolic traits associated with enhanced microbial thermal tolerance.
By investigating the microbial community within the Atlantis II Deep, our research expands the comprehension of microbial diversity in DHABs. Additionally, it provides valuable insights into the ecological roles and evolutionary adaptations of endemic microorganisms that thrive in extreme environmental conditions, challenging the boundaries of life.

Unveiling the enigmatic Deep-Sea of the Red Sea

Carlos Angulo-Preckler

The Red Sea, a region of remarkable biodiversity and unique ecological characteristics, holds hidden treasures within its deep-sea and mesophotic zones. Despite its oligotrophic nature, the Red Sea supports surprisingly high biodiversity, even in the light-deprived depths exceeding 200 meters. The Red Sea Decade Expedition conducted in 2022 provided groundbreaking insights into the deep-sea and mesophotic biology of the region. Observations are essential to explore and discover the ocean. The rapid advancements in technology have revolutionized our capacity to document the ocean and its diverse array of species, pushing the boundaries of our understanding further than ever before. Among the notable discoveries were the first observations of living Firoloida desmarestia, a heteropod mollusk, and the discovery of two distinct species of rhodaliids, including a potentially novel species, has unveiled previously unknown ecological attributes and potential species richness within the Red Sea. These organisms, notably rare in the world's oceans, contribute to the Red Sea's unique and enigmatic biodiversity, underscoring the importance of further scientific exploration and conservation efforts in this region. Furthermore, the diel migration of mesopelagic fish, such as lanternfish, emerges as a crucial component of the deep-sea ecosystems, fueling nutrient transport and sustaining deep-sea organisms. The expedition shed light on the feeding behavior and ecological roles of deep-sea organisms. Anemones, deep-sea corals, and a jellyfish were observed preying on lanternfish, highlighting complex trophic interactions and providing insights into the nutrient flow within these ecosystems. These discoveries reinforce the ecological interconnectedness and resilience of deep-sea and mesophotic organisms. The documented biodiversity and ecological significance of the Red Sea's deep-sea and mesophotic zones underscore the need for effective conservation measures. The Red Sea Decade Expedition yields invaluable insights into the hidden wonders and ecological intricacies of these habitats.

Diversity and functionality of benthic microbial communities in an iron-rich deep seep site of the Saudi Arabian Coast of the Red Sea

Elisa Laiolo

The Red Sea has a relatively recent history, forming as a result of the the diverging movement of the African and Arabian tectonic plate systems. It shows unique geological and oceanographic characteristics and is considered a biodiversity hotspot, but his depths are still largely unexplored. Deep-sea ecosystems are known to harbor diverse and unique habitats and microbial communities play a crucial role in them, in terms of biogeochemical cycling and functionality manteinance. The Red Sea has a peculiar temperature above 20¬∞ C even in his depths, due to his axial rift zone, extending the range for many species and allowing life to thrive in the deep.

This study aims to characterize the microbial communities inhabiting a deep seep site located in the central part of the Saudi Arabian coast of the Red Sea, at a depth of 470 meters. Sediment samples, collected using a submarine in May 2022, were characterized using inductively coupled plasma optical emission spectroscopy (ICP-OES). Results show that the sediment composition of this site is characterized by a high iron concentration, which can influence the microbial community structure and function.

The taxonomic composition and functional potential of the microbial communities in the site was investigated using a metagenomic approach, shedding light on the intricate interplay between microbial life and biogeochemical processes.

Benthic foraminifera assemblages in a mesophotic coral reef ecosystem in the northern Red Sea, Saudi Arabia

Giovenzana Francesca, Mateu-Vicens Guillem, Westphal Hildegard, Petrovic Alexander, and Vahrenkamp Volker

Abstract (word count 300):

Benthic foraminifera (BF) are an important component within the benthic community in mesophotic coral ecosystems (MCEs), which are characterized by low-light levels. They have adopted different mechanisms to tolerate decreasing levels of light, such as changes in the test sphericity and in the pool of symbionts. Nowadays, MCEs remain a challenging environment to explore due to their inaccessibility, and BF have received overall little attention. This study aims to provide a description of BF assemblages in a MCEs developed on a drowned carbonate platform in the northern Red Sea. This isolated platform is located to the southeast of Al Wajh land-attached carbonate platform. Its drowning has been linked to platform-margin fragmentation processes and subsequent rafting towards the center of the basin due to the plasticity of the underlying thick salt layer deposited during restricted conditions in the mid-Miocene. This platform has an elevation of 650 m from the seafloor, and it has been investigated during a joint KAUST-JAMSTEC cruise in February 2022.
11 sediment samples collected between 46 and 130 m have been analyzed for the BF communities. The assemblages are overall dominated by hyaline tests. From statistical analysis, the samples cluster in three different groups according to depth: the shallower group is dominated by miliolids and Amphistegina lessonii; the deeper group is characterized by the deeper species of Amphistegina, namely A. radiata, A. bicirculata, and A. papillosa. The deepest sample is independent and dominated by Bolivina eralndi, Cibicidoides cicatricosus and Heterolepa praecinta.
A major shift in the BF community occurs at 74 m, similar to the shift in the benthic community reported from the Gulf of Aqaba. The spatial distribution of BF assemblages is possibly reflecting the temporal evolution of the platform, and similar changes identified in cores would enable the recognition of drowning sequences related to salt tectonics.

Deep-sea coral frameworks are abundant along the northern Saudi Arabian continental margin

Megan K. B. Nolan

Coral reefs are now one of the most threatened marine ecosystems, due to local anthropogenic pressures and global changes in ocean conditions. Until recently, research has focused on the vulnerability of shallow coral ecosystems, however as climate change continues, effects on deeper coral-dominated ecosystems become more severe. Deep-sea coral frameworks are relatively understudied, especially in the Red Sea, where conditions in the deep are uniquely warm and saline. Exploration of the deep-sea is costly, challenging, and time-consuming, reducing the geographic extent at which it is possible. Habitat suitability models can be used to identify key areas of interest without direct observation, making it more cost-effective to study. During the OceanX-NEOM ‚ÄòDeep Blue‚Äô expedition in 2020, multi-specific deep coral frameworks were identified in the Northern Saudi Arabian Red Sea and Gulf of Aqaba, built either by species of the Caryophylliidae or Dendrophylliidae scleractinian families. We used environmental and geomorphometric variables to inform MaxEnt models for the frameworks between 250 and 700 m. The models were most influenced by depth and measures of seafloor complexity and curvature, and highlight areas of importance for biodiversity in the deep, notably including an expansive area close to Shusha Island. We found over 200 km2 of seafloor in our study area to be suitable for these coral frameworks, equivalent to at least 35% of the area of shallow reefs in the same region, yet almost completely unknown. These first insights into deep frameworks of the Red Sea indicate their importance as biodiversity aggregators. As Saudi Arabia diversifies its economy towards tourism, invests in coastal development, and increases protection of its natural resources, fundamental research and results such as these will be imperative for conservation planning.

Exploring growth patterns of Dendrophylliidae corals from the exceptionally warm deep-sea environment of the Eastern Red Sea

Eleonora Re

Colonial corals, including both zooxanthellate and azooxanthellate species, exhibit diverse growth forms influenced by intrinsic and environmental factors. Understanding the morphogenetic processes in colonial corals is crucial for developing a universal model that can accurately simulate coral growth across species using a parsimonious set of parameters. This study focuses on azooxanthellate deep-sea corals, which comprise up to 50.5% of all scleractinian species and differ from their shallow-water counterparts by not relying on light for sustenance. Instead, these corals capture plankton and suspended organic matter for nutrition.

Previous investigations have explored the budding patterns of Dendrophylliidae species in southern Japan. Dendrophylliidae is a modern scleractinian coral family with a global distribution ranging from 0 to 2165 meters in depth. The colony structure consists of a primary (axial) corallite, which generates secondary corallites through lateral budding. Despite significant growth form variations, colony architecture can be simulated by modifying a few key parameters, such as budding inclination, orientation, and interval.

This project aims to examine the regularities in asexual budding mode among Dendrophylliidae. Samples were collected during the Red Sea Decade Expedition (RSDE) along the Eastern Red Sea. Remote Operated Vehicles (ROVs) and Submersibles were employed to collect Dendrophylliidae colonies at various depths (87-203 meters) along the latitudinal gradient. The collected colonies were identified to the species level, and morphometric parameters including corallite size, branching angle, and budding orientation were measured.

This study presents, for the first time, an investigation into the budding mode regularities of Dendrophylliidae corals in the Red Sea, known for its warmer environment compared to other regions. The findings from this research have the potential to contribute valuable insights to clonal growth models and enhance our understanding of deep-sea coral growth dynamics.

Marine heatwaves associated with coral bleaching are extending further, deeper and persisting for longer time periods

Lily Genevier

As the planet warms, the frequency and severity of marine heatwaves (MHWs) are increasing, accelerating the degradation of coral reefs through mass coral bleaching events. Most bleaching detection tools consist of a single global threshold based on progressive warming, but little is known about the specific extreme temperature events that impact corals between regions. Using the largest coral bleaching database available, we tailored the MHW thresholds to identify the unique MHWs behind coral bleaching in thirty-one Ecoregions. While the characteristics of bleaching-associated MHWs differ markedly between Ecoregions, MHWs have overall increased in spatial extent and duration (2 and 3-fold respectively) over most coral reef zones globally. MHWs are also reaching greater depths in the majority of Ecoregions, jeopardizing the thermal refuge which comes with cooler temperatures at greater ocean depths. As coral reefs around the world face the spectre of ocean warming, coordinated global actions for coral conservation are necessary.

Spatial variation in spawning timing for multi-species Acropora assemblages in the Red Sea

Eslam O. Osman

Corals in the northern Red Sea exhibit high thermal tolerance despite the increasing heat stress. It is assumed that corals throughout the Red Sea have similar bleaching thresholds (32¬∞C) due to evolutionary event after the last glacial maximum. Hence greater bleaching tolerance of corals in the northern Red Sea region is likely due to lower ambient water temperatures (25,Äì28¬∞C) that remain well below the corals,Äô physiological maxima. We tested this hypothesis using remotely sensed surface sea temperature data (1982,Äì2020) to model spatial distributions of Degree Heat Weeks across the Red Sea in relation to assumed coral thermal threshold values of 30, 31, and 32¬∞C. We also used the Coupled Model Intercomparison Project Phase 5 model outputs to predict warming trends in the Red Sea under different greenhouse gas representative concentration pathways (RCPs). We show that applying 32¬∞C thresholds dramatically reduces effective Degree Heat Weeks in the north, but not in central or southern Red Sea regions, a finding that is consistent with historical bleaching observations (1998,Äì2020) throughout the Red Sea. Further, model predictions under the most extreme RCP8.5 scenario exhibited ~3¬∞C warming by the end of the 21st century throughout the Red Sea with less pronounced warming for the northern Red Sea (2,Äì2.5¬∞C). This warming rate will remain below the assumed thermal threshold for the northern Red Sea, before the end of the 21st century, and thus coral reefs in the northern region may be among the last standing against climate change.

Recent Evidence for the Occurrence of Marine Heatwaves from the Red Sea to the North Sea

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Global warming has a profound impact on the occurrence of extreme events such as marine heat waves (MHWs), which have destructive effects on marine environments and ecosystems. MHWs are defined as an extreme positive sea surface temperature (SST) anomaly that lasts for five days or longer, where the SST is above the seasonally fluctuating 90th threshold for that time of year. MHWs have increased in frequency, duration, intensity, and spatial extent worldwide. However, this increase is not uniform in time or space but varies depending on the time and geographic region considered. This study examined the characteristics of MHWs and their spatiotemporal variability over the past four decades in five regional seas, including the Red Sea (RS), the eastern Mediterranean Sea (MS), the Black Sea (BLS), the North Sea (NS), and the Barents Sea in the Arctic Ocean (BS).

Our results showed high spatiotemporal trend variability in MHW frequency in these regional seas, with an average trend (events/decade) of 1.17 ¬± 0.2 (for RS), 1.1 ¬± 0.2 (MS), 1.4 ¬± 0.3 (BLS), 0.85 ¬± 0.3 (NS), and 1.0 ¬± 0.4 (BS). These results are consistent with observed SST warming rates, e.g., the highest (lowest) SST trends of 0.65 ¬± 0.07 (0.33 ¬± 0.06) ¬∞C/decade were found in the BLS (NS), which had the highest (lowest) frequency trend of MHWs. The highest occurrence of MHW events occurred in 2018 in MS, RS, and BLS (with more than 5 events), while they were observed in 2016 (7 events) and 2014 (8 events) in BS and NS, respectively. The occurrence of these events was influenced by large-scale climate patterns (e.g., ENSO and EAP), with ENSO having the greatest influence on RS and BLS and the East Atlantic Pattern (EAP) on NS and BS. We also found that atmospheric forcing plays a larger role in the formation of MHWs, especially in shallow seas (e.g., NS and BS). These results suggest that as climate change progresses, more intense MHW episodes are likely in these regional seas, with far-reaching implications for marine ecosystems.

Analyzing Thermal Modulation Mechanisms and Possible Connectivity-Induced Variability in Beaching Thresholds via Multiscale Hydrodynamics Modeling

Ahmed Eladawy

Despite increasing attention to Red Sea hydrodynamics over the past few years, the interaction between the Gulf of Suez and the Red Sea, as well as the possible natural mitigation mechanisms of heat stress on the southern coral reef zones, have not been adequately examined. To understand the three-dimensional nature of thermal variability in the Red Sea, this study examines several Regional Ocean Modeling System (ROMS) simulations using a nesting approach in the southern parts of the GOS. On a TSUBAME 3.0 supercomputer operated by the Tokyo Institute of Technology, the regional ROMS model was used to simulate general circulation patterns and sea surface temperatures. Ultimately, satellite data spanning 2016-2020 were used to validate the regional model. An offline nesting approach was used to simulate the local 3-D thermal regimes of the northern islands region due to the scarcity of distributed depth-varying temperature data. Intriguingly, the nested model scenarios confirmed an unusual thermal moderating mechanism involving northern islands that act as barriers to influences from the eastern boundary current. A new approach is also presented to using higher-resolution models to precisely represent thermal indices in space and time that surpasses the widely used remote sensing methodologies. Shortly, multiscale modeling provides a valuable tool for assessing the thermal regimes around one of the Red Sea's most precious marine ecosystems.

Physiology of the widespread pulsating soft coral Xenia umbellata is affected by food sources, but not by water flow

Claudia Hill

The trophic ecology of corals is complex, with feeding regimes being easily influenced by environmental conditions like water flow. Most research has been focused on hard corals, however, leaving knowledge gaps on the effect of variable flow on soft coral feeding. In this study, we investigated the effects of feeding and water flow on the physiology of the pulsating soft coral Xenia umbellata. Three feeding treatments i) no food, ii) dissolved organic carbon (DOC) and iii) particulate organic matter (POM) were crossed with four water volume exchange rates (200 L h-1, 350 L h-1, 450 L h-1, 650 L h-1) over 15 days. Pulsation rate, growth rate, isotopic and elemental ratios of carbon (C) and nitrogen (N) and photo-physiological parameters of Symbiodiniaceae were assessed. Our results show that feeding had a significant effect on the physiology of X. umbellata, yet water flow had no significant effect. In the absence of food, corals exhibited significantly lower pulsation rates, lower Symbiodiniaceae cell density, and lower mitotic index compared to the fed treatments, yet significantly higher chlorophyll-a and N content. Our findings suggest that X. umbellata may not gain additional benefits from high flow, nor suffer in low flow as pulsations may simulate an optimal flow at a local scale surrounding its polyps. Furthermore, findings suggest that X. umbellata adjusts its physiology when food is scarce by enhancing photosynthetic energy generation via increasing chlorophyll-a contents. As a result, this may enable X. umbellata to grow in a broad range of habitats, including those with extreme low or high flow and variable food availability. This study contributes to our understanding of the competitive success of X. umbellata in extreme environments within the Red Sea.

A Tale of Thermal Tolerance: Xenia spp. and turf algae assemblages display higher thermal tolerance than hard corals in the central Red Sea

Selma D. Mezger, Yusuf C. El-Khaled, Rodrigo Villalobos, Gloria Gil, Christian Wild, Susana Carvalho

Around the world global and local factors, such as ocean warming and pollution, lead to phase shifts from hard coral to algae or soft coral dominated reefs. These alternative communities, especially soft corals, are highly understudied, and research comparing the heat tolerance of alternative benthic organisms to hard corals is lacking. Hence, we conducted a series of standardized 18h acute thermal stress experiments using the Coral Bleaching Automated Stress System (CBASS). We sampled fragments of Acropora spp. and Pocillopora verrucosa and compared these two hard corals to fragments of Xenia spp. and turf algae assemblages. Sampling took place in June 2023 and will be repeated in September in two regions of the central Red Sea (Thuwal and Al Lith). Al Lith representing a region of maximum annual temperature and higher nutrient availability, while Thuwal being highly oligotrophic and with lower temperatures. At both locations, three offshore and three nearshore reefs were sampled. We measured dark-acclimated photosynthetic efficiency (Fv/Fm), calculating the Fv/Fm effective dose 50 (ED50, the temperature at which 50% of the initial Fv/Fm is measured) as a proxy for thermal tolerance. For both hard corals, ED50 was significantly higher by 1.3 ¬∞C in nearshore compared to offshore reefs. Location did not show significant trends for either organisms. Yet, overall both turf algae and Xenia spp. showed significantly higher thermal tolerance compared to the hard-coral species with average ED50 being 36.2 ¬∞C for Acropora spp., 36.9 ¬∞C for P. verrucosa, while we observed an ED50 of 39.4 ¬∞C for turf algae and 38.7 ¬∞C for Xenia spp. This shows that turf algae and Xenia spp. are more likely to better withstand heat waves and likely also increased temperatures compared to hard corals, which may contribute to explain the currently observed phase shifts.

Eloise Richardson

Conservation of elasmobranch populations is often inhibited by a lack of data, particularly in understudied regions like the Red Sea. Survey efforts in this region have been infrequent and often highly localized. Establishing a broad baseline for elasmobranch diversity and abundance along the Saudi Arabian coastline could inform both conservation efforts and a nascent ecotourism industry. This pilot study compared biodiversity data from baited remote underwater video stations (BRUVS), unoccupied aerial vehicle surveys (UAVs), and environmental DNA (eDNA) collected at five islands in the Farasan Banks region of the eastern Red Sea. Estimates of relative abundance were also compared between the BRUVS and UAVs. Each method identified species missed by the other two, but all three techniques exhibited clear habitat- and taxa-specific biases. Key concerns for each approach need to be addressed before large-scale implementation, but if carefully planned and executed well, a comprehensive multi-method survey of the Saudi Arabian coastline could establish a true baseline for shallow water elasmobranchs in this region. This would in turn, inform best conservation practices and identify potential ecological attractions in accordance with the environmental and economic goals of the Kingdom‚Äôs ‚ÄúVision 2030‚Äù mission.

Primary sex ratio and hatchling success at the Red Sea's largest green sea turtle rookery

Kirsty Scott

The Red Sea is inhabited by five species of marine turtles, two of which nest extensively along the coastline and on offshore islands. The largest green turtle (Chelonia mydas) rookery on the Red Sea is Ras Baridi, north of the city of Yanbu. Marine turtles display temperature-dependent sex determination and previous sand temperatures recorded at Ras Baridi exceed the supposed 29.2ÔÇ∞C pivotal temperature and, in some cases, the thermal maximum for incubation. This alludes to three possibilities: high mortality is occurring, the primary sex ratio of the Red Sea nesting beaches is highly skewed towards females, or local sea turtle populations may be adapted to elevated regional temperatures. Twenty HOBO temperature loggers were placed within the egg mass of 20 nests during the 2023 nesting season. The temperature was recorded every 30 minutes and the nests were monitored for emergence at 45 days. Upon emergence, hatchlings were counted, morphometrics were recorded and their fitness was tested by a series of timed self-righting, running, and swimming tests. After 24 hours, the nests were excavated to, determine hatching success and the temperature loggers were retrieved; the unhatched eggs were categorised by development stage. The thermal reaction norm for embryo growth and sexualisation was modelled from the time series of the incubation temperatures recorded. Our results will determine various metrics for the Ras Baridi rookery, such as nest success, primary sex ratio, and hatchling fitness. This study has implications for the success of the regional populations and could be used as a proxy for other populations facing climatic warming.

