QATAR UNIVERSITY

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MOBILE EPIFAUNA ASSOCIATED TO ARTIFICIAL SUBSTRATES IN OFFSHORE QATARI WATERS

BY

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ABSTRACT

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Title: Mobile Epifauna Associated to Artificial Substrates in Offshore Qatari Waters

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Offshore human-made structures including oil and gas platforms and other energy producing structures, such as foundations of windfarms, serve as hard substratum supporting diverse marine communities of invertebrates both sessile and motile. Stainless-Steel Plates were used to study the spatial distribution and connectivity among mobile invertebrate assemblages in the North of the Qatari EEZ. Thirty plates were deployed, at depths between 10 and 44 m, in each of six offshore sites, along a transect defined between natural and artificial reefs (i.e., oil platforms). After one year, two replicate plates per 5 m depth interval were retrieved and analyzed for each site. A total of 2302 specimens, belonging to 42 operational-taxonomic-units and 32 families were identified. These were comprised of 14 families of annelids, 8 arthropods, 5 echinoderms, 2 gastropods, 2 platyhelminths and 1 sipunculid. Multivariate analysis for abundance and biomass showed that both Site and Depth, as well as their interaction, had significant effects on the mobile macrofaunal community. A general trend of total abundance and average number of taxa decreasing with depth was observed, although with some notable exceptions. Cumulative dominance was consistently larger for biomass, relatively to abundance, at all depths and sites, resulting in positive values of the W statistic, which suggest low levels of disturbance. Nevertheless, an increasing trend of the W statistic with distance from the oil field was also observed, with the minimum value at the site closest to the oil platforms. Strong positive correlations were observed between some groups of mobile and sessile taxa, such as sipunculids and polyclads with bivalves and decapods with barnacles. These mobile-sessile relationships are believed to be mainly driven by trophic interactions and habitat provision. These results highlight the important ecological role of oil platforms in the Arabian Gulf as it has demonstrated the capacity of offshore stainless-steel surfaces to be rapidly colonized by diverse assemblages of mobile macrofauna. Accordingly, knowledge gathered in this project is expected to contribute to reconcile the planning, operation and decommissioning stages of oil platforms with sustainable management of marine ecosystems in the Arabian Gulf.

DEDICATION

I would like to dedicate this project to my

Family

and Instructors

whose support helped me complete my M.Sc.

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BACKGROUND

Marine Artificial Substrates and Their Ecological Significance

Artificial structures get introduced into the marine environment either by accident such as due to shipwrecks or intentionally for various purposes such as coastal protection or oil and gas exploitation. One of the first uses of the artificial reefs was by Persians to block Indian pirates out of the Tigris River (Williams, 2006). Artificial structures may also be introduced for re-establishing the lost or damaged substrates to increase the abundance of target species of benthos and the associated nekton. Artificial structures are indeed increasingly seen as tools for the improvement of fisheries and the protection of key marine ecosystems, due to their capability of providing substrate for the settlement of marine benthos (Friedlander et al., 2014; García & Salzwedel, 1993; Page et al., 2009; Zintzen et al., 2008). Artificial reefs have been successfully deployed for rehabilitation and recovery of affected natural coral reefs worldwide (Burt et al., 2011; Perkol-Finkel et al., 2005).

Various human-made structures including oil and gas platforms and other energy producing structures, such as foundations of windfarms, when deployed into offshore waters serve as hard substratum supporting diverse marine communities of invertebrates both sessile and motile. Oil and gas rigs typically have a prohibiting zone of at least 500 m around them, which prevents fishing and other human impacts, but also restricts sampling for scientific purposes. This deployment process is not simply the addition of new hard substratum to the marine environment but the formation of novel habitats which are distinguishable from those that occur naturally (Zintzen et al., 2008).

Coral reefs are at risk worldwide (Munday, 2004). Coral reefs, although covering only 0.2% of the total marine environment area, are known to harbor about one third of all identified marine species, being considered the most diverse marine ecosystem and are estimated to contain 1 – 2 million (known and unknown) reef associated species worldwide ("Coral reefs | WWF," n.d.; Reaka, 2005). The three-dimensional complex structure provides numerous ecological services, complex species interdependencies and sources for several medicinal compounds. These extensive landscapes provide protection to species from predators and to coasts from storms or wave erosions (Veron et al., 2009). Various anthropogenic activities including overfishing of the reef associated species and inputs of nutrients and pollutants from coastal activities have caused coral mortalities as well as reduced coral recruitment (Sandin et al., 2008). Moreover, other stressors such as introduced alien species are also indirectly related to these more localized man-induced disturbances (Wilson et., 2006). However, despite the climatic and anthropogenic disturbances there exists reefs that are relatively free of direct human damage due to their geographic remoteness. Such reef ecosystems have been observed to attain great recovery rates even after experiencing a mass bleaching event, for example, in the case of Chagos Archipelago, Indian Ocean which went through severe mortality (>90%) during the 1998 warming event but recovered back rapidly reaching values like those existed during Holocene (Perry et al., 2015).