Marine turtles at the Vision 2030 Programme: conservation hotspots, distribution, migratory pathways in the Red Sea

Hector Barrios-Garrido

Marine turtles are highly mobile species, and they are exposed to multiple threats through their habitats. In the Red Sea, previous authors have identified nesting beaches for green and hawksbill turtles; however, there is still little information regarding their re-nesting success, intervals, and post-breeding displacements. As part of the Vision2030 Programme implemented at Red Sea Global, we assessed for green and hawksbill turtles,Äô: (a) nesting behavior; (b) distance between nesting beaches and feeding grounds (migratory pathways); and (c) location of feeding habitats. To achieve this, between 2019 and 2022, we satellite-tracked 64 female turtles (54 greens, and 10 hawksbills) from Breem, Al-Waqqadi, An,ÄôNumann Islands, and Ras Baridi beach. Nesting Success Rate (NSR-%) and the Inter-Nesting Intervals (INI-days) were calculated; and we assessed the movement of equipped turtles. In average, we tracked hawksbill turtles during 269.2 days (range= 58-416), and green turtles during 229.94 days (range= 11-437). NSR was estimated for hawksbill turtles in 85.7%, and 70.42% for green turtles; while the INI average periods had a mean of 13.72 days (range= 11-18) and 11 days (range= 9-20) respectively. Migration periods averaged 5.25 days (¬±5.844; range= 1.1 to 16; n=10) for hawksbills, and 19.06 days (¬±16.701; range= <1 to 51 days; n=52) for greens. Average distances between the nesting and feeding grounds were 121.46 km (range= 12.9-535.82; n=10), and 473.95 km (range=3.8-1,367; n=52) for hawksbill and green turtles correspondingly. Some feeding grounds overlapped between and within species, and we identified some areas that have potential to be considered as foraging hotspots as southern Jeddah bays, Ras Baridi and NEOM seagrass beds, Wadi El Gemal Hamata National Park (in Egypt), and the Dahlak Marine National Park (in Eritrea). Our results are particularly important for conservation planners, as they will inform management and conservation actions at national and international level.

Keywords: Chelonia mydas; Eretmochelys imbricata; FastGPS; RSG; gigaprojects.

Identifying important marine conservation areas for breeding sea turtles in the Al-Wajh region of the Red Sea

Natalie Wildermann

Breeding female sea turtles hold the highest reproductive value of any sea turtle life stage, making them a critical target for conservation from human pressures in near-shore habitats. While many studies focus on the terrestrial nesting phase, it is likewise crucial to understand how sea turtles use habitats at sea during the inter-nesting phase. Here, we aim to identify important marine areas for the conservation of two endangered sea turtle species during the breeding season in the Red Sea. We tracked sea turtles during their inter-nesting phase by deploying satellite tags on 18 green turtles (Chelonia mydas, endangered) and 6 hawksbill turtles (Eretmochelys imbricata, critically endangered) at two nesting beaches within the Al-Wajh lagoon in 2021/2022: Jazirat Mashabah Island (also known as Breem Island; primarily green turtle nesting) and Al-Waqqadi Island (primarily hawksbill nesting). We estimated Utilization Distributions (UD) for each individual to define their home ranges (95% UD) and core areas (50% UD). We identified interspecific variations in habitat utilization and found evidence of habitat partitioning. At Al-Waqqadi, green turtles exhibited larger home ranges (41.6 ¬± 47.4 Km) but smaller core areas (3.5 ¬± 3.7 Km) than hawksbill turtles (home range = 30.8 ¬± 7.7 Km; core area = 4.8 ¬± 1.7 Km). Furthermore, green turtles tracked from Al-Waqqadi occupied considerably larger areas than those from Jazirat Mashabah (home range = 28.6 ¬± 21.1 Km; core area = 3.1 ¬± 2.1 Km), which could be related to the availability of nearby suitable resting habitat during the inter-nesting phase. Although most turtles displayed fidelity to their core areas between different inter-nesting intervals, two green turtles also undertook long-distance movements (>70 Km) during this period. Combined, these findings are informing a variety of conservation efforts to ensure the continued integrity and survival of endangered sea turtles in the Red Sea.

Ashlie J. McIvor

Stingrays play a significant role in maintaining the health of coral reef ecosystems but are vulnerable to the cumulative impacts of human activities and climate change. The blue-spotted ribbontail stingray (Taeniura lymma) is a demersal species common to coral reef habitats across the Indo-West Pacific and can be found on most reefs in the Red Sea. Despite facing similar pressures to other species of stingray, the ribbontail ray is one of the few reef-associated species showing an increasing population trend, though little is known about the species,Äô basic biology and ecology. Here, we provide an interdisciplinary approach that integrates various aspects of multiscale morphology, habitat preference, and movement ecology of this iconic species. Systematic Unoccupied Aerial Vehicle (UAV) surveys conducted at the King Abdullah University of Science and Technology (KAUST) revealed this species' ecological significance to the Red Sea's coastal environments, surpassing many other regions in population abundance. In the KAUST lagoon, we further validated the use of photo-identification (photo-ID) based on the unique blue spot pattern of the ribbontail ray, which demonstrated the extended capability of photo-ID compared to manual tagging efforts (496 c.f. 356 days, respectively) and provided the first direct evidence of structural colouration in elasmobranchs. These findings expand our understanding of communication and camouflage mechanisms in this species. Additionally, acoustic telemetry data revealed the year-round presence of the ribbontail stingray population in the KAUST lagoon. Notably, females exhibited more frequent and longer-distance movements compared to males. These observations underscore potential vulnerabilities to localized overfishing and habitat loss, highlighting the need for targeted conservation measures. Our findings provide invaluable insights into the potential impacts of population changes on coral reef ecosystems and inform conservation measures for the ribbontail ray, thus emphasizing the importance of employing multi-method technologies to define effective conservation strategies throughout the Red Sea.

Stock Assessment and Conservation of Narrow-Barred Spanish Mackerel (Scomberomorus commerson) along the Red Sea Coast of Saudi Arabia: Insights and Findings

Mark Dimech

This study aims to contribute to the current knowledge regarding the population of narrow-barred Spanish mackerel (Scomberomorus commerson) along the Red Sea coast of Saudia Arabia. A total of 1750 fish were sampled monthly between February 2022 and May 2023 from commercial hook and line, gillnet, and demersal trawl fisheries. The primary gears used for this species in the region are hook and line, and gillnet. However, the trawl fisheries targeting shrimps in the southern Red Sea unintentionally capture the juveniles as by-catch. Total length (TL) and total weight (TW) ranged between 10-135 cm and 12-16296 g for all sampled fish. Excluding the unsexed juveniles, the overall ratio of females to males was 1.55:1. As size increased, there was a corresponding rise in the proportion of female fish. The relationship between TW and TL was estimated to be TW=0.0087,àôTL2.91 for females and TW=0.0128,àôTL2.80 for males. The von Bertalanffy growth parameter estimates were TL,àû=146.2 cm, K=0.198 years-1 and t0=-0.852 years. The median size at first maturity was estimated as 39.6 cm TL for both sexes. The estimated annual total mortality rate from the catch curve analysis was 0.875, the estimated average annual natural mortality rate for all age classes was 0.310, and the annual exploitation rate was 0.646. The estimated percentage ratio of immature mackerel caught by the fishery was less than 10%. In recent years, the average annual total catch of narrow-barred Spanish mackerel along the Saudi Arabian Red Sea coast has been around 2000 tonnes, which conservatively amounts to approximately 150 million SAR contribution to the country's economy per year. It is crucial to maintain the current fishery practices, predominantly relying on artisanal fishing techniques, and to sustain the fishing effort at its current level for the long-term sustainability of this species along the Saudi Arabian Red Sea coast.

Isolation and staining reveal the presence of extracellular DNA in marine gel particles

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Marine gel particles (MGP) are amorphous hydrogel exudates from bacteria and mi-croalgae that are ubiquitous in the oceans, but their biochemical composition and function are poorly understood. While dynamic ecological interactions between marine microorganisms and MGPs may result in the secretion and mixing of bacterial extracellular polymeric substances (EPS) such as nucleic acids, compositonal studies currently are limited to the identification of acidic polysaccharides and proteins in transparent exopolymer particles (TEP) and Coomassie stainable particles (CSP). Previous studies targeted MGPs isolated by filtration. We devel-oped a new way of isolating MGPs from seawater in liquid suspension and applied it to identify extacellular DNA (eDNA) in North Sea surface seawater. Seawater was filtered onto polycar-bonate (PC) filters with gentle vacuum filtration, and then gently resuspending them in a small-er volume of sterile seawater. The resulting MGPs ranged in size from 0.4 to 100 ¬µm in diameter. eDNA was detected by fluorescent microscopy using YOYO-1 (for eDNA), with Nile Red (tar-geting cell membranes) as a counterstain. TOTO-3 was also used to stain eDNA, with ConA for localising glycoproteins and SYTO-9 for live/dead staining of cells. Confocal laser scanning mi-croscopy (CLSM) revealed the presence of proteins and polysaccharides. We found eDNA to be universally associated with MGPs. To further elucidate the role of eDNA we established a model experimental MGP system using bacterial EPS from Pseudoalteromonas atlantica that also contained eDNA. Our results clearly demonstrate the occurence of eDNA in MGPs. Further, our study will help further understanding of the micro-scale dynamics and fate of the MGPs underlying the large -scale processes of carbon cycling and sedimentation in the ocean.

Transferring understanding of Red Sea microbial plankton to freshwater sources: Environmental sustainability

Najwa Al-Otaibi

As a transition zone between the Red Sea marine water and surface freshwater ecosystems, the latter is more hydrologically and ecologically dynamic than the former and composed of diverse microbial plankton under the influence of anthropogenic activities, ecological pollution and climate change. The seasonal samples of picophytoplankton (Synechococcus and picoeukaryotes) and heterotrophic prokaryotes were collected from the main channel stream of Saiysad freshwater in Taif city, Saudi Arabia from November 2022 to June 2023. Surface water samples were taken at three distinct stations (St.) chosen according to anthropogenic activities (St. 1), an area of aquatic plants and small fish (St.2) and running water containing various filamentous algae (St. 3). Given the information that is available on the study site, Saiysad freshwater is a eutrophic ecosystem due to higher phosphate concentrations reaching up to 0.1 Œºmol L-1. The temperature decreased in winter (11 ¬∞C) and increased in fall (13¬∞C) with no significant differences between stations or seasons. Ph variations were less marked (5¬± 0.6). Three different groups of picophytoplankton were clearly distinguished by using flow cytometry: Synechococcus (Syn) and two groups of picoeukaryotes (Peuk 1 and Peuk 2). The preliminary results showed the highest total picophytoplankton numbers was in St. 1 (4.70 √ó104 cells mL,àí1) followed by St 2 (3.41 √ó104 cells mL,àí1) and the lowest was in St 3 (1.92√ó104 cells mL,àí1), with a higher contributing of Syn 86.4 %. Syn abundance displayed significant seasonal differences between winter and fall at St. 1 and 2 with maximum values (5.5 √ó 103 cells mL,àí1) in winter at the later station. The two groups of picoeukaryotes shared similar dynamics, with maxima for Peuk1 in winter (6.25 √ó 102 cells mL,àí1). The results highlight that seasonal differences in the fresh waters are fundamentally comparable with the marine Red Sea water.

Long-term Trends and Inter-annual Variations of wind speed in the Northern Red Sea

CHERIYERI POYIL ABDULLA

Wind power is one of the clean energy resources, which can replace conventional energy resources to a large extent. This can also contribute to the reduction of atmospheric carbon dioxide. In the present study, we analyzed the Climate Forecast System Reanalysis (CFSR) winds in the northern Red Sea for the period 1979-2022 to evaluate the suitability of the wind resource for energy conversion. Results indicate that the overall mean wind speed is well above the threshold (3 m/s) required for wind energy conversion. The northern Red Sea experiences winds consistently from the NW direction throughout the year. The offshore mean wind speeds are 6-7 m/s, while the 99th percentile wind speeds are 12-13 m/s. Regional differences in maximum wind speeds with higher values towards the northern area were noticed. The summer wind speeds are higher compared to the other seasons. Long-term trends indicate that the mean wind speeds are increasing at a rate of 1-2 cm/s/y, which is consistent with global trends. The rate of increase in 99th percentile wind speeds is generally higher than that of the mean wind speeds. One of the remarkable observations from this study is that the climatic oscillations such as ENSO, IOD and NAO have no significant role in controlling the wind variability in this region.

Fisheries and Biology of Longnose parrotfish (Hipposcarus harid) ‚Äì a fish of cultural, commercial, and ecological importance in the Red Sea of the Kingdom of Saudi Arabia.

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The surging global temperature and degradation of many of the world's marine ecosystems, along with their adverse impact on fisheries in recent decades, are alarming. Therefore, it is vital to understand the stocks status of commercial species. Hipposcarus harid (Longnose parrotfish) is a unique commercial fish that holds significant cultural importance for the fisheries of Saudi Arabia. The people of the Farasan Islands, celebrate the ‚ÄòHareed Fish Festival‚Äô annually between April and May when the fish aggregates in the shallow waters. In this study, a total of 3035 fish (14 - 545 cm TL and 303 - 1858 g TW) were sampled along the Red Sea coast of Saudi Arabia between February 2022 and May 2023 on a monthly basis to assess the status of its fishery. The samples were predominantly caught by gillnet (90%) followed by traps (10%). The overall ratio of females to males was 1.65:1, and the relationship between TW and TL was estimated for all fish as TW=0.0558,‚àôTL2.59. The maximum age, based on otolith readings, was found to be 5.5 years. The von Bertalanffy growth parameter estimates were TL,‚àû=57.6 cm, K=0.21 years-1 and t0=-1.04 years, based on age readings of sagittal otoliths. The median size at first maturity was estimated as 23 cm TL for both sexes. The annual total mortality rate estimated from the age based catch curve analysis was 0.806 year-1. The estimated natural mortality rate for all age classes was 0.380 year-1, and the annual exploitation rate was 0.522. The average annual total catch was estimated at 273 tonnes, contributing approximately 12.5 million SAR to the country's Red Sea economy. Based on this information the stock does not seem to be in overfishing. Nonetheless, it is important to exercise caution and ensure the maintenance of the current level of exploitation for long-term sustainability.

Stock assessment of the Sky Emperor, Lethrinus mahsena, in the Saudi Arabian Red Sea.

Ricardo Clapis Garla

This study aims to contribute to the current understanding of the Sky Emperor population (Lethrinus mahsena) along the Red Sea coast of Saudi Arabia. A comprehensive sampling effort was conducted between February 2022 and May 2023, involving the collection of 4327 specimens from commercial hook and line, gillnet, and trap fisheries on a monthly basis. The sampled fish exhibited a range in total length (TL) from 10.5 to 54 cm and total weight (TW) from 54 to 2,810 g. After excluding unsexed juveniles, the overall sex ratio indicated a prevalence of females, with a ratio of 1.77:1 compared to males. The relationship between TW and TL did not exhibit significant differences between sexes and was described by the equation TW=0.0123√óTL3.11, for all specimens. The von Bertalanffy growth parameters were estimated as TL,àû=54 cm, K=0.21 years-1, and t0=-1.67 years. The median size at first maturity was estimated at 19.36 cm TL for females and 21.11 cm TL for males. Utilizing catch curve analysis, the estimated annual total mortality rate was 0.61. Additionally, the average annual natural mortality rate across all age classes was estimated at 0.24, with an annual exploitation rate of 0.57.. The fishery demonstrated a relatively low proportion of immature fish caught, approximately 15% of the total catch. Furthermore, the average annual total catch of the Sky Emperor species between 2016 and 2021 along the Saudi Arabian Red Sea coast amounted to about 363.83 tonnes. This contributes significantly, with an estimated annual economic value of around 11,278.73 million SAR, to the country's economy in the Red Sea. The presented data is of paramount importance in assessing the species' exploitation levels and provides crucial initial insights for effective management and long-term sustainability along the Saudi Arabian Red Sea coast.

Population dynamics and Fishery biology of yellow,Äëedged lyretail Variola louti (Forssakal, 1775) along the Saudi coast of the Red Sea

Sirajudheen Thayyil Kadengal

Population dynamics and Fishery biology of yellow,Äëedged lyretail Variola louti (Forssakal, 1775) along the Saudi coast of the Red Sea
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The yellow,Äëedged lyretail Variola louti is one of the most targeted species in the Red Sea and hence it requires the attention of fishery managers for sustainable management of the species. Age, maturity, growth, and mortality were assessed from fishery-dependent samples collected along the Saudi coast of the Red Sea from February 2022 to July 2023. A total of 1012 specimens with a fork length (FL) and total weight (TW) ranging from 175 to 560mm and 90 to 2700g, respectively, caught by hand-line and trap, were analyzed. Since there were no significant differences between males and females, the FL to TW relationship was estimated to be TW= 0.0123FL3.079. The estimated sex ratio was 1.74 females per male. The von Bertalanffy growth parameters based on age readings of sagittal otoliths were estimated as FL,àû= 67.52cm, K= 0.094year-1, and t0= -3.043years. Current findings revealed no significant difference in the value of median length at first maturity (FL50) between sexes, and a pooled value of 23.79cm was determined as FL50. However, it is recommended to conduct more research using a larger number of observations as Variola louti is a protogynous hermaphroditic species. Using age converted catch data, the annual total mortality was estimated as 0.39. The natural mortality coefficient calculated based on the growth parameters, was 0.15year-1, and resulting fishing mortality was 0.24year-1 with an exploitation rate of 0.63. Based on this information the stock does not seem to be in overfishing. Annually, an average estimated quantity of 264 tonnes of V. louti is being landed along the Saudi Arabian Red Sea coast, which conservatively amounts to approximately 20 million SAR contribution to the country's revenue. Despite its lower vulnerability to exploitation, regular monitoring of the stock and the fishery is recommended to maintain the sustainability of this species in the Red Sea.

Life history patterns of the orange,Äìspotted trevally, Carangoides bajad (Forssk√•l, 1775) from the Red Sea

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The present study investigated the life history patterns of orange,Äìspotted trevally, Carangoides bajad (Forssk√•l, 1775) using 4495 specimens sampled monthly between February 2022 and June 2023 from the commercial fishery along the Red Sea coast of Saudi Arabia. Four of the nine main fishing ports chosen for sampling, viz., Jizan, Al,ÄìQunfudah, Al,ÄìLith and Thuwal contributed 60% of the total samples. A variety of fishing gears were employed to exploit C. bajad, with handline being the primary gear, accounting for 77% of the total sampled fish. The mean monthly sample size ranged between 56,Äì627 specimens, with a mean of 285.6 ¬± 160.82. Total length (TL) ranged between 14 and 91 cm with a mean of 340.79 ¬± 84.41, and total weight (TW) ranged from 37 to 8810 g with a mean of 599.45 ¬± 532.48 for all sampled fish. The overall sex ratio of females to males deviated from unity, with an observed ratio of 1.21:1, and a total of 247 individuals were sexually immature. The relationship between TW and TL for all sampled fish was estimated as TW=0.00748,àôTL2.99. The von Bertalanffy growth parameter estimates were TL,àû =89 cm, K=0.11 years-1, and t0 = -1.2 years. The median size at first maturity was estimated as 23.5 cm TL for both sexes. Examination of age distribution of samples and the majority of caught fish being mature suggest that the orange,Äìspotted trevally is currently optimally,Äìexploited in the Red Sea; however, continuous monitoring of the stock and commercial fishery is essential to ensure sustainable exploitation of C. bajad as this species is known to have higher vulnerability to fishing pressure.

Observations on the Biology and Fishery of the Marbled Spinefoot (Siganus rivulatus) in the Eastern Red Sea

Zahra Okba

Observations on the Biology and Fishery of the Marbled Spinefoot (Siganus rivulatus) in the Eastern Red Sea.
This research study aims to enhance our understanding of the Marbled Spinefoot (Siganus rivulatus) population along the Red Sea coast of Saudi Arabia. A comprehensive sampling effort was conducted between February 2022 and May 2023, encompassing various fishing methods including handline, trap, gillnet, and demersal trawl fisheries. By analyzing the collected data, we observed a higher abundance of Marbled Spinefoot in the northern regions. The size range for sampled fish, in terms of total length (TL) and total weight (TW), was 86-280 mm and 8-360 g, respectively. Overall, female Marbled Spinefoot outnumbered males with a sex ratio of 0.56 , and larger individuals were predominantly female. We established the relationship between TW and TL, and found it to be TW=0.0166,àôTL2.9426 for females and TW=0.0175,àôTL2.9229 for males. Furthermore, using the von Bertalanffy growth model, we estimated the asymptotic length (TL,àû), growth coefficient (K), and theoretical age when TL is 0 cm (t0) as 34.44 cm, 0.38 year-1, and -0.4 year. Respectively. The median size at first maturity for both sexes was determined to be 17.5 cm TL. From a length-converted catch curve analysis, the annual total mortality rate was estimated to be 1.64. The exploitation rate was relatively low at 0.46 year-1, attributed to the high natural mortality rate of 0.89 year-1. Considering the economic significance, the average annual total catch of Marbled Spinefoot along the Saudi Arabian Red Sea coast has consistently reached approximately 325 tonnes, contributing around 11 million SAR to the country's economy per year. To ensure the long-term sustainability of this species, it is crucial to maintain the current fishing practices, primarily relying on artisanal techniques, and sustain the fishing effort at its current level along the Saudi Arabian Red Sea coast.

Title: Assessing the Resilience and Metabolic Adaptations of Rhizotrochus typus a Deep-Sea Coral in Response to Hypoxic Conditions in the Red Sea

Jacqueline Alva

Deep-sea corals form unique and fragile ecosystems that are susceptible to environmental perturbations, including oxygen depletion. Understanding the tolerance limits of these organisms to low oxygen concentrations is crucial for assessing their vulnerability to future oceanic changes. This study investigates the dissolved oxygen (DO) concentration at which deep-sea corals in the Red Sea experience lethal or sub-lethal impacts and explores their resilience and metabolic adaptations to extreme hypoxic conditions.

Based on the distinctive environmental conditions of the Red Sea deep-sea, characterized by consistently high temperatures (>20¬∞C) and naturally low oxygen concentrations (with the lowest measurement below 1 mg O2 L-1). We postulate that deep-sea corals in this region have developed higher resilience and tolerance mechanisms to extremely low oxygen levels compared to corals elsewhere.

To test this hypothesis, our primary objective is to determine the hypoxic threshold of a solitary Red Sea deep-sea coral species, Rhizotrochus typus. We will employ transcriptomics and metabolomics techniques to identify the oxygen concentration at which corals transition from aerobic to anaerobic metabolism. By examining these corals' gene expression patterns and metabolic profiles across a range of dissolved oxygen levels, we aim to elucidate the molecular and biochemical adaptations that enable their survival under hypoxic conditions.

The outcomes of this study will contribute to our understanding of the physiological responses of deep-sea corals to oxygen stress and their potential resilience to future climate change scenarios. Additionally, the findings will shed light on the ecological dynamics and conservation implications of deep-sea coral ecosystems in the Red Sea. Ultimately, this research will aid in formulating effective conservation strategies for these unique and vulnerable marine habitats.

Anieka Parry

Mesophotic coral reefs remain vastly understudied and yet highly biodiverse ecosystems. In the face of global climate change, it has been previously suggested that mesophotic coral ecosystems (MCE‚Äôs) may provide a thermal refugia against coral bleaching. However little is known about the thermal limits or bleaching thresholds of mesophotic corals, and those that are known are generally restricted to the upper mesophotic zone (30-40m). Here we assessed the thermal threshold of a coral species Leptoseris striata, a depth-specialist scleractinian living in symbioses with both Symbiodiniaceae and Ostreobium spp. We collected L. striata specimens from across the eastern Red Sea from the Farasan Banks in the south, to the Gulf of Aqaba at varying depths from 60-125m in April-June of 2022.
To quantify their thermal threshold, we conducted a thermal stress experiment, increasing the temperature by 1¬∞C per day from the ambient temperature of 23¬∞C. No corals showed any signs of mortality until the temperature reached 34¬∞C, +6¬∞C above the highest temperature we recorded in-situ at the time of collection and +11¬∞C above the mean temperature. We also recorded respiration and photosynthetic rates at temperature increments, as well as microsensor measurements of the boundary layer and found that these corals are net heterotrophic but that overall rates of metabolism are extremely slow. Our results challenge the notion that Red Sea corals are generally living close to their thermal limits, and potentially the slow metabolism of L. striata is the mechanism that allows them to survive such extreme temperature increases.

Title: Respiration in Deep-Sea Corals: Unveiling Metabolic Adaptations in Extreme Environments

Alexandra Steckbauer

Abstract: Deep-sea oceans are a widespread habitat on our planet, and also an important part of the Red Sea. Although the Red Sea is highly oligotrophic, it supports high biodiversity even in depths over 200 metres, where deep-sea corals thrive in extreme oceanic regions. Respiration is a pivotal process in their survival and growth. Field sampling was conducted as part of the Red Sea Decade Expedition 2022, and incubations were conducted onboard R/V OceanX to analyse oxygen consumption rates and patterns in various deep-sea coral species along the coastline of Saudi Arabia. Live coral samples were collected using remotely operated vehicles (ROVs) and manned submersibles. To investigate deep-sea coral respiration mechanisms and their metabolic adaptations to low oxygen environments, we conducted a total of 67 incubations, and measured respiration from 82 different corals. Our findings will enhance our understanding of the ecological significance of deep-sea corals and their responses to changing oceanic conditions. By shedding light on their metabolic adaptations and respiration mechanisms, we expand knowledge of deep-sea ecosystems and their interconnectedness with global processes.

New depth records and novel feeding observations of three elasmobranchs species in the eastern Red Sea

Sofia Frappi

Understanding the vertical distribution of elasmobranch species and associated ecological dynamics can be a crucial component of developing effective conservation strategies, particularly in light of their global population decline. Previous studies have primarily focused on horizontal extent and movement patterns of elasmobranchs, with limited knowledge about their vertical distribution. This knowledge gap stems from limited access to technological advancements and reliance on surface data from fisheries operations. Today, advancements in observing platforms such as remotely operated vehicles (ROVs) and submersibles, and reductions in costs for drop cameras and BRUVs, allow for direct observation of animals at great depths, facilitating improved understanding of their ecological and trophic niches. This study reports new global depth records for three elasmobranch species observed in the Saudi Arabian Red Sea (Carcharhinus altimus, Rhinobatos punctifer, Iago omanensis), also presenting ethological evidence on Iago omanensis feeding behavior. Our findings have significant implications for conservation strategies and the development of targeted conservation measures. The provisioning of data on new depth ranges allows places like NEOM to better manage and protect deep sea habitats, due to the presence of species occurring at those depths.

What goes bump in the dark? Uncovering cryptic biological activity using Passive Acoustic Monitoring (PAM) in the Central Red Sea Mesophotic reef zones

Michelle-Nicole Havlik

Despite covering a large amount of seafloor & representing a significant percentage of coral reef ecosystem biomass, Mesophotic Coral Ecosystems (MCEs) globally have been largely understudied in comparison to their shallow counterparts. The Red Sea is a unique and biodiverse tropical ecosystem, where few mesophotic coral reefs have been studied. Underwater visual surveys are the typical method of assessing biology of reef ecosystems, however this technique is limited by depth, available light, and by cryptic species. As sound travels 5 times faster underwater than in air, it is an essential survival tool used by all marine life. Passive Acoustic Monitoring was therefore undertaken in the Central Red Sea (Saudi Arabia) to define spatiotemporal activity of marine life and characterize the overall soundscape. Hydrophones and CTD sensors were deployed at two locations at 70-80m, as well as at two adjacent shallow reef sites at ~10m depth, during a winter (Jan, 2022) and summer (Jul-Aug, 2022) season. The results of this study, the first of its kind in the Red Sea, show a clear shift in the soundscape between seasons, representing a change in fish and invertebrate activity. Temperature and oxygen levels in the mesophotic zone remained relatively stable, in comparison to the shallow reef zone which saw a steep temperature increase and large diel fluctuations in oxygen in the summer. Finally, chronic exposure to man-made noise is shown to negatively impact marine life, and is evident across Red Sea MCE soundscapes, especially deriving from the deep shipping lane. To ensure Saudi Arabia meets ambitious environmental goals in line with Vision 2030 impact-neutral coastal development plans and the UN SDGs, focus should be placed on how to manage and reduce sonic impact on these critical coral reef ecosystems.

Evaluate the resilience status of the coral reef ecosystem in Wadi El-Gemal-Hamata National park, Southern Red Sea

Abdulrahman Shaaban

This study aims to evaluate the resilience status of the coral reef ecosystem in Wadi El-Gemal-Hamata National park, Southern Red Sea. Six resilience drivers (coral diversity, coral diseases, anthropogenic impacts, herbivores biomass, recruitment, and algae) have been chosen to be assessed in the different sites. Data were collected seasonally in the period from August 2015 to July 2016 using SCUBA diving from three inshore and two offshore reef sites. Offshore sites, Wadi El-Gemal and Suyul Islands recorded higher coral cover, higher fish abundance, and biomass, fewer algae, than inshore sites. Coral cover recorded 82.3% in the exposed sites compared to 63% in the sheltered sites. The average abundance of hard and soft corals was higher in the exposed sites with 91 and 5.4 colonies/125m2, respectively. Massive corals were more abundant in the exposed sites (67) than in the sheltered sites (15). On contrary, branched corals had a higher number in sheltered sites (34 colonies/ 125m2) than the exposed sites (23 colonies/125m2). The average biomass of grazer, browser, and excavator fishes was higher in the exposed sites than in the sheltered sites with 9581g, 4601g, and 1029g/250m2, respectively. Whereas the average biomass of scrapers was higher in sheltered sites (902g/250m2) than in exposed sites (678g/250m2). The new coral colonies of different sizes had almost the same density in both exposed and sheltered sites. The analysis of variance (ANOVA) showed that resilience factors varied significantly among sites. Based on resilience factors evaluation in this study, offshore sites are more resilient than onshore sites.

Influence of Global Warming and Industrialization on Coral Reefs: A 600-Year Record of Elemental Changes in the Eastern Red Sea

Chunzhi Cai

he Red Sea has been recognized as a coral reef refugia, but it is vulnerable to warming and pollution. Here we investigated the spatial and temporal trends of 15 element concentrations (Na, Mg, P, S, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Sr, Mo, and Cd) from 9 central Saudi Arabian Red Sea coral reef sediment cores (aged from the 1460s to the 1980s). We found several element concentrations were higher in the northern (Na, Ca, Cr, Fe, Co, Ni, and Sr) or southern (Mg, P, S, Mn, and Cd) Red Sea reef sediments, respectively ($p < 0.05$). In the central (i.e., Thuwal) to southern (i.e., Al Lith) Red Sea, the temporal trends of element concentrations were diverse, but the reef sedimentation rates (-36.4% and -80.5%, respectively) and all elemental accumulation rates (-49.4% for Cd to -12.2% for Zn, and -86.2% for Co to -61.4% for Cu, respectively) declined over time, potentially caused by warming-induced thermal bleaching. In the central to northern Red Sea (i.e., Yanbu), the severity of thermal bleaching is low, while the reef sedimentation rates (187%), element concentrations (6.7% for S to 764% for Co; except Na, Mg, Ca, Sr, and Cd), and all elemental accumulation rates (190% for Mg to 2697% for Co) exponentially increased from the 1970s, probably due the rapid industrialization in Yanbu. Our study also observed increased trace metal concentrations (e.g., Cu, Zn, and Ni) in the Thuwal and Al Lith coral reefs with severe bleaching histories, consistent with previous reports that trace metals might result in decreased resistance of corals to thermal stress under warming scenarios. Our study points to the urgent need to slow down global ocean warming and reduce the local discharge of trace metal pollutants to protect this biodiversity hotspot.

DNA-Stable Isotope Probing identifies acetate and pyruvate consumers in the brine seawater interface's microbial communities of the Afifi brine pool in the Red Sea

Charlene Odobel

Brine pools, also called Deep Hypersaline Anoxic Basins (DHABs) are bodies of highly saline seawater found at seafloor depressions and are among the most extreme marine environments. The brine body salinity can reach ten times that of seawater, creating a density barrier preventing mixing with the overlaying seawater and generating sharp chemo-redoxclines at the Brine-Seawater Interface (BSI). The BSI hosts active, unique stratified microbial communities whose distribution and diversity are influenced by environmental gradients. We aim to identify active microbial communities that consume carbon sources to thrive in these extreme conditions. Due to the difficulties in preserving the microorganisms sampled under laboratory conditions, we used a culture-independent method, DNA-Stable Isotope Probing (DNA-SIP), which labels with the heavy C signature the components of the cells able to utilize 13C-labeled substrates.
Afifi brine pool was sampled during the Red Sea Decade Expedition 2022. It is sulfide-rich, shallow DHAB and benefits from inputs of coastal organic matter, with BSI microbial cell concentration being the highest observed for a brine pool in the Red Sea. Samples taken along the salinity gradient (54 to 250 PSU) were incubated with 13C-labeled pyruvate or acetate to monitor substrate consumption and microbial cell growth over time. The DNA-SIP enabled identifying the active key community players. Whatever the salinity, pyruvate and acetate promoted the growth of Marinilabiliaceae, Vibrionaceae, Thalassospiraceae, Desulfovibrionaceae and Desulfobacteraceae. Halanaerobiaceae developed on pyruvate only. Several 13C consumers are salinity-specific, such as Rhodobacteraceae at low salinity, Desulfohalobiaceae and Desulfuromonadaceae at higher salinity. This method also identified potential secondary consumers, using the products of pyruvate and acetate metabolism, mainly sulfate-reducing bacteria, such as Desulfocapsaceae and Sulfurimonadaceae at low salinity and Desulfosarcinaceae and Desulfuromonadaceae at higher salinity. DNA-SIP can provide a new understanding of the functioning and spatial dynamics of microbial groups involved in fermentation, chemo-heterotrophy, nitrate and sulfate reduction, which support ecosystems in such polyextreme conditions.

Culturing the Microbiome of the Hypersaline Pink Lake on the Red Sea Coast

Nicholas Kontis

Extreme environments exhibit not only inhospitable conditions for microbial life, such as high temperatures, pH, or salinity but also frequently display remarkable characteristics, such as color or odor. These distinctive traits are often connected to the intricate biochemical strategies employed by extremophilic microorganisms to thrive in challenging environmental conditions.

Saudi Arabia harbors a vibrant pink-pigmented lake on the Red Sea coast, located near to Al-Lith region. The pigment coloring has sparked several scientific questions regarding the unique nature of microbes and their corresponding metabolic functions. The combination of color, extreme temperatures, desiccation, and high salt concentrations in Saudi environments make these habitats promising sources of novel extremophiles.

Water and sediment samples were collected, and an amount of 1L of water was filtered through a 0.22¬µm pore-size filter. For the microbial culture, six serial dilutions were prepared using sediment and water filters. An amount of 100ul was plated onto agar plates of both low (NA/10, PDA/10, R2A) and high nutrient composition media (NA, BH, PDA) in triplicates. All media was prepared with 50% Pink Lake and 50% Milli-Q water. The agar plates were left to incubate at 40¬∞ for 3 weeks.

Based on in situ CTD measurements, the temperature was roughly 35¬∞C, the conductivity at 274 mS/cm, the pH between 6-7, the salinity at 22%, and the dissolved oxygen between 1-2 ppm. Although microbial growth is slow and limited, there are some promising microbial isolates observed in the R2A medium.

Deciphering the origin of the color, the correlated microbial metabolisms and the culturable fraction of the microbial community are crucial aspects of this study. This research will enable a comparative analysis of microbial consortia and their associated pigments and correlate with other pink lakes beyond Saudi Arabia.

DNA-Stable Isotope Probing reveals the diversity of glucose consumers in the microbial communities in the brine-seawater interface of the Afifi brine pool

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Deep Hypersaline Anoxic Basins (DHABs) are extreme hypersaline environments extending below the seafloor. Despite their harsh conditions, these environments support thriving ecosystems and host unique microbial communities. However, limited information is available on the diversity and functioning of these microbial communities due to limited sample access and challenges in cultivating the microorganisms in the laboratory.
The most active part of DHAB ecosystems is the brine-seawater interface (BSI), which harbours different microbial communities. This study focuses on the Afifi DHAB, a shallow site near the eastern coast of the Red Sea, and employs the DNA-Stable Isotope Probing (DNA-SIP) method to link microorganisms' identities with their associated functions. Two samples with different salinities (54 and 138 PSU) were collected from the middle and the lower parts of Afifi BSI, respectively. These samples were anaerobically incubated with glucose as C source. DNA-SIP allowed to identify carbon consumers under the different conditions of the two BSI layers of the Afifi and to construct a hypothetical carbon flow among among the different microorganisms in the communities.
The predominant glucose utilizers were Vibrionaceae and Halanaerobiaceae, while several sulfate-reducing bacteria were recognized as potential secondary glucose consumers, i.e. utilizing the metabolites produced by the primary glucose degraders. Layers specificities were also revealed, e.g., glucose is consumed by Deferribacteraceae, Rhodobacteraceae and Pseudoalteromonadaceae in the upper, less salty layer, and by Acetothermiia, Melioribacteraceae and Spirochaetaceae in the deeper and saltier layer.
Overall, DNA-SIP provides an initial functional characterization of the microbial community within the Afifi DHAB, offering insights into the ecological dynamics and metabolic activities of microorganisms in this unique ecosystem.

A sea of birds: first seabirds population assessments in the Saudi Red Sea

Licia Calabrese

Phenology, abundance, and distribution of breeding birds, as well as breeding success are important baseline parameters needed to assess population trends and dynamics, identify biodiversity hotspots and potential breeding sites, and assess habitat selection.
In the Red Sea region, seabirds have generally been understudied, and reliable and complete data are lacking for most of the 19 Important Bird Areas islands established on both Saudi and Egyptian/ Djibouti sides. Such data are now especially important since tourism development projects have started at several of these locations.
Among the areas being developed are several islands in the Al Wajh Bank IBA, three islands in the Duba region and one of the islands located north of the Farasan Bank (offshore of Al Lith). For the latter two regions, prior to this study there were no published data on breeding species and population abundance. Within the Al Wajh Bank five out of the 92 islands had been visited in 2011, but there was no comprehensive data for the whole lagoon. Moreover, for the four species triggering the Al Wajh IBA, the most recent estimates (which did not include numbers but only presence/absence) dated back to the early 1990s.
The aim of this study is to assess distribution, abundance, phenology, and population trends of 13 priority seabird species that breed in the Al Wajh lagoon, the Al Lith islands and the Duba islands. These species were selected based on their global and local conservation importance (IUCN Red list global and regional classifications, and High Conservation Priority species list for Saudi Arabia), their level of endemism, and other special local considerations. This assessment includes three out of the four species that triggered the Al Wajh IBA, notably Crab plover (Dromas ardeola), White-eyed gull (Ichthyaetus leucophthalmus) and Sooty gull (Ichthyaetus hemprichii). Breeding success for seven species was also assessed.
In 2018 and 2019 the Al Wajh islands were visited once in summer to have an idea of the species breeding there while from December 2020 to August 2022, they were visited multiple times throughout each year to assess bird phenology and breeding population in different seasons. The islands West of Al Lith were visited once - during the seabird breeding season in 2021, while the islands in the Duba area were visited multiple time throughout 2022. For all surveys, all nests were counted, and the area occupied by the

different colonies georeferenced. Habitat selection was assessed for some of the 13 targeted species.
In total, more than 25,000 nests were counted each year, mainly in summer, when eggs or small chicks were present. The most abundant and widespread species was the White-cheeked tern, and the second most widely widespread species was the Osprey. The colonies of Lesser-crested tern had the highest density of breeding pairs.
Global population estimates are not fully reliable and probably incomplete for most of these species, but we estimated that the Al Wajh lagoon alone hosts the following percentages of global populations: Crab Plover 5%, Sooty gull 17-35%, White-eyed gull 15%, Bridled tern 1%, White-cheeked tern 4%, Lesser-crested tern 2%, making the area a regional and global hot spot for these species.
Some of the islands occupied by breeding birds will be developed for tourism activities within the Saudi vision 2030. At the same time, the Saudi Green Initiative, and the Red Sea Global have goals to enhance biodiversity in these areas . Such ambitious conservation objectives can only be achieved by informed spatial planning built on reliable and complete data of the kind presented here. We also discuss potential mitigations and enhancement actions that could be used to manage impacts and enhance populations. Continued assessment of population trends will be essential to understand the success of those conservation and enhancement efforts.

Estimation of main turtle nesting areas and total nesting female population in The Red Sea and Amaala project areas.

Raul Vilela

Between the months of March and November 2022, a sea turtle nesting survey was conducted in The Red Sea (TRS) and Amaala project areas. Daytime monthly beach patrols were conducted to estimate the populations of nesting female Green and Hawksbill turtles, utilizing the number of tracks and identified nests for estimation.

The Amaala surveys focused on An Numan Island and the coastal beaches in and around Triple Bay. When possible, two additional small islands (An Nabaqiyah and Awandia) offshore from Triple Bay, as well as other coastal beaches, were also surveyed. In TRS, 64 out of the 92 islands were surveyed, while the other 28 islands lacked suitable nesting habitat, had restricted access, or had no previous nesting evidence from extensive surveys conducted in 2021. Surveys were conducted at least once per month in the primary nesting areas and less frequently in other islands.

The survey identified overall timing and peaks of nesting activity, with main nesting seasons for Hawksbills of May to July and for Green July to September. In Amaala, nesting was primarily located on An Numan island, with some nesting also on the mainland coast and (at very low numbers) on other islands. In TRS, main nesting sites for Hawksbills were concentrated in Waqadi (around half observed nesting), Breem, Quman, Mardunah, and Ghawar, and for Greens at Breem (around ¬æ of all recorded nesting tracks), Waqadi, and Ataweel.

The total estimated female nesting population for the 2022 season was 19 Hawksbills and 40 Green turtles in Amaala, and 69 Hawksbills and 173 nesting female Green turtles in TRS.

These findings are crucial for assessing population status and trends and guiding conservation measures. They provide valuable information for conservationists and policymakers working towards the preservation of these endangered turtle species.

Evaluation of Marine megafauna bycatch in Saudi Red Sea Shrimp trawl fisheries using on-board observers

Chris Poonian and Rex Santucci
KAUST Beacon Development

Population declines in large marine vertebrates have highlighted the need to evaluate the impacts of bycatch in global fisheries. Marine megafauna are particularly vulnerable due to their late maturity, slow rates of reproduction, migratory nature and the array of other potential threats at various life history stages. However, comprehensive assessments are limited due to logistical complexities, high costs, and sparse baseline datasets, as well as a limited understanding of many affected populations' demography; this absence of comprehensive recording and monitoring systems has likely led to underestimations of megafauna mortality.