Climate related disturbances such as warming sea waters, rising sea levels and ocean acidification as well as human-induced pressure and disease outbreaks are all speeding up the changes in coral reefs across the globe (Perry et al., 2015). The 2016 mass bleaching event caused about 51% reduction in coral cover in the Great Barrier Reef and western Coral Sea (Stuart-Smith et al., 2018).

Artificial substrates and their associated coral reef ecosystems are significantly replacing natural reefs and therefore natural habitats for marine benthos and associated organisms (Sanabria-Fernandez et al, 2018). Additionally, artificial habitat enhances the ecosystem's carrying capacity producing a sustained increase in biomass of fish and invertebrates.

Quantifying the effect of artificial reefs in producing sustainable increase in fishery production was first studied by Polovina & Sakai (1989) in the northern Japanese waters. Japanese government has been spending US$ 10 million annually on the construction and deployment of artificial reefs in coastal waters throughout its history of long commercial use of artificial reefs. The study by Polovina & Sakai (1989) showed that the regional catch per unit of the Pacific giant octopus, previously habitat-limited, was enhanced positively with the addition of artificial reefs. Hence, the fish populations are not only limited by recruitment (survival, dispersal and settlement) but can also be restricted by availability of suitable habitat (space-resource limitation) which in return may negatively affect the food availability, reproductive output as well as trigger an increased predation rate (Macreadie et al., 2011).

The goals of Artificial Reef (AR) ecology mainly addressed colonization and succession; recent studies focused on hydrodynamics, bioenergetics, and food webs, and the role played by reefs in species recruitment. The recent researches (including the current study) focuses on the variations in the epibiotic community composition and structure as the aim of AR research has shifted from improving fisheries as a resource to additionally the restoration of the marine ecosystems (Lee et al., 2018).

Oil Platforms

One third of the oil and gas extracted worldwide is from offshore sources with thousands of oil and gas platforms distributed worldwide from the North Sea to the Southern Asian seas (Torquato et al., 2017). Page et al. (2009) estimated over 8,000 offshore active oil/gas platforms globally with additional 1,500 on their way to completion. The current numbers are likely to be much greater as new oil and gas marine fields are exploited as opposed to traditional terrestrial reservoirs.

Offshore platforms have been known to indirectly provide a large sophisticated artificial habitat for a range of colonizers comprising of invertebrates and fishes (Torquato et al., 2017). Moreover, the platforms anchored to the seabed, extending up into the atmosphere provide substratum throughout the complete vertical water profile. The complex structure of these platforms further plays an important role in providing a large three-dimensional surface for marine organisms over a relatively small footprint of seafloor.

Places where fouling assemblages settle and grow on the submerged portions of offshore oil/gas platforms have previously been reported such as in Beibu Gulf of China, the Gulf of Mexico, off the Californian coast, the southern Arabian Gulf which encompass Qatari waters (Stachowitsch et al., 2002), the Mediterranean, and the Celtic and North Sea (Stap, Coolen, & Lindeboom, 2016).

Several thousands of oil and gas platforms in northern Gulf of Mexico have been a source of hard substratum for marine organisms (Zintzen et al., 2008). For example, more than 40 invertebrate colonizers belonging to seven phyla were recorded at the offshore platforms of Carpinteria, Santa Barbara Channel (California, USA) by Bram et al. (2005). On the other hand, recruitment density (secondary production), a proxy for evaluating the ecosystem functioning, was observed to be extremely high (by an order of magnitude, 104.7 - 886.8 g m^{-2} y^{-1}) in the oil and gas platforms off the California coast compared to any other marine ecosystems which indicate high levels of recruitment (Claisse et al., 2014). Besides, some sizable platforms have been estimated to provide acres of hard substratum for the epibenthic assemblages (Sammarco et al., 2012).

Apart from providing suitable area for the recruitment and growth of marine invertebrates and fishes, offshore platforms are subjected to minimum human pressure and are usually located in deep waters with strong currents. Open marine systems have been known to have potential for dispersal of many marine species, during their pelagic phases, over large distances and long periods of time (Molen et al., 2018). Hence, these substrates can act as stepping stones to bio-geographic expansions by facilitating genetic connectivity of the species that flow in through the larval dispersal especially for crucial organisms such as corals and coral associates allowing connectivity between the reefs. Thus, a better understanding of the type of species that exist within and around the platforms and other several thousand offshore energy structures worldwide is essential to estimate the effects of these platforms on the associated marine biota (Stap et al., 2016).

Friedlander et al. (2014) while studying the oil platforms in Gabonese waters off the coast of west Africa describes these platforms as oases of biodiversity. Thirty-four percent of the total fish species recorded was new to the Gabonese waters and six percent to the Western African continental shelf (Friedlander et al., 2014). The Gabonese platforms acted as stepping stones allowing in the fish species that were seen to have Amphi-Atlantic affinities, previously unknown to local Gabonese waters. However, these stepping stones may also be a source of invasive species that may produce adverse effects on the local community.