Our work aimed to address these challenges by evaluating marine megafauna bycatch in Saudi Red Sea shrimp trawl fisheries including the spatial distribution and frequency of capture. Onboard observers were deployed on a representative sample of shrimp trawlers in Jazan and Qanfudah, and recorded the occurrence and frequency of bycatch in each haul. The most commonly captured species included rays and bottom-dwelling sharks such as Himantura uarnak (Vulnerable), Maculabatis ambigua and Rhinoptera bonasus (both Near Threatened), indicative of the soft bottom, shallow habitats that dominated shrimp trawling grounds. Bycatch-related mortalities of two sea turtle species Chelonia mydas (Endangered) and Eretmochelys imbricata (Critically Endangered) were also recorded.

Analysis of the spatial distribution and frequency of capture can identify sites of high bycatch occurrence and threatened species hotspots. These findings will inform the development of targeted mitigation measures, such as modified fishing gear designs and area-based management approaches. There is a wider need for improved management measures that address the bycatch of threatened marine megafauna species to mitigate potential population declines and ensure the long-term sustainability of shrimp fisheries in the Red Sea.

Title: Using Multidisciplinary Approaches to Understand Threats to Dugongs In NEOM

Authors: Patricia ZR Davis; Mishari Alghrair; Abdulqader Khamis; Stephen Parr; Ricardo Oliveira Ramalho

Abstract:Dugongs (Dugong dugon) are herbivorous marine mammals that rely on seagrass meadows as their primary food source. This study implemented a comprehensive approach to assess dugong populations and inform conservation strategies in NEOM. Through in-water evaluations, boat observations, fisher interviews and drone surveys, we aimed to collate data on dugongs in NEOM.
A total of 10 dugong feeding areas were identified across four survey sites: Muweileh (4), Um Shujarat (1), Sindalah (3), and Ras Sheikh Humed (2). Halophila spp. dominated most feeding areas, except for Sindalah (SINM2), which had a mix of Thalassodendron ciliatum and H. uninervis. Seagrass density and condition varied across feeding areas. Feeding trail widths ranged from 14 cm to 28 cm, suggesting the presence of juveniles. Trail lengths varied greatly, ranging from 2m (Sindalah) to 15m (Ras Sheikh al Humed). Drone surveys generated over 55 thousand images that were evaluated for the presence of various megafauna using both human and AI approaches. Interviews with fishers revealed occasional sightings of individuals and groups of adult dugongs, as well as carcasses on beaches. Dugongs were seen all year, but mainly between June and December, with seagrass beds as the predominant habitat.
The proximity of key shallow dugong feeding areas to the coast and ongoing development plans pose significant threats. Sedimentation from construction activities, eutrophication, sound pollution, collisions with watercraft, and climate events jeopardize seagrass habitat and dugong populations. However, incidental capture in fishing nets is likely low. The study provides evidence of dugongs using all regions of NEOM throughout the year, with possible avoidance of colder waters in winter. This study's findings underscore the need for targeted conservation measures and ongoing monitoring to safeguard the survival of this vulnerable species.

Keywords: Dugong, Dugong dugon, Conservation

Identification of a potential new Red Sea elasmobranch nursery area within the Al Wajh Lagoon

Royale Hardenstine

Indian Ocean Humpback dolphins (Sousa plumbea) are one of the 17 species of cetacean that have been observed in the Red Sea and the only Red Sea cetacean listed as endangered on the IUCN Red List. Due to their nearshore, shallow-water habitat preferences, a threat to humpback dolphins includes coastal development. Unfortunately, data for S. plumbea is lacking throughout most of the Saudi Arabian Red Sea coast, making it difficult to detect any potential impacts or changes in population size. During other monitoring efforts within the Al Wajh lagoon, between March 2021 and April 2023, opportunistic sightings of all cetaceans observed were made including recording a location, the species, and number of individuals. When possible, photographs of dorsal fins and other identifiable markings were recorded. Overall, there were 18 observations of humpback dolphins, in some cases associating with bottlenose dolphins (Tursiops spp.). From these observations one pod that included a calf could be reliably identified four times throughout 2021. Additionally, at least two other individuals were identified, with one being observed 10 months apart both times associated with a large pod of bottlenose. As monitoring efforts for cetaceans continue to be implemented the addition of photo-identification, would make it possible to better understand the individuals within Al Wajh lagoon. In the future to get an accurate population estimate continued improvements in monitoring this species along the Saudi Arabian coast will be essential. Citizen scientists or local dive guides could be enlisted to help collect additional photos. When possible different entities should combine photo-databases and data.

Hugo Mann

Seagrass meadows are natural carbon sinks, and as such are important to conserve due to their capacity to mitigate impacts from climate change resulting from anthropogenic carbon emissions. Understanding their contribution more accurately is vital, but there are challenges involved in mapping them and understanding their distribution and extent. In this study we investigate the use of satellite telemetry of green turtles Chelonia mydas for identifying seagrass blue carbon resources in the Red Sea. Fifty-three nesting female C. mydas were satellite tracked and identified 41 foraging sites. Fourteen of these foraging sites were ground-truthed with a resulting 100% accuracy of tracking data correctly identifying seagrass meadows, whilst the satellite imagery-based Allen Coral Atlas was only 40% accurate (N=30). Six of the ground-truthed sites identified by C. mydas were deeper than 8 m, the standard depth to which remote imagery can be used. Carbon stocks estimated from C. mydas derived sites were 4.89 ¬± 0.83 kg Corg m-2. Successful identification of seagrass meadows in the Red Sea using C. mydas could lead to the application of this novel method around the world and improve estimates of seagrass extent. This would be a great benefit for estimating the amount of carbon stored in seagrass meadows, which is important for understanding the global carbon cycle, and informing conservation, as the carbon stored in these habitats would be reintroduced if these habitats are damaged.

A Multidisciplinary Approach to Quantifying Marine Megafauna Populations and Habitat Use in NEOM

William Paterson; Hector Barrios Garrido; Mishari Alghrair; Abdulqader Khamis; Enjey Ghazzawi; David Wells; Ricardo Oliveira Ramalho

The term ‚Äúmarine megafauna‚Äù encompasses a wide range of large, charismatic species across several taxa. Multiple species including cetaceans, dugong, marine turtles, sharks and rays are present at NEOM. Multidisciplinary and innovative survey techniques have been used to target knowledge gaps regarding species abundance/diversity, distribution and habitat use. Here, we summarise data collected during dedicated boat transects, at-sea drone surveys, use of artificial intelligence (AI) to identify species in aerial imagery and a centrally managed sightings database for data collected at NEOM. The more common cetacean species observed in NEOM waters are spinner dolphin, pantropical spotted dolphin, Indo-Pacific bottlenose dolphin, common bottlenose dolphin and Indian Ocean humpback dolphin. More rarely seen are Bryde‚Äôs whale, false killer whale and Risso‚Äôs dolphin. Dugongs are also present in relatively high numbers with a significant proportion of the global population being found at NEOM. Two species of marine turtle, green turtle and hawksbill turtle, frequent NEOM waters with its islands likely to represent important nesting sites. Lastly, many shark and ray species have been observed including whale shark, manta ray and eagle ray. This high diversity and abundance of marine megafauna demonstrates the importance of recent surveys that aim to analyse the extent and overall biodiversity value of habitats and species found within NEOM waters. These results contribute to enhancing the otherwise limited knowledge base of marine megafauna species at NEOM where construction activity at several islands is likely to occur. Understanding these species‚Äô distribution, frequency and seasonality will inform management plans to minimise potential impacts over their habitats. Recent work by NEOM and KAUST Beacon Development aims to identify hotspots where conservation measures should be implemented to have an optimal effect.

Keywords: Marine megafauna, Conservation, Cetaceans, Dugongs, Elasmobranchs

Linking social and economic value to the extinction risk of species

Andrew J. Temple

To achieve sustainable marine resource use, it is as important to understand the social and economic drivers of unsustainable uses as it is the biological drivers and environmental consequences. The Red Sea is no exception, and here there is little-to-no research conducted on the social and economic drivers of unsustainable resource use. We present an example of how such research can help to guide the formulation of effective management strategies, in the hope that researchers will begin to integrate similar aspects into their future research.

The extinction risk of sharks is disproportionately higher in coastal tropical waters where small-scale fisheries dominate, presenting unique management challenges. Small-scale fisheries provide a critical source of economic and nutritional security, but fishers are among the most vulnerable socio-economic groups because their exposure to economic, social, and environmental shocks is combined with limited adaptive capacity. Using Kenya and Zanzibar as a case study, we examine the interactions between sharks and small-scale fisheries. We find that sharks are an important source of economic and nutritional security, primarily from species threatened with extinction. Further, the most economically valuable sharks are larger, slower reproducing, and more likely to be threatened with extinction, providing a strong economic incentive to target endangered species. Given the high economic motivation and intensive fishing pressure, small-scale fisheries are undoubtedly important contributors to the ongoing decline of many threatened shark species. The decline of sharks may have damaging consequences for wider marine ecosystems and ecosystem services. In the absence of effective fisheries management, we show that within small-scale fisheries the conditions exist for an economically incentivised positive feedback loop in which vulnerable fishers are driven to persistently overfish vulnerable and declining resources. In doing so, they undermine their own economic and nutritional security and that of their communities. To be successful management must break the feedback loop or be doomed to failure.

Numerical Investigation of Shipping Noise in the Red Sea

Rihab Larayedh, George Krokos, Bruce D.Cornuelle, and Ibrahim Hoteit.

Abstract: Underwater noise pollution is a significant environmental issue that can have detrimental effects on marine ecosystems. One of the main sources of underwater noise pollution is ship traffic, which has been shown to negatively impact marine animals by masking communication signals and altering their behaviors. This study represents the first comprehensive analysis of underwater ship noise in the Red Sea. It aims to generate noise maps of ships sailing through the main shipping lane in the Red Sea. The Range-dependent Acoustic Model (RAM), incorporating anthropogenic and environmental inputs, was utilized to predict maps of underwater ship noises. The application of RAM yielded maps showcasing the spatial and temporal distribution of underwater ship noise in the Red Sea, providing valuable insights for policy makers and facilitating targeted mitigation efforts, with implications for future research on the impacts of underwater noise pollution on marine life.

Mangrove response to coastal development using UAV remote sensing and environmental monitoring

Ioana Andreea Ciocanaru

Coastal development threatens mangroves through modifications to the hydrological regimen and water quality caused by land reclamation (e.g., dredging). Red Sea mangroves are adapted to extreme environmental conditions due to the very hot and arid climate. Along the Saudi Arabian coast, mangroves provide nursery habitats and shoreline protection but they are facing the effects of rapid coastal development associated with increasing tourism. Here we studied the effects of coastal development on mangroves, at two construction sites within the Al-Wajh lagoon, in the northern Red Sea. These locations support stands of the two native mangrove species in the Red Sea, Avicennia marina and Rhizophora mucronata. To assess the impact of dredging and causeway construction, we measured changes in water quality (i.e., salinity, nutrients) and leaf carbon and nitrogen content. We also used multispectral UAV remote sensing to capture the mangrove community's response to disturbance. This research effort has been carried out using monthly in situ and UAV data, collected over the course of a year, in the middle of ongoing land reclamation activities. The present study offers some of the first insights into the temporal dynamics of mangrove canopies in the Red Sea and provides a framework for understanding the natural and anthropogenic drivers of long-term changes in mangrove distribution throughout the region.

Impacts of coastal sprawl and the importance of monitoring non-indigenous species in artificial coastal habitats. A case study in a marina of the Red Sea

Juan Sempere-Valverde

Coastal zones provide approximately 70% of the world's ecosystem services. Unfortunately, over 25% of these vital habitats have undergone alterations due to human activities, with nearly 20% of the world's shoreline being now artificial. Artificial structures are more prevalent in areas of high ecosystem richness, diversity, and productivity, such as lagoons, estuaries, and bays. Within artificial infrastructures, ports and marinas are major hubs of human activities associated with trade and recreation and important hotspots of environmental and biological pollution. They pose a serious threat to coastal communities, leading to habitat degradation and the spread of non-indigenous species (NIS) and pests. Because of this, port infrastructure has emerged as priority area for the monitoring of non-indigenous species (NIS), which can be potentially harmful to the environment, coastal economies, and health; and for the integration of ecological-engineering interventions, which have become essential to integrate urban areas with nature and enhance the quality of life for coastal settlements and coastal ecosystems health. Within this framework, a pilot study is currently underway in CMOR marina, near King Abdullah University, with the objective of catalogue NIS, using morphological and molecular methods, and as an initial step for the monitoring of NIS in the natural and artificial habitats of the Red Sea. Within the outputs of the study, the construction of a DNA barcoding reference library emerges as a crucial step for further monitor the presence and spread of these species in different coastal habitats. This information will contribute to a better understanding of the effects of coastal infrastructure on coastal marine ecosystems, the threats posed by NIS in the Red Sea, and support the development of targeted conservation and mitigation measures. Ultimately, the study seeks to promote the sustainable management of coastal zones, safeguarding their ecological integrity and preserving the vital ecosystem services they provide.

Diversity and potential commercial value of edible discarded by-catch species in shrimp trawl fishery in the Southeastern Red Sea

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Beacon Development Department, King Abdullah University of Science and Technology, Thuwal, Jeddah, 23955, Saudi Arabia

Globally, by-catch is one of the major challenges facing the managers of multi-species marine fisheries. Shrimp trawling in tropical waters produces enormous amounts of by-catch including species with significant economic value as food, ornamental or other purposes. This study documents the diversity and potential commercial value of by-catch fauna that may have nutritional value. Sampling was conducted onboard commercial trawl vessels off Al-Qunfudhah and off Jizan in the southeastern Red Sea from October 2022 to March 2023. The study recorded a total of 86 species of commercially important marine fauna belonging to 16 orders, 31 families and 50 genera. The whole fauna comprised 72 species of fishes, ten crustaceans and four cephalopods. Scads and trevallies (Carangidae) represented most diverse group with 23 species followed by snappers (Lutjanidae) and sweetlips (Haemulidae) with six species each. No significant variation in diversity was observed between the two sites studied. It was estimated that a total of 4421 tons of commercially important marine fauna comprising 3443 tons of fishes, 580 tons of crustaceans and 398 tons of cephalopods are being discarded as by-catch in the area each year. The quantity estimated conservatively amounts to approximately 90 million SAR market value. The quantity and value of potential commercial species in Jizan (3370 tons and 72 million SAR) surpasses that of Al-Qunfudhah (1051 tons and 18 million SAR). This can be attributed to the highest number of active boats and high-value species particularly shrimps in Jizan. Considering that the main reason these potential resources are treated as discards is their smaller size, it is crucial to find sustainable solutions, such as the introduction of bycatch reduction devices or reducing fishing effort, in order to maintain a sustainable fishery in the shrimp trawling grounds along the Saudi Arabian Red Sea coast.

New Standard for Mitigating Dredging Impacts in Sensitive Marine Habitats in the Red Sea

David McGrath

The Red Sea Project (RSP) is being developed in a unique and sensitive area with a high-quality marine environment and complex ecosystems. Protection and enhancement of the natural capital within the proposed development areas has been identified as a central tenant driving the project planning process. However, the development of successful tourist destinations often requires associated marine infrastructure, such as marinas. Marina construction often requires dredging of shallow areas to obtain adequate draft for the vessels that will utilize the marina.

KAUST ‚Äì Beacon Development (KBD) and the Danish Hydraulic Institute (DHI) have developed a proactive approach to turbidity monitoring and management during dredging operations targeted at managing water quality impacts that risk generating chronic or acute stresses outside the immediate dredging footprint, in areas of high ecological sensitivity.

A management system should be implemented where coupling operational mathematical models (hindcast/forecast) and measurement data ensures eco-compliance and minimizes the risks. The system includes:
‚Äì Implementation of an environmental management and mitigation framework in alignment with an approved Dredging Management Plan.
‚Äì Water quality monitoring buoys that provide real-time feedback;
‚Äì Use of drones or satellite images to provide aerial inspections of the dredging activities and map plume dispersion; and
‚Äì Use of plume dispersion modelling to hindcast and forecast turbidity plumes.

Weekly Turbidity Management Group meetings should be conducted with involvement of all concerned stakeholders (Project Owner, Environmental Consultant, Hydrodynamic Modelers, Dredging Contractor, PMC). The TMG should review:
1) Review of previous week‚Äôs dredging operations and associated results of hindcast modelling;
2) Forecast of works scheduled for the week ahead with associated environmental risks identified;
3) Review of modelled turbidity plume dispersion forecast and mitigation actions required to protect sensitive ecological receptors; and
4) Environmental incidents or near-misses identified during the previous week and remedial actions required.

Our presentation outlines the approaches employed and presents a case study from Sindalah Island where the system was successfully applied by KBD and DHI ‚Äì the first time such an approach has been implemented in the region.

Critical Aspects of Marine Corrosion and its Management

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Abstract

Seawater covers more than 70 per cent of the earth's surface and many common metals and alloys are attacked by seawater. Seawater is a complex, delicately balanced solution of many salts containing living matter, suspended silt, dissolved gases etc. However, effect of bacteria, dissolved oxygen and chloride are very critical in marine corrosion. This paper explores detrimental effect of above factors on corrosion of metals in marine environment. Possible remedial measures to protect the metal and alloys in marine conditions will also be discussed.

Diversity and drivers of coral reef cryptobenthos across a remote and pristine system

Margaux Steyaert

To predict the impacts of projected global climate change and anthropogenic stress on coral reefs, we must have a comprehensive understanding of all the communities which reefs harbour, including organisms that are hidden and inconspicuous such as cryptofauna. Little research has been conducted on cryptobenthic communities of the Chagos Archipelago Marine Protected Area, a remote and protected reef system in the Central Indian Ocean, which acts as a reference site for the wider region. Between 2018 and 2022, cryptobenthic communities were studied across the MPA using Autonomous Reef Monitoring Structures (ARMS), artificial devices used to study benthic ecosystems. Fluorescence and daylight imaging, community multi-marker metabarcoding, barcoding and eDNA sampling methods were utilised to assess benthic eukaryotic diversity. We found a rich and highly diverse cryptobenthic assemblage with high spatio-temporal turnover across sampling sites, but a community poorly represented across genetic reference databases. Only 3-4% of >18,000 sequence variants were assigned to species level. We also integrated biological and physical data to show how cryptobenthic groups vary across exposed and sheltered reef habitats. This research significantly advances our knowledge of reef diversity within the Central Indian Ocean, highlighting the importance of the MPA as a biodiverse scientific reference site, and providing a baseline for future studies of these complex communities across the region. We are now scaling up this work and present a new multi-institutional collaborative project, Future Reef, which collates ARMS multi-marker datasets to assess taxonomic and functional diversity across global gradients of anthropogenic stress on reef systems.

Genetic differentiation of green and hawksbill turtle rookeries in the Arabian Gulf

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Understanding genetic diversity and connectivity of sea turtle populations in the extreme environment of the Arabian Gulf and to the wider western Indian Ocean is crucial for effective species conservation, particularly in the face of climate change and anthropogenic activities. This study focused on the genetic diversity of hawksbill turtles (Eretmochelys imbricata) nesting in the Gulf at rookeries in Saudi Arabia and United Arab Emirates (UAE) and green turtles (Chelonia mydas) at Saudi rookeries, and investigated the extent of genetic differentiation with other rookeries previously studied in the Gulf and the western Indian Ocean. Blood and flipper tissue samples were sampled from nesting hawksbill (n = 19) and green (n = 76) turtles at Jana and Karan islands in Saudi Arabia from 2017-2020. Data from a previous study of hawksbill turtles at UAE rookeries were reanalyzed in this study. Sequencing was done of approximately 766 base pairs of the d-loop (control region) of mitochondrial (mt)DNA. For hawksbill turtles, four new haplotypes were discovered, yielding eight haplotypes at Jana Island and 10 haplotypes in the UAE, resulting in a total of 18 haplotypes in Gulf rookeries. The Jana Island rookery was not differentiated from either the Iran or UAE rookeries, but there was a suggestion of limited gene flow between the Iran and UAE rookeries. All Gulf rookeries were highly differentiated from rookeries in the Seychelles. For green turtles, four haplotypes were recorded in the Saudi rookeries with one haplotype as newly observed in the Gulf. Tests of genetic differentiation between sample sites in the Arabian Gulf, Gulf of Oman, western Indian Ocean and the Red Sea indicated that the green turtles nesting at Karan and Jana Islands form a unique population that is differentiated from all other populations. Implications for species conservation and management in the Gulf and western Indian Ocean will be discussed.

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These findings are crucial for assessing population status and trends and guiding conservation measures. They provide valuable information for conservationists and policymakers working towards the preservation of these endangered turtle species.

Opening Rates of the Red Sea

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Due to rotation of the Arabian plate, opening rates of the Red Sea change significantly along the over 2000 km long inland sea. To study this variability in opening rates, we have combined velocities from 168 continuously operating GNSS (GPS) stations located on the Arabian plate to provide a new estimate of the present-day motion of the plate with respect to its neighboring tectonic plates. A single Euler pole at 50.93¬∞¬±0.15¬∞N, 353.91¬∞¬±0.25¬∞E with a rotation rate of 0.524¬±0.001 ¬∞/Ma explains well almost all the GNSS station velocities relative to the ITRF14 reference frame, confirming that the entire Arabian plate moves coherently as a rigid body. Internal strain rates at the plate-wide scale are small, although at a smaller scale some areas are actively deforming, mostly due to groundwater pumping. The new Euler pole estimate provides updated information about the relative movement directions and rates between the Arabian plate and the surrounding Nubian, Sinai, Anatolian, Eurasian, Indian, Somalian and Danakil plates. For the Red Sea, the opening rates increase from 7.0 mm/year in the north where the Dead Sea fault meets the Red Sea rift (~27.5¬∞N), to 9.6 mm/year at the Zabargad Fracture Zone (~24.0¬∞N), to 12 mm/year south of the Jeddah transect (~21.0¬∞N), and to 15 mm/year where the rift meets the triple junction between the Arabian, Nubian and Danakil plates (at ~17¬∞N). South of that triple junction opening rates within the Red Sea decrease to zero near Hanish/Zukur Islands (at ~13.8¬∞N), less than 200 km away from Bab al-Mandab Strait where the Red Sea meets the Gulf of Aden. Instead, the opening motions are progressively transferred inland along the Danakil Rift with opening rates reaching the full Nubian-Arabian motion (~19 mm/year) at the Afar triple junction.

Earthquake relocations in the Gulf of Aqaba

Sofia Manzo-Vega, Laura Parisi, Sigurjon Jonsson and Martin Mai

Seismic activity in the Gulf of Aqaba (GoA) poses serious threats to the development of the infrastructure in the NEOM region of Saudi Arabia. For such a reason, a temporary seismic network (GA network) has been deployed along the Saudi coast of the GoA to identify seismically active faults. A preliminary catalog obtained from data of this temporary network and least-square inversion of first arrivals of P and S waves displays a previously unknown onshore cluster of earthquakes in the proximity of the planned NEOM infrastructures. Moreover, the Saudi Geological Survey (SGS) catalog contains a swarm of events that occurred in September 2021 in the southern GoA that depicts an unknown fault striking NE-SW in slight disagreement with the tectonics of the GoA.

In this work, we use a probabilistic method based on partial waveform inversion to relocate the onshore cluster and the offshore swarm by using the QuakeMigrate location method. Important changes are found in the distribution of previously localized events. For the onshore cluster, we locate 250 events from the 262 initial catalog. Their locations moved from onshore to the Gulf of Aqaba and their depth increased. For the September 2021 swarm, we identified 394 seismic events, which corresponds to about 80% more events when compared with the existing SGS catalog. The new locations depict a fault striking NW-SE and a ‚Äúbanana‚Äù shape depth distribution roughly centered on the coastline.

Our results suggest that the geometry network and traditional location methods might influence fault imaging. However, the extent of this influence depends on the fault strike and can be mitigated by employing alternative localization methods.

Quantitative Assessment of Seismic Strain and Crustal Deformation in the Southern Red Sea Rift System

Basem Al-Qadasi

The Southern Red Sea (SRS) is situated in a geodynamically active zone, where it intersects with the Gulf of Aden (GA) and the East African Rift (EAR) plate boundaries, forming a triple junction. This intersection fosters a vibrant tectonic deformation, predominantly manifesting as seismic activity. The objective of this study is to quantify the seismic strain rate and examine its contribution to the overall crustal deformation within this region. This investigation initially involves partitioning the region into fourteen distinct seismogenic zones. Subsequently, the moment tensor summation technique is utilized to compute the seismic strain rate and velocity tensors for each zone. To ascertain the ratio of seismic to aseismic deformation, the seismic coupling coefficient is measured.

Seismic deformation estimates disclose extension rates ranging from 1.0-7.7 mm/yr in the SRS, 1.3-10.0 mm/yr in the GA, and 1.5-10.2 mm/yr in the Afar plate boundaries. Seismic coupling coefficient assessments reveal that seismic strain contributes less than 10% to the total crustal deformation across all seismogenic zones, with the exception of south-eastern Afar (15-20%), and the Alula-Fartak Fault zone (24%).

Remarkably, regions of low seismic coupling correlate with high heat flow, elevated volcanic activity, positive Bouguer gravity anomalies, and a relatively low stress drop. A significant association was also discovered between areas exhibiting higher vertical seismic deformation and vertical mantle flow velocity rate anomalies.

These findings ratify the prevailing hypothesis that the overarching tectonics of the southern Red Sea Rift system are primarily governed by the Afar mantle plume. However, this influence is not uniformly distributed across the plate boundaries, resulting in spatial heterogeneity in crustal strength and, consequently, seismic flux rates. This heterogeneity could potentially elucidate the recurrent large earthquakes in southern and south-eastern Afar, as well as the frequent swarm-type earthquakes associated with high volcanic activity in the SRS and GA.

Coral Reef Community Mariculture ‚Äì RSG coral enhancement approach

Carol Buitrago-Lopez

Saudi Arabia's Red Sea coral reefs are one of the most valuable natural assets in the kingdom‚Äôs efforts to diversify its economy following the Saudi Vision 2030. Coral reef enhancement is one of the pioneer regenerative tourism programs carried out by the Red Sea Global (RSG) company in the Al-Wajh lagoon off the northern Saudi Arabian Red Sea coast. Rather than focusing on coral monocultures, the RSG coral enhancement program aims to mariculture diverse reef communities that preserve intrinsic relationships between corals and other reef creatures (e.g., fish, crustaceans, CCAs and filter-feeders), which may improve coral survival after outplanting, resulting in more effective restoration efforts. During the program's initial phase, eight large floating coral nurseries (64 m2 each) were deployed at three distinct locations and were populated with 8,000 adult coral colonies of Acroporidae, Pocilloporidae, and Poritidae among other coral families, along with other reef organisms relocated in advance of planned dredging activities. These coral nurseries were monitored using Structure from Motion photogrammetry, enabling 3-D model reconstruction and coral cover and surface area quantification. Preliminary results indicate average coral growth rates of 5%, with some species showing growth rates ‚â•10%, within the course of only 4 months. During the same period, fish community biomass and abundance on nurseries increased by 4X and 5X respectively. These results support the potential of using floating coral nurseries to cultivate reef communities capable of providing sustainable source material for active enhancement of key reefs in the area.

Sea Surface Temperature Predictions-A Machine Learning Approach

Sumayah Siddiqui

The rising sea temperatures caused by rapid climate change and increased global warming have had a significant impact on ecosystems and marine species. Coral reefs and breeding grounds for marine species have been directly affected by extreme sea surface temperatures (SST). SST is a crucial variable in understanding the global climate system. Not only does it help in predicting weather conditions, but it also enables the study of marine ecosystems. Extensive research has been conducted to estimate and measure SST in oceans, including the Red Sea. Analyzing the data can help identify the major contributing factors to SST fluctuations. However, the complexity and high setup costs associated with data obtained from satellites, ships, autonomous underwater vehicles, and other sources pose challenges. To overcome these challenges, state-of-the-art machine learning (ML) algorithms can be utilized to predict SST based on various input variables. In this study, experimental data on relative humidity and wind speed is used to train different ML models for SST prediction. The accuracy of these models is evaluated using root mean squared error (RMSE) and coefficient of determination (R2) as comparison metrics. The results demonstrate that ML models can accurately predict SST, achieving accuracies of up to 95%. Future research aims to develop time series forecasting models using Recurrent Neural Networks (RNN) and physics-based ML models to further enhance and improve the accuracy of existing models.

The status of marine crab and its management strategies along the Sudanese Red Sea coast

Abdirahman Mohamed

This study was conducted between April and September 2016. In three coastal regions of Sudan: Suakin, Port Sudan, and Mohamed Gulf, to determine the state of crabs and the methods used to manage them. For each of the three regions, 30 fishermen were chosen from among 90 total, and questionnaires and interviews were given.
The fishermen's ages ranged from 20 to 80 years old. This demonstrates the value of the fishing industry and its capacity to offer opportunities for a living to fishermen of all ages. The findings indicated that mud crab and blue crab are the two most significant marine crab species that may be found on the Sudanese coast. These crab species are used in coastal fisheries. Fishermen catch marine crabs along the coast in a variety of habitats, including coral reefs, muddy bottoms, and sandy bottoms. However, due to the abundance of fluids, particularly mud crabs, it is widely distributed in the southern region (Suakin).
This survey found that 59% of fishermen used nets to catch crabs, and 60% of them did so at night. Additionally, some fishermen just fish, especially in the southern region (Suakin). On average, winter costs 49% less than summer. This illustrates that the organism passes through several life phases in a single season, from a state of hibernaculum to the stage of reproduction. This boosts the organism's resistance to fishing gear throughout the winter.
Despite the resource's economic significance,Äîone kg of marine crabs costs between 50 and 100 Sudanese pounds,Äîand personal conversations with the Department of Fisheries and Fishermen, it was discovered that there is no plan to manage this resource.

Using BRUVS to Assess Elasmobranch and Predator Communities in the Red Sea Project Area

Jacob Asher

Global declines to large-bodied, mid- to high-level coral reef predator populations and elasmobranchs is a fundamental issue facing coral reef ecosystems. In the Red Sea Project area (RSP), divers belonging to the Red Sea Zone Authority (RSZA) Department of Environmental Protection and Regulation (DEPR) surveyed more than 350 distinct sites over the past 2.5 years, with more than 100 of those visited annually. However, sightings of elasmobranchs (particularly sharks) were relatively uncommon, which may be a result of either localized depletion over time, general rarity of elasmobranchs in the region, or elasmobranch diver-avoidance during surveys. Spatial closures (e.g., marine protected areas) are one option used to address conservation and fisheries management goals, including the protection of shark populations, and fishery-targeted species. However, limited research has been published on the effectiveness of area closures in the Red Sea to protect sharks and other larger-bodied, targeted species, which is partially a result of incomplete pre-closure baseline data being available. Starting in September 2023, we will deploy baited remote underwater video systems (BRUVS) to examine a variety of targeted groups around the RSP, including elasmobranchs (sharks, rays), and highly targeted mid- to high-level predatory fishes (e.g., groupers, snappers) across a variety of habitats (shallow-water; mesophotic; pelagic). The RSZA EPR will examine a.) elasmobranch and predator abundance in shallow-water areas, beginning with BRUVS surveys at sites previously assessed by divers from 0 ‚Äì 20 m, b.) BRUVS surveys in other areas, e.g., seagrass beds and deeper mesophotic strata (up to 150 m). c.) pelagic BRUVS. This information will be used to identify a.) elasmobranch and targeted mid- to high-level predatory fishes species that are present, along with providing information to help track the relative abundance, biomass, diversity, and distribution of target species that are present prior to the establishment of MPAs or other regulatory protection measures, b.) understand the ecology of targeted species communities, with information that can contribute to more effective local fisheries management strategies.

The potential use of photo identification to monitor Indian Ocean humpback dolphins Sousa plumbea an endangered cetacean in the Red Sea

Royale Hardenstine

Indian Ocean Humpback dolphins (Sousa plumbea) are one of the 17 species of cetacean that have been observed in the Red Sea and the only Red Sea cetacean listed as endangered on the IUCN Red List. Due to their nearshore, shallow-water habitat preferences, a threat to humpback dolphins includes coastal development. Unfortunately, data for S. plumbea is lacking throughout most of the Saudi Arabian Red Sea coast, making it difficult to detect any potential impacts or changes in population size. During other monitoring efforts within the Al Wajh lagoon, between March 2021 and April 2023, opportunistic sightings of all cetaceans observed were made including recording a location, the species, and number of individuals. When possible, photographs of dorsal fins and other identifiable markings were recorded. Overall, there were 18 observations of humpback dolphins, in some cases associating with bottlenose dolphins (Tursiops spp.). From these observations one pod that included a calf could be reliably identified four times throughout 2021. Additionally, at least two other individuals were identified, with one being observed 10 months apart both times associated with a large pod of bottlenose. As monitoring efforts for cetaceans continue to be implemented the addition of photo-identification, would make it possible to better understand the individuals within Al Wajh lagoon. In the future to get an accurate population estimate continued improvements in monitoring this species along the Saudi Arabian coast will be essential. Citizen scientists or local dive guides could be enlisted to help collect additional photos. When possible different entities should combine photo-databases and data.

Minimally Invasive Platforms for Profiling Coral Reefs Associated Microorganisms

Abdullah Bukhamsin

The extracellular calcification medium (ECM) of corals plays a crucial role in controlling the architecture of the calcium carbonate-based skeleton. The ECM is sandwiched between the skeleton and the epithelium and has a thickness that varies between a few nanometers to micrometers. Despite its importance in mediating the environmental resilience of corals, the majority of the studies conducted on the ECM are centered on characterizing its pH and ECM carbonate chemistry. While these parameters are crucial, they leave out the role of potential microbial colonies that may be present in the ECM. As the ECM is largely inaccessible, addressing this question has been difficult. To that end, we present an integrated microneedle device for the extraction of microbes from the ECM. The device is equipped with microneedle electrodes of varying shank heights that can simultaneously penetrate the coral tissue and identify ECM by way of in situ pH measurement. The microneedles are equipped with an open-side microfluidic channel for the extraction of the microbes and subsequent identification. Herein, we demonstrate the mechanical ability of the device to penetrate the Fungia and Bubble corals and determine the in vivo pH level of depths starting from 300 ŒºÊm up to 2 mm.

The Microbiome After Bailout How microbes associated to Red Sea corals react to micropropagation

Pedro Moreira Cardoso

Micro-scale in vitro models have been essential to understand fundamental cellular and molecular processes of many organisms. In the case of corals, there is still a significant knowledge gap in relation to micro-scale processes involved in their health, which could be solved with models adopted to microscopic studies. Individual coral polyps separated from their colonies through a bail-out induced by acute stress have been suggested in the past as miniaturized models to study corals. However, the changes that polyps undergo after bail-out are still not completely understood. Before isolated polyps can be reliably used for research, it is important that they are well characterized. In order to assess the changes related to the microbiome of polyps after bail-out, an aquarium experiment was performed to study differences in the diversity, composition and gene expression of microbes between bailed-out polyps and their parental fragments belonging to the red sea coral species Pocillopora verrucosa. There were no major differences in the microbiome immediately after bail-out, but this pattern changed following the second week after the separation of the polyps. Still, high rates of common microbes were found between the two groups up to three weeks after bail-out. We propose that the lack of fixation of the polyps is the major driver of differences in the microbiome in the long term, and that bailed-out polyps can still be accurate models for the study of coral microbiology.

Shannon Klein

In tropical seas, shallow-water coral reefs have been subject to rigorous research. However, large and complex reef systems comprise distinct ecosystems interconnected within seascapes through the physical, chemical, and biological processes they shape. Deep areas within these seascapes, defined here as >30m depth, are often inaccessible to research vessels and problematic to examine using conventional survey methods (e.g., scuba diving, habitat mapping via remote sensing). Despite their close proximity to shallow coral reefs, the identification and exploration of deep environments embedded within complex reef systems are scarce. Our study region - the Farasan Banks of the southern Red Sea - is the third largest coral reef system in the world, which spans 16,000km2 and comprises hundreds of submerged coral reefs, small islands, and lagoons. We used an interdisciplinary approach to characterize deep environments within the Farasan Banks during the Red Sea Decade Expedition 2022. Our approach used a combination of technologies, including piloted submersibles, remotely operated vehicles, CTDs, and multi-beam technology. Two remarkable environments (419 and 620m max depth) revealed stark environmental gradients with depth, suggesting persistent and intense water column stratification at both sites. At depths >100m, median O2 levels were extreme and consistent with anoxia and pCO2 levels far exceeded end-of century ocean acidification projections. We further describe the biological communities inhabiting these distinct environments using both environmental DNA and video footage from underwater vehicles, provide bathymetry, and hypothesize their geological origin.

Water column bioluminescence in the Red Sea

Isabel Armelles Vicent

Bioluminescence is the emission of light by organisms, generated in an oxidation reaction. It is a well-spread trait in nature, with marine organisms representing around the 80% of them. Given the heterogeneity of bioluminescent organisms, it can be powerful to quantify and identify organisms in the ocean. This phenomenon has been reported and studied in most oceans in the globe, but any extensive research has been conducted in the Red Sea, where most publications are based on single species observations or bacterial communities. For the first time, we sampled the entire Arabian Red Sea, from the Gulf of Aqaba to the Farasan Banks, including the whole water column. During the Red Sea Decade Expedition, on board R/V OceanXplorer, 33 stations were sampled using an ROV equipped with a low light camera and CTD for environmental data collection. Vertical and horizontal profiles were recorded along the Arabian Red Sea to quantify bioluminescence produced by zooplankton using bioluminescence events/m3 units. Vertical and latitudinal gradients were observed, the former mostly associated to the deep scattering layer. Interestingly, bioluminescence abundance seems to have a latitudinal gradient, increasing bioluminescent records towards the north, showing an opposite tendence of productivity.

Lost in the dark: Antipatharia-Symbiodiniaceae association in the deep waters of the Red Sea

Silvia Vicario

The Red Sea is a young ocean basin characterized by unique abiotic conditions, driven by extreme environmental latitudinal and bathymetric gradients in temperature, salinity, oxygen, and nutrients. These conditions play a significant role in shaping the diversity and distribution of marine organisms. The Red Sea environmental latitudinal gradients shape the Symbiodiniaceae community associated with shallow-water hard corals. Currently, however, no information is available in the Red Sea on the symbiosis between Symbiodiniaceae and the Antipatharia, an order of anthozoans historically considered to lack zooxanthellae due to its preference for low-light environments in both shallow and deep waters. Here, we report the occurrence of zooxanthellae in the deep-sea black coral Bathypathes thermophila (Antipatharia: Schizopathidae), representing the first observation of zooxanthellae in the species, and the deepest record to date of Symbiodiniaceae associated with an anthozoan. A total of 27 colonies of B. thermophila were collected between 190 and 627 m depths from the Gulf of Aqaba, Northern, Central and Southern Red Sea. For each of them, the internal transcribed spacer-2 (ITS2) region of the associated dinoflagellates was amplified and high-throughput sequenced to identify algal genotypes and reconstruct the Symbiodiniaceae community composition. Overall, 20 colonies (74%) contained zooxanthellae. Our findings shed light on the need for further research to understand the role, type and mechanisms involved in the symbiosis between antipatharians and Symbiodiniaceae.

First record of a live adult heteropod Firoloida desmarestia in the Red Sea

Carlos Angulo-Preckler

The Red Sea, a region of remarkable biodiversity and unique ecological characteristics, holds hidden treasures within its deep-sea and mesophotic zones. Despite its oligotrophic nature, the Red Sea supports surprisingly high biodiversity, even in the light-deprived depths exceeding 200 meters. The Red Sea Decade Expedition conducted in 2022 provided groundbreaking insights into the deep-sea and mesophotic biology of the region. Observations are essential to explore and discover the ocean. The rapid advancements in technology have revolutionized our capacity to document the ocean and its diverse array of species, pushing the boundaries of our understanding further than ever before. Among the notable discoveries were the first observations of living Firoloida desmarestia, a heteropod mollusk, and the discovery of two distinct species of rhodaliids, including a potentially novel species, has unveiled previously unknown ecological attributes and potential species richness within the Red Sea. These organisms, notably rare in the world's oceans, contribute to the Red Sea's unique and enigmatic biodiversity, underscoring the importance of further scientific exploration and conservation efforts in this region. Furthermore, the diel migration of mesopelagic fish, such as lanternfish, emerges as a crucial component of the deep-sea ecosystems, fueling nutrient transport and sustaining deep-sea organisms. The expedition shed light on the feeding behavior and ecological roles of deep-sea organisms. Anemones, deep-sea corals, and a jellyfish were observed preying on lanternfish, highlighting complex trophic interactions and providing insights into the nutrient flow within these ecosystems. These discoveries reinforce the ecological interconnectedness and resilience of deep-sea and mesophotic organisms. The documented biodiversity and ecological significance of the Red Sea's deep-sea and mesophotic zones underscore the need for effective conservation measures. The Red Sea Decade Expedition yields invaluable insights into the hidden wonders and ecological intricacies of these habitats.

Mangrove crabs harbor gill bacterial microbiomes shaped by host lifestyle and gill physiology

Authors:
Xinyuan Yang, Elisa Garuglieri, Marco Fusi, Ramona Marasco, Daniele Daffonchio

Abstract:
The gills of mangrove crabs represent a unique ecological niche for microbial colonization, providing shelter and nutrients for the settlement and thriving of a rich microbiota. The compositions of gill-associated bacteria have been shown to be driven by the host lifestyle rather than the specific evolutionary history, making the crab-microbe relationship an interesting focus to assess the role of ecological signatures on the host-microbiome co-evolution.
Crab species are characterized by a different number of gills supporting different physiological functions, and the influence of such features on the gill microbiota within the same crab host has never been investigated. Moreover, the microbiomes of several mangrove crab species are overlooked.
We investigated the microbial communities inhabiting the posterior-to-anterior gills portions of three crab species from the same mangrove setting but with distinct intertidal lifestyles: i) Thalamita crenata, a swimming crab living in low intertidal waters; ii) Metapograpsus messor, a climbing crab inhabiting the intertidal belt in intimate connection with mangrove trees; iii) Cranuca inversa, a detritivore fiddler crab burrowing in the high-intertidal mudflats.
Our results demonstrate that the gill microbiomes exhibit species-specificity, and the relative abundance of certain bacterial taxa varies in correlation with the habitats and behaviours of the respective crab species. The active predators, T. crenata and M. messor, harbour bacterial communities with higher richness but lower evenness compared to the detritivorous C. inversa, which spend long periods of time burrowing in the mud. We also observed that the physiological specialization of different gill portions select specific bacterial assemblages in terms of composition and diversity.
We point out that both lifestyle and the host physiological properties shape the microbial communities of mangrove crabs‚Äô gills, opening novel perspectives on understanding the host-microbiome evolutionary relationship.

Differential responses to heat wave scenarios reveal species-specific physiological resilience in common Red Sea corals

Marleen Stuhr

The increasing frequency and severity of marine heat waves constitute a major threat to coral reefs, resulting in the global loss and degradation of coral reef ecosystems and their ecological functions. Corals' abilities to resist and recover from stress, i.e. their resilience capacity, greatly influence how strongly a reef is affected. In the Gulf of Aqaba (GoA), northern Red Sea, various marine taxa display exceptionally high thermal thresholds, making it a potential reef refugium from climate change. To better understand the physiological mechanisms involved in resilience, common reef-building coral species from the GoA were exposed to two simulated marine heat wave scenarios (+3-4¬∞C and +7-8¬∞C above ambient seawater temperature), followed by a recovery period. Among the three species examined, Stylophora pistillata was the most sensitive and showed distinct responses between treatments. While photosynthetic parameters were enhanced at +3-4¬∞C, severe bleaching was recorded at +7-8¬∞C, from which it recovered partially. Pocillopora verrucosa, in contrast, showed minimal responses overall, signifying an extraordinary thermal resistance through physiological plasticity. Massive coral Porites lobata appeared initially robust to thermal stress, but showed a delayed bleaching response, potentially linked to longer-term variations in photosymbiont physiology and density. These species-specific stress and recovery responses reveal bleaching resilience capacities and mechanisms varying between taxa, and how these may shape future coral reef communities.

Fish spawning aggregations in The Red Sea Global area

Luis Silva

Fish spawning aggregations are impressive natural phenomena that occur when large numbers of fish gather in specific locations to reproduce. These events are not only vital part of many fish species,Äô life cycle, but can also provide opportunities for spectacular wildlife tourism. Influenced by various factors (e.g., lunar cycles, food availability), spawning aggregations are generally highly predictable (spatially and temporally), hence easily targeted by fishermen. The potential removal of large numbers of individuals during these events can ultimately disrupt population dynamics. Therefore, protecting these aggregations can be a valuable component of an effective conservation strategy. During our baseline survey efforts conducted in The Red Sea project area since 2020, we have documented fish aggregations and some pre/post-spawning behaviors for 7 species in 6 different areas. Two of those locations involved multiple species at the same time with the notable presence of apex predators. Among our observations, we have encountered a school of around 100 bumphead parrotfish, and at another times several thousand blackspotted snapper. So far, we have not observed spawning. To improve our ability to manage these events, we aim to gather more data about the location and timing of these aggregations, including with the help of the local fishing community. Moreover, to document these events we will be deploying live camera feeds, ROVs observations, and SCUBA dives. We are already incorporating these events into our management strategy, but improved knowledge and documentation will help us to improve management, and provide opportunities to enhance the guest experience in our area.

The role of microbes in the formation and stabilization of the Al Wajh carbonate platform

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Since the late Precambrian microbial carbonates like stromatolites were slowly replaced with more efficient calcifying organisms like corals & foraminifera for example. However, although no longer obvious, the products of microbially induced carbonate precipitation (MICP) are still ubiquitous in warm water shallow marine environments. The Red Sea with its high temperature and salinity is exceedingly conducive to MICP. We have discovered a diverse array of microbial carbonates on the Al Wajh carbonate platform (NE Red Sea) allowing us to assess the importance of microbial constructs for the building and lithification of carbonate platforms. Samples consist of modern stromatolites, beachrocks, polygonal teepee structures and ooids. Component diversity and structures were observed with thin section petrography. Microbial diversity was established by DNA extraction and sequencing. Samples were dehydrated and prepared for scanning electron microscopy (SEM) and SEM-EDX analysis to ascertain morphology and elemental composition. Bulk mineralogy was analyzed via X-ray diffraction.
Most commonly, microbial carbonates are composed of grains of diverse biogenic origin that are bored, miciritized and cemented by microbial activities. Microbial communities are diverse but generally contain a significant share of cyanobacteria. Mineral precipitates associated with microbial activity are identified as nano- to micrometer sized calcite and aragonite crystals, which are enveloped by bigger needle-shaped aragonite and bladed calcite cement. The mineralogy of microbial carbonates is composed of varying proportions of aragonite, high and low magnesium calcite and traces of dolomite.
Despite being relatively insignificant in terms of mass, microbial cementation and alteration of sediment particles is key in binding and stabilizing the shoreline and flanks of carbonate platforms. MICP features in the Red Sea are comparativly less studied to other prominent carbonate system like western Australia and the Great Bahama Bank and demand further investigation.

Microbiome of the sea skaters (Genus: Halobates) associated with the Red Sea mangroves

Juan David Escobar Prieto

A peculiar group of predator insects, the sea skaters Halobates, inhabit the sea surface of shallow coastal areas and open ocean. As the only insects known to inhabit the sea, sea skaters represent a fascinating and understudied group that offers valuable insights into the adaptability and evolutionary processes of insects in marine environments. The species H. hayanus and H. melleus live along the mangrove fringe of the Red Sea. Considering the poly-extreme conditions of such environments and the selective pressure imposed by salinity, drought, and oligotrophy, these insects have evolved several physiological and morphological adaptations, including reduced body size, super-hydrophobic body surface, and a fast-jumping response. However, nothing is known about how these adaptative traits are influenced by the host-associated microbiome, which is well known to have contributed to insect success and adaptability. By employing multi-omics techniques, including amplicon sequencing and metagenomics, the composition and assembly of microbial communities associated with the two Halobates species, along with their potential functional and ecological roles, have been investigated. The sea skater's microbiome is dominated by the bacterial genus Wolbachia. Although Wolbachia is a well-known sexual manipulator in insects, members of this group have been proposed as a primary symbiont (i.e., essential for host survival). In H. melleus, the microbial metagenome shows the highest expression level of all the genes for the riboflavin (vitamin B2) synthesis identified in the Wolbachia metagenome-assembled genomes (MAGs). Even if vitamin B2 plays a vital role in several metabolic processes, such as energy production, growth, and development, it cannot be synthesized by insects de novo. Other components of the Halobates microbiome have been found to carry genes encoding for osmoprotectants and heat-shock proteins that may help the insect host cope with the salinity and thermal stress in the mangrove environment. This initial survey revealed how the sea skaters' microbiome acts as an additional ‚Äúadaptative tool‚Äù for the host to cope with nutritional limitations, high salinity, and fluctuating temperatures, contributing to our understanding of the ecological and evolutionary significance of microorganism-insect interactions in (extreme) marine ecosystems.

The Tapponnier, seamount, an off-axis volcano along the Saudi margin of the northern Red Sea

Davide Berno, Guillaume Baby, Maria Camila L√≥pez Su√°rez, Abdulkader M. Alafifi

The current morphology of the Red Sea is the result of a complex, polyphase tectonic process and took place from the uppermost Oligocene (~30 Ma) to the current day. Due to the scarcity of industrial subsurface data (seismic profiles and wells), many models and hypotheses have been proposed to define its tectonic evolution. One of the main debates revolves around the distribution and the extent of oceanic crust along the northern Red Sea. As it is largely covered by mobile evaporite-rich deposits, the basement can only be observed very locally in specific windows along the axis of the Red Sea (Conrad, Shaban, and Mabahiss deeps), giving no indication of the extent of the oceanic crust beneath the basin.
In order to investigate the nature and extent of the underlying crust, most studies have focused on basement sections exposed to the surface (Ikhwan islands and Zabargad Island). In comparison, submarine morphologies such as the seamounts that litter the region have been little studied. In this contribution, we characterize for the first time an important seamount of the Saudi margin, dubbed ‚ÄúTapponnier‚Äù seamount. Our study is based on the interpretation of geophysical data (seismic reflection and high-resolution bathymetric imagery) and on the petrological characterization of a series of samples collected during ROV dives.
The ‚ÄúTapponnier‚Äù seamount is located in an off-axis area south of the city of Duba (26¬∞43‚Äô11‚ÄùN; 35¬∞26‚Äô49‚ÄùE) at a depth from 150 to 500 meters. Multibeam bathymetry was acquired during multiple scientific cruises over two years, while seismic reflection profiles were obtained in a recent expedition on the AEGAEO vessel. Initial seismic interpretations provide age constraints on the formation of the main effusive edifice, which probably formed around 5 Ma. The samples collected were analyzed with both bulk (XRD and XRF) and in-situ (SEM-EDX) techniques. They are composed of an association of Mg-rich phyllosilicates, quartz, and calcite typical of hydrothermal seafloor settings.

Red Sea Volcanism: Afar plume influence on seafloor morphology and deep Red Sea habitats

Konstantinos Thomaidis, Froukje M. van der Zwan, J√∂rg Follmann, Murtadha Y. Al Malallah, Vincent Pieribone, Mohammad Qurban, Carlos M. Duarte

The Red Sea is shaped by geological processes that started 30 million years ago with the separation of the African and Arabian plates and forms one of the youngest ocean basins on Earth. In the deep Red Sea the oceanic crust is being produced by volcanic and tectonic processes that determine the seafloor morphology, the occurrence of hydrothermal systems, and influence currents and sedimentation, thereby the suitability of the deep Red Sea as a habitat.
The main volcanic process of the Red Sea is related to decompression melting at the mid-ocean ridge (MOR). However, the presence of the Afar mantle plume in the southern Red Sea influences volcanic activity, crustal thickness, rift morphology, and seafloor chemistry along the rift axis between the southern and central Red Sea. Although it is known that the Afar plume is affecting the southern Red Sea, this is based on limited high-resolution bathymetry and sporadic seafloor sampling and the extent of its influence on the Red Sea Rift has yet to be studied in detail.
This project aims to provide a systematic assessment of the volcanic processes and the sources of the volcanism in the deep Red Sea Rift and attempt to estimate the influence of the different volcanic components on the rift environment and habitats. We will employ petrological and geochemical tools on a unique set of MOR-basalt samples, along and across the Red Sea Rift, together with high-resolution bathymetric data and morphological information from ROV video. In the presentation, we will give an overview of the project and its objectives, together with the first preliminary petrographic results.

A Lagrangian model-based physical connectivity atlas of the Red Sea coral reefs

Yixin Wang

The Red Sea is an extremely warm tropical sea that hosts diverse ecosystems; thus, it is important to understand its ecology in the context of global warming. Using a coupled physical,Äìbiogeochemical model validated against in situ data, we provide the first report on the diel cycle (i.e., diel variability) in the Red Sea chlorophyll (CHL) concentration, revealing near-sunset CHL maxima at 17h ¬± 1h local time over the entire basin. This CHL peak time is considerably later than those reported in most other oceans, suggesting low grazing rates in this high-irradiance tropical sea. Model-based analyses reveal that CHL diel cycle is predominantly controlled by irradiance, whereas longer-timescale (e.g., seasonal) CHL variability is regulated by nutrient availability, suggesting a light-limited biological production at diel timescale. The identified CHL diel cycle comprises a fundamental component of the Red Sea ecology and has implications for CHL remote sensing and in situ measurements.

Impacts of nighttime hypoxia on the physiological performance of Red Sea macroalgae under peak summer temperature

Taiba Alamoudi

Eutrophication-induced hypoxic sites are increasingly reported in coastal regions. At the same time, ocean warming, water column stratification, and changing circulation lead to open-ocean deoxygenation. In coastal areas and reefs with dense vegetation, aquatic organisms can be exposed to oxygen limitation stress where oxygen concentration reaches extremely low levels, particularly during nighttime once photosynthetic O2 production has ceased. Despite scientists being aware of this for decades, little is known about the impact of deoxygenation on the physiology of marine primary producers, such as macroalgae. In the Red Sea, in particular, the physiological adaptations of macroalgae under future climate scenarios are nonexistent. Here, we investigate the impact of different oxygen levels (6.5, 2.5, and 1.3 mg O2 L-1) at night for three conspicuous Red Sea macroalgae species Halimeda opuntia and Padina boryana (calcareous) and the brown algae Sargassum latifolium (noncalcifying). We monitored algal physiological responses during a 12-hour nighttime (dark) period at 32¬∞C by measuring photochemical efficiency (Fv/Fm), respiration rates, and cellular viability. No lethal thresholds were detected. However, both deoxygenation treatments decreased respiration rates and induced changes in cellular activity, and only under severe hypoxia was a decrease in photochemical efficiency observed in all species. We calculated sublethal O2 thresholds SLC(50) of 1.2 ¬± 0.1, 1.5 ¬± 0.1, and 1.7 ¬± 0.1 mg O2 L-1 for H. opuntia, P. boryana, and S. latifolium, respectively. Therefore, the effects of nighttime hypoxia are evident over short timescales and may impact ecosystems via reduced primary production. Future consequences of persistent hypoxia and subsequent performance in multifaceted stressor exposures will provide a fundamental understanding of hypoxia‚Äôs threat to biodiversity and ecosystems.

Establishing Red Sea coral reef calcification as an indicator of ecosystem health

Vincent Saderne, Maggie Johnson

Coral reefs of the Red Sea provide a suite of ecosystem goods that are essential to the success of the Kingdom's development initiatives. A central tenet of Vision 2030 is to increase coastal biodiversity, which requires maintaining and enhancing the function of ecologically and economically valuable habitats. To accurately evaluate the status of Red Sea coral reefs (i.e., reef ‚Äúhealth‚Äù), and to quantify the success of development and restoration projects, standardized metrics that provide direct and accurate information on reef health are necessary. We propose to use Net Ecosystem Calcification (NEC), an essential ecosystem function that supports biodiversity and habitat persistence in coral reefs, as an indicator of reef ‚Äúhealth‚Äù. We are collecting the first baseline data on NEC as a metric of ecosystem health across Kingdom reefs, from KAUST and The Red Sea Project (TRSP) to the Shushah Island Coral Reefscape project. We are currently assessing NEC from total alkalinity anomaly at the reef scale using an Eulerian approach. We are monitoring the variations of total alkalinity as water masses pass over the reefs for periods of three days in different seasons, using autonomous water samplers, CTD-O2 sensors, and acoustic Doppler current profilers.
In the end, this project will allow us to evaluate the impacts of climate change on Red Sea reefs and the positive impacts of enhancement efforts implemented with the mega-projects. As these projects initiate coastal development and embark on reef enhancement efforts, NEC data will provide an essential benchmark for illustrating how those reefs are functioning now, and how the enhancement efforts may improve the health of focal reefs.

Decoding Fatty Acid dynamics in Planktonic Communities of the Red Sea: Nutritional perspective

Sarah A. Alghamdi

Fatty acids (FAs), particularly long-chain omega-3 and omega-6 essential fatty acids (LC-EFAs), are indispensable nutrients for the well-being of aquatic organisms and humans alike. Within the ocean's euphotic layer, microalgae,Äîintegral components of the marine pelagic food webs,Äîserve as the primary producers of LC-EFAs. Subsequently, these LC-EFAs are transferred through grazing from microplankton to mesoplankton (zooplankton being the dominant group), ultimately making their way to higher trophic levels.
In light of the rapid warming of the Red Sea, it is imperative to establish a comparative framework for future FA profiles of the basin's biota. This time-series study aims to establish a comprehensive baseline dataset for planktons FA profiles and explore temporal and trophic-level variations in planktonic FA quality and quantity within the Red Sea ecosystem.
We collected monthly seawater samples from a fixed station spanning 2022 to 2023. Employing diverse sampling and filtration strategies revealed four distinct plankton size fractions ranging from 0.2 ¬µm to >200 ¬µm. We applied a direct technique to extract the volatile form of FAs from these samples, followed by analysis using gas chromatography-mass spectrometry (GC/MS). Our findings provide insights into FA content, and composition, as well as nutritional quality by evaluating multiple indices such as saturation, LC-EFAs, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). Additionally, we assessed temporal and seasonal variations in FA profiles across the plankton fractions.
This study undertakes a pioneering effort to elucidate the FA profiles and nutritional quality of Red Sea planktonic communities,Äîa critical component of the marine food web. The dataset presented in this study possesses a significance as indicators of ecosystem health, maritime food security, and quality. Furthermore, it establishes a robust basis for monitoring the dynamics of LC-EFAs in response to the ongoing warming in the Red Sea.

Oxyregulation of probiotic-treated corals and their larvae under deoxygenation and heat stress

Yusuf Christian El-Khaled

Oxyregulation of probiotic-treated corals and their larvae under deoxygenation and heat stress

Beneficial microorganisms can ameliorate the impacts of increasing sea surface temperatures on reef building corals. This knowledge has sparked interest in the application of beneficial microorganisms (termed probiotics) to aid corals as ocean temperatures rise. Despite empirical evidence of this practice‚Äôs success, the underlying response mechanisms and our understanding of how such microbial manipulations could modify coral responses to other stressors remain elusive. Providing insight into these unknowns, a recent investigation reveals that coral microbiome manipulation may act to elicit metabolic restructuring to help mitigate heat stress. The link between aerobic metabolism and heat tolerance is well established because increases in temperature modulate oxygen consumption rates across a variety of marine organisms. This poses the question as to whether probiotic applications modify the responses of coral holobionts to deoxygenation and their ability to regulate their aerobic capacity under heat stress. The ability to regulate aerobic respiration under deoxygenation is an important eco-physiological trait for adult coral survival in dynamic oxygen environments, and can influence the mutualistic partnership between endosymbiotic algae and corals. However, the extent to which coral larvae are capable of oxyregulation under deoxygenation, the effects of heat stress on oxyregulation and the role of probiotics in this context, are still unknown. Hence, we here examined oxygen consumption patterns, mortality and bleaching status at two different temperatures (ambient, 34¬∞C) of adult probiotic and placebo-treated Acropora sp. and their larvae. Adult corals have received continuous in situ treatment for 10 months prior to this study. The results of this study help to resolve the physiological response of corals and their larvae to the single and combined effects of heat stress and deoxygenation. These novel insights are of paramount importance towards understanding the beneficial effects of probiotics on coral fitness and survival and the heritability of these traits to their offspring.

Seasonal carbon fluxes in the Red Sea

M. Ouhssain, M. Kheireddine and B. H. Jones

Carbon dynamics in the ocean play a fundamental role in the global carbon cycle and, thus, in regulating atmospheric CO2 concentration. Until recently there has been little work on the carbon fluxes within the Red Sea, one of the warmest and most saline regions of the global ocean. Remote sensing and numerical modeling studies have shown that the Red Sea is dominated by mesoscale eddies, and demonstrates significant temporal and spatial variability at a range of scales. Using autonomous platforms (AUVs and profiling floats), we initiated a sustained study of the physical and biogeochemical variability in the central Red Sea, one of the most oligotrophic subregions of the Red Sea. The goal of this effort is to understand the processes affecting carbon dynamics from the daily through interannual time scales, and from the submesoscale through basin spatial scales, and vertically from the mixed layer into the mesopelagic zone (100 - >500m). Current results show that carbon fluxes within this region are controlled by several processes including mixed layer variability, eddy-driven processes, and biologically-driven fluxes. The results presented here represent the first characterization of an annual cycle within the Red Sea attained through the a sustained AUV line, and are a first step in coupling this variability to longer term, interannual processes. This study aimed to see the effect of monsoon on the flux of POC in the mesopelagic zone. The data used in this study consisted of bio-optical data from gliders and HF radar data. The results obtained, from October 2017 until march 2018 during Winter northeast monsoon (NE) , POC in mesopelagic zone were significantly higher within higher eddy activity and higher productivity in the MLD compared to Summer southeast monsoon (SE) from April 2018 to September 2018.

Microbial landscape associated with micritized carbonate sediments from tidal environments of the Arabian Peninsula

Rawan Alhazmi

Micritization is a widely distributed diagenetic process described in tropical shallow marine carbonate settings. Influenced by biotic and abiotic factors, the two main micritization phases, microboring and micritic texture reprecipitation, have been driven by microbial activities.

Although the topic has attracted geobiological research in the last six decades, an integrated approach taking advantage of the most advanced microbial ecology techniques is still lacking.

We compared the environmental factors, sediment characteristics and microbial communities of four different shallow marine micritized settings across the Arabian Peninsula: Al-Kharrar lagoon (Red Sea, Rabigh, Saudi Arabia), Ras Tanura south lagoon (Arabian Gulf, Dammam, Saudi Arabia), Ramhan Island eastern lagoon (Arabian Gulf, Abu Dhabi, United Arab Emirates) and Bar-Al-Hikman peninsula lagoon (Arabian Sea, Oman).

The Abu Dhabi site showed the highest abundance of endolithic biosignatures, resulting in a suitable location for establishing and thriving micritizing microbial communities.

Metabarcoding analysis based on the prokaryote 16S rRNA marker gene and scanning electron microscopy imaging confirmed that Abu Dhabi sediments harbour unique bacterial assemblages able to actively sustain the different phases of the micritization process, which included cyanobacteria and sulphate-reducing bacteria (e.g., Chroococcidiopsis sp. and Thermodesulfovibrionia order).

Functional prediction of the microbial consortia highlighted that Abu Dhabi,Äôs sediments have the highest abundance of metabolisms supporting carbonate precipitation.
All this evidence points to Abu Dhabi as a location with ongoing active micritization driven by microbial endolithic activities.
A primary objective for future research will focus on the most abundant taxa in these communities, including Chroococcidiopsis, Pleurocapsa, candidatus Thiobios, and SBR1031 (Anaerolineae) sp.

As future perspectives, metagenomic and metatranscriptomics studies, and attempts to isolate these taxa will allow us to explore the complex web of microbial metabolic pathways subtended to micritization.

Towards a Cnidarian-Symbiodiniaceae Symbiosis Model: Insights from Cassiopea

Shiou-Han Hung

Corals rely on the symbiotic relationship with Symbiodiniaceae dinoflagellates to receive photosynthates in exchange for inorganic nutrients. The breakdown of this mutualistic relationship causes coral bleaching, which can result in mortality and coral reef declines. Despite the importance of this symbiosis, the cellular and molecular processes behind it are not well understood. Just like corals, the upside-down jellyfish Cassiopea exhibits a mutualistic endosymbiosis with Symbiodiniaceae yet features many advantages over corals with regard to its amenability to work in laboratory settings. Specifically, its short life cycle can be closed in the laboratory, and if fed regularly, Cassiopea polyps can remain aposymbiotic and reproduce. To further elucidate the molecular mechanisms behind this symbiosis, we generated a high-quality genome assembly of Cassiopea from the Red Sea and compared gene expression profiles from aposymbiotic and symbiotic polyps, discovering genes and pathways that may be involved in symbiosis. In symbiotic polyps, we identified 2,971 differently expressed genes, with 1,395 being up-regulated and 1,576 down-regulated. GO enrichment and KEGG pathway analyses found terms and pathways in accordance with growth and increased metabolism upon symbiosis, such as: ribosome biogenesis, DNA replication, spliceosome, and cell cycle. Lipid metabolism pathways also increased, which indicates translocation of lipids from the symbiont to the host. The use of Cassiopea as a model organism to study cnidarian symbiosis with Symbiodiniaceae will help us understand this important interaction and will bring us one step closer towards the development of a cnidarian-Symbiodiniaceae symbiosis model.

Rayyan Alamoudi

Members of the Epsilon-proteobacteria class, known for their metabolic versatility, are integral contributors to different biogeochemical cycles in various environments. Nevertheless, their metabolic profile and adaptation strategies in brine pools remains elusive. Located at the bottom of marine environments, brine pools are poly-extreme environments that are characterized mainly by their extreme salinity and anoxic conditions. The brine-seawater interface (BSI) is the most biologically active layer within brines and it houses a gradient in various physicochemical parameters within less than one meter. Recently, it has been shown that different Epsilon-proteobacteria taxa had unique stratification along the BSI, implying a distinct ecological and functional role. However, a comprehensive analysis of their metabolic capacities and ecological roles have never been realized.
in this study, we aimed to elucidate the metabolic capacities and adaptation strategies of a newly discovered Epsilon-proteobacteria, derived from a metagenome-assembled genome (MAG) From Afifi Brine, a shallow and sulfidic brine pool located at the southernmost parts of the Red Sea. We utilized a high-resolution sampling approach along the BSI of Afifi Brine combined with a whole-genome shotgun (WGS) metagenomic sequencing on the samples. Phylogenetic analysis revealed close similarities to the Sulfurospirillaceae family; however, a partial 16S sequence had only 90% identity to the closest Sulfurospirillum species, suggesting a potentially novel lineage. Unlike other known Sulfurospirillum, our MAG encodes complete set of markers required for the reductive TCA cycle but not citrate synthase, indicating a capacity for carbon fixation. Moreover, the detection of an incomplete denitrification pathway suggests a potential implication in the nitrogen and carbon biogeochemical cycles in Afifi Brine.
The findings of this study provide important insights into the metabolic potential and ecological roles of Epsilon-proteobacteria in a Sulfidic Red Sea brine.

Developing fatty acid methyl esters (FAME) as a standardized technique for studying energy flow and trophic structure in the Red Sea

Ghalih. Althagafi, Nicole. Burt, Mafalda.Isidro, Raquel.Lubambo, Patricia. Lopez, Michael D. Fox

Fatty acids (FAs) are vital molecules found in all organisms as they are essential for membrane structure, lipid metabolism, and energy storage. FAs are an emerging technique for studying energy flow and trophic links in marine ecosystems. The analysis of fatty acid methyl esters (FAME) is increasingly being used to study coral reef ecosystems, as it represents an affordable and high-throughput method for investigating complex food webs. As such, there is a need to coordinate a standardized protocol for quantifying FAME profiles from organisms across multiple trophic levels. To address this need, we conducted a comprehensive evaluation of five different protocols (Lewis, Parish, Folch, BF3, and MTBE) for extracting FAME across five different tissue types: macroalgae, coral and their symbiotic microalgae, shark muscle, and shark blood. The FAME were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) and multivariate techniques were used to assess the consistency of fatty acid compositions across methods and tissue types. We established the optimal protocol based on the highest FAME yields and extraction consistency, whilst also taking into consideration the challenges and limitations of each method. This study contributes to the advancement of FA research in the Red Sea by providing a standardized protocol for FAME profiling across coral reefs and other marine ecosystems. By standardizing preparation methods, we aim to develop a collaborative, comprehensive, and consistent database of FAME profiles from Red Sea organisms. The resulting database will provide an impact resource for developing trophic and physiological biomarkers that will enable studies to address how coral reef ecosystem functioning will be impacted by climate change in the Red Sea and beyond.

Vertical and latitudinal distribution of heterotrophic prokaryotes, viruses and heterotrophic nanoflagellates along the Red Sea

Eman Sabbagh

Prokaryotes represent a large fraction of microbial biomass in the ocean. Understanding the interactions between heterotrophic prokaryotes and their controlling factors is important to advance our knowledge about microbial ecology in the little known but vast tropical regions. In this study, we assessed the vertical (5-1000 m) and latitudinal (16¬ſ-27¬ſ) variations in heterotrophic prokaryotes and their bottom-up (nutrient availability) and top-down controls (predators and viruses) at 8 stations along the Red Sea between 2017 and 2019 in three seasons (spring, summer and fall). We found that inorganic nutrient and dissolved organic carbon (DOC) concentrations did not vary significantly along the latitudinal gradient of the Red Sea. The more pronounced effect of heterotrophic nanoflagellate (HNF) on heterotrophic prokaryotes was found towards the equator ($p < 0.05$) that was also reflected in increasing heterotrophic prokaryotes:HNF ratio to the south. The decrease in heterotrophic prokaryote abundances over depth was less variable than that of HNFs and viruses. The abundances of heterotrophic prokaryotes were coupled with DOC over depth ($p < 0.05$), which probably indicates an active viral shunt of organic matter in the deep layers of the Red Sea, while the effect heterotrophic nanoflagellate (HNF) was more pronounced in the cell sizes of the low and high nucleic acid prokaryotes (LNA and HNA, respectively) where HNF predate on larger cells of both prokaryotes groups To our knowledge, these findings provide the first description of the latitudinal and vertical distribution of HNFs and viruses in the unique Red Sea system and give evidence of top-down control of prokaryotes communities over a latitudinal range.

Macroalgae and Associated Bacterial Microbiome Communities from the Red Sea

Saeed Amin

The Red Sea is a unique marine environment harboring diverse and poorly known Or unexplored ecosystems. The macroalgae-associated microbiomes, however, in this region remains largely unexplored with a dearth of knowledge about these bacterial microbiomes composition. Herein, this research endeavors to address the existing knowledge gap by investigating macroalgae-associated bacterial communities, with a specific focus on Padina species, collected from the southern to the northern Red Sea. This study aims to assess how variations in temperature and geographic location along the north-south gradient of the Red Sea affect the stability of associated bacterial communities of Padina species.
In this study, samples were collected during the Red Sea Expedition decade (RSED) expedition in 2022. The samples were processed rigorously, including rinsing with filtered seawater and snap-freezing with liquid nitrogen for subsequent storage at -80¬∞C. After DNA was extracted, the V3-V4 regions of the 16S ribosomal RNA gene were amplified using the marine universal prokaryotic primers Par515F and Par926R. The amplicon libraries were prepared and sequenced using the Illumina MiSeq platform at KAUST Bioscience Core Lab. Data analysis involved QIIME 2, which employed the DADA2 method for demultiplexing and clustering into operational taxonomic units (OTUs) at 97% sequence identity to the SILVA database. It shows that this study provides significant insights into the diversity and dynamics of bacterial microbiomes associated with Padina species in the Red Sea. The findings of this study will contribute to understanding the unique ecological interactions between macroalgae and their bacterial symbionts in this particular environment.

Exploring the coral resistome: abundance and diversity of antimicrobial resistance genes (ARGs) in Pocillopora verrucose

Giovanna Sabini-Leite

The collection of antimicrobial resistance genes (ARGs) in an environment is known as the resistome and has been extensively studied in soil, wastewater, animals, and humans. Many clinically relevant ARGs originate from such environments. ARGs can be transmitted horizontally through the biotic and/or abiotic environment or vertically through parent-progeny relationships. Identification of resistomes and ARGs in corals is an emerging field with the potential to have a significant impact. Research has shown that coral-associated microbial communities are complex and display adaptive abilities to their surrounding environments. As sessile animals, corals are highly exposed to co-occurring anthropogenic stressors, which can cause dysbiosis and lead to an influx of ARGs. Here, we conducted metagenomics analyses on the coral Pocillopora verrucosa to investigate the abundance and diversity of ARGs. Corals were exposed to the coral probiotic Cobetia sp. and/ or the opportunistic pathogen Vibrio coralliilyticus BAA450 in a month-long heat stress mesocosm experiment. In Vibrio-inoculated corals, we expected to see an increase in the abundance of ARGs whereas with Cobetia-inoculated corals, we expected to see a decrease in their abundance, proving the positive effect probiotics have in conferring resilience to corals. Microbiome analysis of these samples show that co-inoculation diminished Vibrio abundances and, given this mitigation in the microbial community, we expect that ARGs will mirror this pattern. To our knowledge, this is the first study to report ARG abundance and diversity in corals. While further studies are necessary to continue elucidating the coral resistome and immunity response, such findings have important consequences for reef management and disease mitigation strategies.

Ontogenetic Variability in RNA Quantities in Red Sea Clownfish

Wajd Alaidrous

Larval dispersal, or the spread of individuals away from their original habitat, provides a mechanism of connecting populations that are distant physically and genetically, making it an important component of population connectivity. Dispersal outcomes are largely variable among individuals, even siblings, and the factors that drive this variability are not understood, making it challenging to create marine protection plans for marine species.

Clownfish, Amphiprioninae, are among one of the most important species both ecologically and economically. Thus, creating protection plans for clownfish is extremely necessary, especially as they are under habitat loss threat.

Clownfish have long been considered an optimum model of organisms for studying larval dispersal and population connectivity. Because of their ecological and economic importance, Since dispersal traits are influenced by genes, transcriptomic studies can reveal insights into larval dispersal. Thus, the variation in dispersal outcomes could be better understood if the differential expression of genes related to dispersal, such as swimming abilities, are considered.

The aim in this study is to explore the underlying causes of variability in dispersal traits in marine species and the link between these traits and transcriptomics specifically in terms of differential gene expression (DGE). To explore these research questions, we performed transcriptomic analysis using larvae of Amphiprion bicinctus clownfish reared at KAUST SeaLabs to explore the link between transcriptomics and dispersal outcomes.

Spatial distribution and habitat use of Dottybacks (Pseudochromidae) and color morph plasticity in Pseudochromis flavivertex.

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Coral reef fish communities are influenced by benthic composition and topographic characteristics through the provision of habitat and food, and mediating predator-prey interactions. Dottybacks (Family: Pseudochromidae) are a diverse group of small reef predators that display a color variation within several species. In the Red Sea, this family has the highest rate of endemism with some species common across reef habitats while others appear to be habitat specialists; however, knowledge about their habitat use and the function of color variation within species is still limited. To enhance our understanding of this group, abundance, distribution pattern, habitat use, and color variation, were recorded on reefs across a distance from shore and depth gradient, and with different wave exposure in the Central Red Sea. We found differences in habitat use among Pseudochromis species and color morphs within a species, influenced by benthic composition. Further, we found two color morphs of Pseudochromis flavivertex of four reported for the Red Sea. Based on an aquaria experiment with individuals of two color morphs of P. flavivertex placed in contrasting habitat types (live, bleached, and dead coral), we determined that habitat composition influences color change. The morph commonly found in healthy reef habitats changed to the morph commonly found in degraded habitats. This study highlights the influence of benthic composition on coral reef fish distributions and provides information to predict how changes in habitat characteristics will affect their diversity on reef ecosystems, and if color morph plasticity allows these species to adapt to changing habitat conditions.

High-Resolution Analysis of Synechococcus spp. Abundance temporal variability in the Coastal Red Sea Based on In-Situ Flow Cytometry Observations

Luthfiyyah Azizah

Picophytoplankton dominates primary production in the oligotrophic Red Sea as observed in other oligotrophic waters. The cyanobacteria Synechococcus is a relevant component of the Red Sea planktonic community dominating the pico-sized group. Synechococcus populations vary at different temporal scales, and monitoring at the relevant time scale of variability is challenging but required for understanding responses to environmental changes and increased human impacts as ocean warming.

In this study, we applied advanced technologies using a combination of abundance and cell size measurements with a high-resolution sampling. Since 2018 to present, a Cytobuoy flow cytometer has been moored at the Ibn Sina field research station KAUST in the coastal waters of Red Sea to quantify the picophytoplankton. This is done in an automated and semi-continuous manner, with samples taken every hour. We use specific approach to identify the Synechococcus based on the signal of orange fluorescence and the cell size (FWS length < 4¬µm). Concurrently, environmental monitoring data, including temperature and salinity are obtained through a CTD moored in the buoy and seawater sampled are collected biweekly to measure chlorophyll a and nutrient concentration.

Due to the COVID-19 pandemic restrictions on sampling and laboratory work, there were data gaps from April 2020 to January 2021. Over the course of five years (2018-2023), the abundance of Synechococcus in the Red Sea exhibited distinct seasonal patterns. The winter months recorded the highest abundance (9.91 x 10^4 cell.ml-1), while the summer months showed the lowest abundance (2.62 x 10^1 cells.ml-1). Furthermore, there was a noticeable diel fluctuation in cell abundance, characterized by peak values observed during the evening (6 pm), followed by a subsequent decrease throughout the night.

Genomic potential and short term in situ application of a probiotic consortium in Pocillopora verrucosa

Ines Raimundo

A key component promoting coral homeostasis is their association with microorganisms from different phylogenetic groups, including bacteria. In the Red Sea, the large coral diversity and unique conditions combining high temperature and high salinity make it a suitable model environment for studies about the future of coral reefs under climate change scenarios. Beneficial Microorganisms for Corals (BMCs) have been successfully used as probiotics to improve coral health and resilience in mesocosm setups. Here, after investigating the coral microbiome composition of 9 healthy coral species in the Red Sea, by using culture-dependent techniques, 350 bacterial strains were isolated. From those, six strains were selected based on the presence of beneficial traits (e.g., nitrogen fixation, catalase synthesis), and a native multispecies BMC consortium was developed. Each BMCs DNA was extracted and sent for whole-genome sequencing using Pacbio. Putatively beneficial genes were identified using several platforms and databases (e.g., BV-BRC, Prokka, Roary). This consortium was applied on Pocillopora verrucosa colonies, in a Red Sea reef, for 2 months in the summer of 2021 and 2 weeks in the summer of 2022. Coral health and the successful establishment of the consortium were evaluated by multi-omics analysis to better understand the microbial dynamics and unravel changes in functional responses. All coral colonies inoculated with BMCs and placebo were healthy after the end of the experiments, and preliminary results indicate a dominance of Endozoicomonas across treatments and suggest a potential enrichment of the BMC strains. These efforts constitute the first coral-derived bacterial culture collection in the Red Sea, and this pioneer bacterial cocktail will be used for further research regarding its physiological capacities and symbiont-related features

Coral probiotics reshape the coral microbiome without affecting the surrounding environment

Nathalia Delgadillo

The use of Beneficial Microorganisms for Corals (BMCs), or coral probiotics, is a promising microbial therapy aimed at restoring and enhancing coral health and resilience. In this study, we present the first in situ application of a coral probiotic consortium. The objective was to assess the feasibility and safety of the in situ probiotic inoculation on Pocillopora verrucosa colonies in the central Red Sea. The inoculation lasted for three months, and samples were collected at four time points within a seven-month period. Throughout the experiment, we monitored the bacterial communities of nearby seawater and sediment before and after the inoculations. The bacterial community, photosynthetic capacity, and the holobiont thermal threshold were also monitored. No signs of disease or bleaching were observed in the corals, and microbiome analysis revealed a significant impact of the probiotic treatment on the coral's associated bacteria at the end of the inoculations. Over time, the probiotic-treated corals exhibited an enrichment of some of the applied probiotic strains (Halomonas sp and Pseudoalteromonas galathae), along with an overall increase in Proteobacteria and Firmicutes groups. Several families among the top 10 most abundant were enriched in the probiotic-treated corals, including Rikenellaceae, Prevotellaceae, Lachnospiraceae, and Rhodobacteraceae, while Endozoicomonadaceae decreased. Additionally, the abundance of groups with potential beneficial functions for the holobiont, such as bacteria from the genus Ruegeria and Limosilactobacillus, increased in probiotic treated corals, while potential pathogens like members of the Vibrionaceae family decreased in abundance. Importantly, the bacterial communities in the surrounding water and sediment were not disturbed by the probiotic inoculation, suggesting its safety application in the marine environment. This pioneering study demonstrates the feasibility and safety of using coral probiotics as a tool for active coral restoration in real world conditions.

Mesoscale eddies aggregate juvenile whale sharks in the Red Sea

Raquel L Ostrovski

Shib Habil is a submerged reef platform approximately five kilometers off the Red Sea coast of Saudi Arabia. Whale sharks, Rhincodon typus, are known to aggregate at this site in March, April, and May. Several studies have documented the population structure, residence patterns, and broad movement patterns of sharks from this site, but fine scale movement and behavioral data is lacking. Using high resolution accelerometry data from at least three whale sharks (two males and one female), I will present findings on diel shifts in vertical behavior and crepuscular feeding patterns. Animal borne video from the same individuals will be used to give context to the observed movements and reveal both the intra- and inter-specific interactions of our tagged sharks. This work highlights the importance of reef habitats to whale sharks and other pelagic visitors. Reef associated megafauna aggregations are valuable economic resources and local human communities should look to conserve these sites as sustainable sources of ecotourism revenue.

Stock assessment of the Squaretail Coral grouper (Plectropomus areolatus) along the Red Sea Coast of Saudi Arabia

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The squaretail coralgrouper (Plectropomus areolatus) is a commercially important species in the Red Sea (vulnerable status IUCN Red List). With an average price of 95 SAR per kg, the species contributes to an annual 39 million SAR to the Red Sea Saudi economy. This study aims to determine the exploitation level of this important natural resource. A total of 1590 individuals were sampled monthly between February 2022 and March 2023 from the Red Sea coast of Saudi Arabia. 94% of the samples were from the handline fishery, followed by traps and gillnets with contributions of 5.8%, and 0.2%, respectively. 1091 female and 474 male specimens were measured with total length (LT) and weight (WT) ranging between 21.0-67.2 cm and 21.5-60.4 cm, and 120-4771g and 125-3320 g, respectively. The median LT at first maturity (L50) estimate was 23.47 cm for combined sexes. The relationship between LT and WT for all individuals yielded parameters a = 0.0075 and b = 3.188. The estimated von Bertalanffy growth parameters, i.e., asymptotic length (TL,àû), growth coefficient (K) and theoretical age when LT = 0 cm (t0) were 75.61 cm, 0.187 years-1 and -2.296 years respectively. Sex ratio (F:M) was 2.3:1. Age was estimated by counting annual annuli from transverse sections of sagittal otoliths, with the oldest specimen being a 7-year-old female. From an age-based catch curve, the annual total mortality rate (Z) was estimated to be 0.89 year-1, with a natural mortality (M) of 0.33 year-1 and a fishing mortality (F) of 0.56 year-1. Consequently, the exploitation rate (E) was 0.63. Based on this information the stock does not seem to be in overfishing. Precautionary measures may be necessary to maintain the sustainability of the stock by not increasing fishing effort, with a continuous monitoring of the stock for an improved assessment of the resources.

Title: Morphological evidence of the Zabargad Transform Fault Zone termination on the Arabian Red Sea margin.

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Abstract: The Zabargad Transform Fault Zone (ZFZ) located in the northern Red Sea, has so far only been delineated by satellite-based geophysical data, causing uncertainties and debates on the exact locations and orientation of the fault and associated fractures zones. Using newly acquired high resolution bathymetry and lidar survey data we present the first morphological evidence of the northern extent of the ZFZ from the spreading center towards the NE Red Sea margin from seafloor geomorphological features. These features align for over 84 km from the spreading axis near the Mabahiss Deep, and continue to the shallow Saudi Arabian shelf along the northern termination of the Al Wajh carbonate platform. Investigation of the seafloor morphology revealed three geomorphic terrains: i) a deep incised canyon feeding into the Mabahiss Deep, which is characterized by dozens of amphitheater-shaped scarps, ii) a 22 km-wide head-scarp that follows the Al Wajh platform edge, iii) and multiple fault scars and graben like structures on the shallow shelf. We postulate that these morphological indicators represent the northern end of the ZFZ. In addition, ZFZ likely delineates and influence the morphology of the northwest margin of Al Wajh carbonate platform. This research gives new insights into the interaction between the ZFZ and the continental margin of the Red Sea and its role in the Al Wajh platform delineation and development.

The Bathymetry and Active Faults of the Gulf of Aqaba

Ribot Matthieu

Detailed knowledge of fault geometry and earthquake history is important for accurate seismic hazard assessment. The Gulf of Aqaba, which corresponds to the southern termination of the 1000-km-long Dead Sea strike-slip fault system, remains one of the least known parts of this plate boundary fault, in large part due to its location offshore. The Gulf of Aqaba has been described as a succession of left-stepping strike-slip fault segments bounding three pull-apart basins. Based on a recent multibeam bathymetric survey of the Gulf of Aqaba, we provide details about the geometry of the faults at the bottom of the gulf that controls its morphology. In particular, we identify a 50-km-long fault section (Aragonese fault) that shows evidence of recent activation, which we associate with the main fault section that ruptured during the 1995 magnitude Mw7.3 Nuweiba earthquake. In the southern part of the gulf, the bathymetry emphasizes the strike-slip nature of the Arnona fault, while dip-slip motion seems to be accommodated mostly by faults located along the eastern edge of the gulf. Considering the historical earthquake cycle of the Dead Sea Fault, the 1995 earthquake could be seen as the start of the new cluster sequence of major earthquake on the southern Dead Sea Fault. In addition, the simple linear geometry of the Arnona fault and the absence of any large earthquake for several centuries, despite an average slip-rate of ,àº5 mm/yr, the Arnona fault should be considered as a significant candidate for an earthquake rupture of magnitude 7 or above in the near future.

Distribution of Seismo-turbidite Sediment Layers in the Gulf of Aqaba

Ribot Matthieu

The Gulf of Aqaba (GoA) is seismically the most active area of Saudi Arabia and of the 1000-km-long Dead Sea Fault system. The rapid development of the NEOM mega-project in the area is leading to an increase of the seismic risk and makes further seismic hazard research in the region both important and urgent. The last major earthquake in the GoA occurred in 1995 along one of the main strike-slip fault segments, bringing both extremities of the fault rupture closer to failure. Studies of the DSF have found that large events along the entire DSF cluster during relatively short active seismic periods lasting about 100-200 years, separated by longer quiescent periods of about 350-400 years. From a tectonic point of view, the time gap between 1995 and the previous major earthquakes in 1588 CE and 1068 CE conforms to this scheme and suggests that the southern DSF may be ripe for a new earthquake sequence, with the 1995 earthquake as the starter. We investigate new sub-bottom profiling data acquired in February 2023 in the GoA to map the extent of sand layers present in the different basins of the gulf and correlate them with seismo-turbidite layers found in sediment cores collected in 2018. By looking at the geographic extent of these sand layers we aim to define the source of these deposits. The preliminary results indicate that our dataset allows to gain an overview of the sediment infill of the GoA over the past 20 ky or more. Even if the resolution of the sub-bottom profiling data is lower than that of the sediment cores we can still propose a longer-term overview of the earthquake activity and discuss the temporal organization of large events in the area.

Shallow crustal elasticity heterogeneity in the Dead Sea region constrained by InSAR measurements

Xing Li

Elasticity heterogeneity is not unexpected across large active strike-slip faults which juxtapose geologic terrains with contrasting mechanical properties, and which have structural complexities such as stepovers. Despite geophysical evidence of such mechanical heterogeneity, direct evidence from geodetic measurements is rare. Here, we process the Interferometric Synthetic Aperture Radar (InSAR) data covering the Dead Sea whose water level has been steadily declining at ~1 m/yr since the 1980s. Our InSAR-derived vertical rates averaged over 2014-2021 clearly show two stripes of uplift along the eastern and western banks of the Dead Sea. The ongoing uplift along the western bank is about 2 mm/yr, ~25% greater than along the eastern bank. Those InSAR-derived patterns can be replicated by our elastic finite element models in response to water unloading. Our preferred model(s) has the Young,Äôs modulus of 29-38 GPa and 40-52 GPa for the shallow crust above 3 km depth for the western and eastern domains, respectively. The preferred boundary defining the two domains is likely along the Dead Sea fault, a predominantly strike-slip fault passing through the eastern bank. However, the InSAR-derived uplift may be the footwall uplift due to normal fault motions on the Dead Sea fault and an east-dipping normal fault along the western bank that was found to be inactive in the Holocene. Unless the western normal fault became reactive recently, more active than that on the Dead Sea fault, it is unlikely that normal fault motion alone can explain the InSAR-derived uplift. The success of our simple finite element model and seismic evidence of crustal heterogeneity support that the InSAR-derived uplift is of mechanical property origin. The elastic heterogeneity across the Dead Sea fault likely arises from the structural evolution of the Dead Sea basin, a pull-part basin to the west of the Dead Sea fault.

Morphology of rifted volcanoes in the southern Red Sea as a proxy of seafloor spreading directions: insights into the Nubia-Arabia-Danakil triple junction localization.

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On magmatic slow spreading centers such as the Red Sea, seafloor spreading is accommodated by the interplay of two major processes: magmatism and rifting. Emplacement of large central volcanoes within Mid-Ocean-Ridge (MOR) rift valley is a manifestation of melt focusing during the magmatic cycles at the midpoints of MOR segments. Large volcanoes formed during the magmatic pulses are rifted and carried away by the next tectonic phase, and the deep axial valley formed by the tectonic phase is progressively filled by a new volcanic ridge during the next magmatic phase. The position of half-volcanoes relative to the axis is a function of their age and spreading direction.
Seafloor spreading in the Red Sea is the result of oceanic crust accretion since 14 Myr. Along its axis, the Red Sea is divided into northern and southern domains. The northern domain consists of short oblique MOR segments that are highly segmented by transform discontinuities, and largely covered by allochtonouns sedimentary rocks. The southern domain consists of a-long continuous MOR segment where the Plio-Pleistocene oceanic crust is well exposed. Here, the MOR is bisected by long nested axial grabens floored by volcanic features. Away from the spreading axis these features become progressively covered by flat lying, thickening pelagic sediment wedges.
In this presentation, we discuss the morphology of one of the world‚Äôs best examples of rifted volcanoes observed in the southern Red Sea and their implications for locating the triple junction between the Arabian, Nubian, and Danakil plates. By reproducing and measuring their spreading directions, we identify a 9¬∞ shift in spreading direction north and south of 18¬∞N. These findings contribute to understanding the geodynamic history of the Red Sea and we conclude that the triple junction position is approximately at 18¬∞N ¬± 0.5¬∞.

Surface expressions of rift-transform motion under salt deposits: analogue-model application to the Zabargad Fracture Zone, northern Red Sea

Margherita Fittipaldi

The Red Sea rift is largely covered by Miocene evaporite deposits, that, flowing as glaciers into the rift, hide its main structure and geomorphology, especially in the northern Red Sea. This thick salt cover is made up mainly of halite and has led to contrasting interpretations of bathymetric, magnetic, and gravity data. The most recent studies suggest that the Red Sea is an oceanic ultra-slow spreading ridge composed of offset ridge segments separated by complex fault systems, interpreted as transform faults. One major 100 km offset, the Zabargad Fracture Zone (ZFZ), separates the northern Red Sea axis from the central one and is the location of the most intensive seismic activity in the north. Since the ZFZ is located near coastal communities, a possible large earthquake could cause harm. Consequently, knowing its structure and its related seismic hazard is important. New bathymetric data we collected show highly deformed salt deposits in the ZFZ with multiple curved and stretched salt lineaments. Considering the inability of the salt to erode underlying geology, pre-existing structures and rift movements probably control the salt flow pattern and lineaments direction. In this light, we built analogue models to simulate salt deformation in a strike-slip regime between two oceanic ridges. We use silica powder to simulate the brittle crust and transparent silicone to simulate salt deposits. Three different obliquities of the strike-slip fault between two ridges were tested. Preliminary results show that the salt acts as a filter of the sub-salt structures and movements and only the more prominent structures are replicated at the surface. Several modeled salt flows, especially in the center of grabens, form compressional ridges. Curved lineaments are present along the fault offsets. The scaled models will be compared with the ZFZ area, thus providing a better understanding and interpretation of the bathymetric data.

Earthquake relocations in the Gulf of Aqaba

Sofia Manzo-Vega, Laura Parisi, Sigurjon Jonsson and Martin Mai

Seismic activity in the Gulf of Aqaba (GoA) poses serious threats to the development of the infrastructure in the NEOM region of Saudi Arabia. For such a reason, a temporary seismic network (GA network) has been deployed along the Saudi coast of the GoA to identify seismically active faults. A preliminary catalog obtained from data of this temporary network and least-square inversion of first arrivals of P and S waves displays a previously unknown onshore cluster of earthquakes in the proximity of the planned NEOM infrastructures. Moreover, the Saudi Geological Survey (SGS) catalog contains a swarm of events that occurred in September 2021 in the southern GoA that depicts an unknown fault striking NE-SW in slight disagreement with the tectonics of the GoA.

In this work, we use a probabilistic method based on partial waveform inversion to relocate the onshore cluster and the offshore swarm by using the QuakeMigrate location method. Important changes are found in the distribution of previously localized events. For the onshore cluster, we locate 250 events from the 262 initial catalog. Their locations moved from onshore to the Gulf of Aqaba and their depth increased. For the September 2021 swarm, we identified 394 seismic events, which corresponds to about 80% more events when compared with the existing SGS catalog. The new locations depict a fault striking NW-SE and a ‚Äúbanana‚Äù shape depth distribution roughly centered on the coastline.

Our results suggest that the geometry network and traditional location methods might influence fault imaging. However, the extent of this influence depends on the fault strike and can be mitigated by employing alternative localization methods.

Efficiency of the Biological Pump in the Red Sea

Wang Liu

The biological pump is a crucial mechanism facilitating the transfer of carbon dioxide from the atmosphere to the deep ocean through the interconnected activities of marine organisms, thereby regulating the global climate. Photosynthesis of phytoplankton and decomposition of bacteria promote the aggregation and sinking of organic particles, contributing to the biological pump. The efficiency of the biological pump signifies the percentage of carbon captured through photosynthesis that is effectively transported and requested in the deep ocean, which is influenced by biotic factors of the phytoplankton diversity and bacterial activity. The Red Sea, with oligotrophic and warm waters, shapes the distribution and abundance of microorganisms, making it a fascinating region to study its biological pump efficiency. Via The Red Sea Decade Expedition 2022, we collected samples of microphytoplankton and bacteria at various depths and latitudes. Our findings unveiled the following patterns: with increasing depth, there was a decline in both microphytoplankton species and abundance, consequently leading to reduced primary production. Additionally, as the depth increased, microphytoplankton experienced prolonged periods of darkness exposure while settling from the epi- to the bathypelagic zone, which caused the degradation of the light-harvesting complex and photosynthetic reaction center, resulting in diminished photosynthetic performance. The feasibility of microphytoplankton photosynthesis, along with the identification of microphytoplankton species, provided evidence of the prevalence of healthy cells in the deep Red Sea. Notably, diatoms were particularly abundant among these microphytoplankton, possessing dense silicate cell walls that facilitated their negative buoyancy, leading to their efficient settling and contribution to both organic and inorganic components of fine sediments.

Exploring The Microbial Communities and Their Plastic Degrading Enzymatic Activity

Patterns in Extremely Micro-plastic Polluted Mangrove Forests

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Plastic production worldwide reached a staggering 390.7 million tones in 2021, with over 250,000 tones being dumped into the oceans. Due to the low rate of degradation, (micro)plastics remain in the ecosystem for long periods. There is currently a knowledge gap and growing interest in seeking green alternatives to mitigate marine plastic pollution, and fortunately, they may be susceptible to biodegradation by certain groups of microorganisms that live in the environment. However, the process of degradation of synthetic polymers by microbes is not globally well developed.
The Red Sea coast of Saudi Arabia is home to unique marine ecosystems. Mangrove sediment contains diverse microbial communities and has been found to act as a long-term sink for microplastics. Here, we apply metagenomics and dilution to stimulation approaches to investigate the mechanisms of how microbial consortia degrades microplastics. Synthetic microplastic was used as the sole carbon source in the enrichment culture. The Stimulated Raman Scattering (SRS) microscopy technique was used to classify microplastics in environmental samples collected in different mangrove forests along the Red Sea. We estimate that our results will show several genes and microorganisms associated with the degradation of microplastics and open space for the mining of genes or enzymes involved in the degradation of complex polymers (hydrolases, laccase, etc.). There will be correlation between the abundance of these microplastics and these genes. We believe that our results will help to select consortia and build a framework to, in the future, engineer the microbial community and its metabolic activity to accelerate the degradation process.

Ahmed Hafedh

FSO Safer, a deteriorating oil tanker with 1.1 million barrels of oil onboard it, continues to pose the threat of spilling oil in the Red Sea. As previous spills and research suggest, a spill of the magnitude of Safer would be catastrophic for the region, greatly affecting its ecosystem and many of the benefits drawn from it. In this investigation, we model the possible trajectories of the potential oil spill under different seasonal conditions, in order to determine the possible effects of the spill depending on the weather of the region. We find that oil spills in the region pose a high risk of evaporating leading to dangerous levels of potential air pollution, as well as pose a risk of contaminating local food and water supplies. Furthermore, we observe how during the summer, the oil spill tends southwards towards the Gulf of Aden, which opposes the trajectory a winter, autumn, or spring spill would take; a spill during this time, we predict, would cause mass beaching along the coast of Yemen and the northern countries along the Red Sea. Our results emphasize the importance of planning around a potential spill and possibly directly solving the issue of the unattended tanker.

Coral holobiont functioning under environmental change: Determining the drivers of coral-associated denitrification

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Nitrogen (N) plays a central role in the production of biomass in coral reef environments. Coral reef's main habitat builders, hard coral holobionts, have evolved strategies to exploit N whenever possible, i.e., via N_2 fixing microbes, promoting their survival and huge productivity in oligotrophic waters. Despite the importance of N for the coral, an N-limited state is required to maintain a symbiotic relationship with its partners Symbiodiniaceae. Various anthropogenic factors, such as global warming, aquaculture, or untreated wastewater disposal, can cause the inhibition of N-limitation, and may thus threaten holobiont health. Novel research identified specific microbes -namely denitrifiers- that can help to alleviate the coral holobiont from excess N. Yet, detailed knowledge about coral-associated denitrification, and especially what drives it, is still lacking. To fill this gap, we aimed to understand the extent to which denitrification is limited by the trophic strategy of the coral holobiont under unstressed, i.e., stable state, conditions through natural seasonal fluctuations. We hypothesised that (*i*) autotrophic corals would exhibit higher denitrification than those that are more heterotrophic as, similar to N-fixing microbes, denitrifiers may rely on photosynthates released by the Symbiodiniaceae, and (*ii*) that the more autotrophic coral holobionts will display the most variable response to seasonal change. To carry out this research, we sampled four common Red Sea hard corals, that vary in trophic capacity, across an entire year; *Stylophora pistillata, Acropora* sp., *Millepora dichotoma* and *Tubastrea coccinea*. We monitored environmental variables and assessed the corals' denitrification potential by performing combined blockage/acetylene reduction assays, colloquially termed "COBRA incubations". We will present the first results at ICMERS 2023. Our findings will contribute towards a better understanding of N-cycling in coral holobionts.

Assessing the abundance of anthropogenic seafloor litter in the Eastern Red Sea

Anastasiia Martynova

Approximately 8 million metric tons of plastics enter the oceans annually. While some debris may remain afloat in the surface waters or be washed ashore, the majority sinks to the bottom, which may result in the degradation of vulnerable benthic communities. Consequently, the amount of anthropogenic litter accumulating on the seafloor will continue to increase in upcoming years owing to the constant growth in plastic production and waste generation rates. To identify the hotspots and assess the spatial distribution of benthic litter pollution in the Eastern Red Sea, we conducted transect surveys of the seafloor. These surveys were carried out using a Remotely Operated Vehicle (ROV) during the Red Sea Decade Expedition on the R/V OceanXplorer in 2022. Overall, we examined more than 67 km of the seafloor in 84 dives and identified 737 individual litter items. The majority of the observed litter was plastic (40% total), followed by metals (28%), glass (4%), textiles (3%), and rubber (1%). Miscellaneous and unspecified items accounted for 11% and 13% of the total items, respectively. On average, litter density ranged from 2,344 to 13,803 items km-2 in different parts of the Red Sea, with a mean density of 5,360 ¬± 1,514 items km-2. Eighty-four percent of debris was observed on the sea bottom, 15% on slopes, and only 1% was seen attached to vertical walls. The influence of several factors on the distribution of benthic litter will be explored in future work. The findings of this comprehensive study could be valuable for developing strategies to monitor seafloor litter in the region, aiding conservation efforts to preserve the unique ecosystem of the Red Sea.

First report of meso-parasitic copepod on the endemic Red Sea Vinciguerria mabahiss

Kah Kheng Lim

This study investigates the presence of a novel species of parasitic copepod (family Pennellidae) associated with the deep-sea host lightfish, Vinciguerria mabahiss, in the Red Sea. Such parasitism has been reported in the deep-sea ecosystem elsewhere, however information regards copepods inhabiting the Red Sea fish species is scarce. Microscopic examinations were conducted on two specimens, complemented by DNA barcoding using nuclear markers for genetic analysis. Preliminary findings reveal distinct morphological features and significant genetic divergence, indicating a potential new copepod species. Infestation rates of 34.6% suggest a symbiotic relationship with implications for the ecology and evolution of both copepods and the host. The study unveils the importance of lesser-known ecosystem in uncovering novel species and ecological interactions. This discovery contributes to our understanding of deep-sea biodiversity and host-parasite interactions in the unique Red Sea ecosystem.

The First Network of Ocean Bottom Seismometers in the Red Sea to Investigate the Zabargad Fracture Zone

Laura Parisi

In the last decades, the slow-spreading Red Sea rift has been the subject of many studies on the initiation of rifting, extension of the oceanic crust, thickness of the sedimentary cover, and formation of transform faults. However, local seismologic datasets have been lacking despite their potential in contributing to the understanding of the tectonic evolution of the Red Sea.

The Zabargad Fracture Zone is located in the Northern Red Sea and offsets the rift axis by ~100 km, which is the largest offset in the Red Sea. Thus, it is considered a key tectonic element for a better understanding of the formation of the Red Sea rift. Moreover, the possibility of a tens-of-km-long transform fault in the ZFZ could constitute a high seismic hazard for the coastal cities of Yanbu, Um Lujj, and the infrastructures of the Red Sea Global tourism project.

To fill the gap in earthquake data due to only widely spread onshore seismic stations, we deployed the first passive seismic network in the Red Sea, within the Zabargad Fracture Zone. This network included 12 Lobster OBSs from the DEPAS pool, 2 OBS developed and deployed by Fugro, and 4 portable seismic land stations deployed on islands of the Al Wajh lagoon and onshore on the Saudi Arabian coast. Data were collected from July 2021 to January 2023.

Data from the first OBS deployment in the Red Sea will be used to build a high-resolution earthquake catalog to identify potential transform faults and derive thermal information about the Red Sea. Moreover, earth structure studies based on this dataset may offer an explanation of the morphology and location of the ZFZ. Analysis of the seismic signal can also reveal the location and characteristics of volcanic and hydrothermal activity. Finally, this dataset can be exploited to gain oceanographic insights and track mammals in the Red Sea.

Laura Beenham

A diversity of human-assisted approaches to rehabilitate and boost coral health have been suggested and investigated throughout the past years. Vitamins and trace-metal supplementation is a well-known strategy in human medicine and aquaculture, but vitamin addition is not currently actively tested for coral growth and recovery. These molecules are essential cofactors that have been correlated with coral thermal resistance and upregulated in corals treated with beneficial microorganisms (i.e., probiotics). To assess the effects of B12, B6 and zinc supplementation on coral health, we conducted a 2-month experiment in an open-closed-loop system mesocosm joined to a peristaltic pump continuously dosing the vitamins and/or zinc to individual 250 L tanks. Fragments of five different colonies of Acropora hemprichii were randomly distributed into the respective treatment tanks (B12, B6, zinc, multi-treatment and control). After 21 days, the corals were exposed to a pulse (1 day) of thermal stress, followed by three weeks of recovery. Substantial mortality (55%) in the control treatment was observed during the stress and recovery, with B12, B6, zinc and multi treatments exhibiting significantly less mortality (<20%). Coral health data combined with analysis of microbiome and metabolomic approaches suggest that both vitamins and zinc have a positive effect on coral health recovery. This study is the first to provide evidence that complex B-vitamins accompanied by zinc supplementation, can be a valuable tool for coral reef rehabilitation, and paves the way to further understanding specific mechanisms by which these nutrients promote coral health will be needed.