Several physical and biological factors such as disturbance, temperature fluctuations, food availability, light availability, biological competition and predation and transportation of larvae by currents could contribute to the spatial variations in macro-benthic assemblage structure and dynamics (Page et al., 2008). Previous studies such as Page & Hubbard (1987) found vertical patterns of the macrofaunal assemblages, with certain groups of taxa abundant at specific depths. For instance, the mussel *Mytilus edulis* was found abundant at an offshore oil platform in Santa Barbara Channel, California, between the sea-surface and 20 meters sub-surface and this distribution was defined by its trophic mode (Page & Hubbard, 1987).

Depth associated patterns in a benthic community structure examined using deployed artificial substrates at depths 8, 16 and 24 m concluded depth-specific species relation, where most species were consistently abundant at specific depths. Patterns of total abundances of major taxonomic groups maintained for depths at both studied geographic sites (Islands) and during the two considered seasons (Rule & Smith, 2007). Depth was considered the structuring factor for the epifaunal assemblages of subtropical rocky reefs. Also, Bram et al., (2005), while examining the early development of an invertebrate assemblage at an offshore oil platform concluded that the depth influenced the growth rates along with other factors.

The general patterns of abundance, species richness and biomass of marine species decreased with increasing depth. These generally known patterns of density and abundance of macrobenthos decreasing with depth is believed to be mainly because of decreasing primary production and food supply (particulate matter) down the water column (Vedenin et al., 2018).

Similarly, to the depth-related variations, the macrofaunal distribution and community structure may also be defined by geographic spatial gradients such as the gradient between two reefs or gradient down the offshore reefs all the way from the coastal sources.

According to Page et al. (2008) the spatial variations in the recruitment and growth rates of selected macrofaunal species on seven offshore oil and gas platforms were defined by prevailing oceanographic gradients along the channel. Some of the selected taxa exhibited a general increase in abundance with increasing distance along the channel from south-east towards north-west and some were more abundant in the southern platforms. The study concluded that an assessment of these colonizing assemblages could be a useful indicator of short- or long-term change in the marine climate (Page et al., 2008). Stap et al., (2016) found that species composition and abundance on the five oil platforms varied over depth and along the distance-from-shore gradient. The species richness (S) decreased significantly with increasing distance from shore. Friedlander et al. (2014), while studying benthic communities on 10 oil platforms in Gabonese waters, concluded three distinct clusters formed by the platforms in the ordination space. The study found higher diverse assemblages of the benthos in the southern and inshore platforms when compared to other locations. Similarly, it observed highest number of fish species in the northern platforms, partly due to the platforms in the north being the oldest ones.

Production platforms can provide habitat for epibiotic invertebrates that can be of various sizes and many of these species are found common with natural habitats despite the distinct physical and biological environment of the offshore platforms (Bram et al., 2005). The ecological dimensions such as biological structure and function of these artificial habitats as well as their physical characteristics imitate natural reefs to variable degrees. Therefore, it is pivotal to study the community structure in such isolated and disconnected marine habitats, to compare their structural and functional similarity and variability to the natural ecosystems. High habitat structural complexity is usually associated to highly diverse and abundant marine communities. Hence, decommissioning thousands of oil and gas platforms, at the end of their service life, must consider the potential effects on the community of invertebrates and fishes inhabiting these habitats and incorporate options such as rigs-to-reefs (Claisse et al., 2014).

Rigs to Reefs

Another important reason to study these artificial habitats is to contribute to the planning of the decommissioning stage of the oil platforms. Considering the substantial habitat and diversity losses in coastal reefs, the perceived capacity and ecological significance of the offshore structures is gaining increasing importance. Numerous programs have tried to promote the transition of decommissioned platforms into artificial reefs (Dauterive, 2000; Kaiser & Pulsipher, 2005; Lee et al., 2018; “Louisiana Aims to Turn Shut-Down Oil Rigs into Reefs,” 2017; “Proposed law could jumpstart California’s rigs-to-reefs program,” n.d.; “Relics to Reefs,” n.d.; Macreadie et al., 2011; Rezek et al., 2018; Techera & Chandler, 2015). However, only a limited amount of studies has been conducted on ‘active’ rigs.

As the global number of offshore oil and gas rigs approaching de-commissioning is ca. 6,500 rigs, there is an increasing need for the employment of a "rigs-to-reefs" decommissioning program in the offshore waters to convert the prospective obsolete rigs into artificial reefs, on a large scale. Rigs-to-Reefs (RTR) was first performed in 1979 off the Coast of Florida followed by other regions worldwide such as Southeast Asia, Mexico and North Sea countries (Macreadie et al., 2011). These rigs to reefs programs left in place the ‘under the water’ parts of the man-made structure (aka rigs-to-reefs) and are expected to sustain biological production, enhance ecological connectivity, and ease conservation and restoration of deep-sea benthic community for example by protecting cold-water corals on natural substrates by physically limiting access to the area by coastal fishing trawlers. However, if the rigs to reefs conversion is not implemented correctly there are possible negative impacts such as the release of abandoned contaminants on rigs, introduction of invasive species in its function as a stepping stones and changes to benthic habitats and associated marine food webs (Macreadie et al., 2011).

The structural design, specifically the stainless-steel component, makes the RTRs a suitable habitat for invertebrate colonization and growth. Sedentary macro-invertebrates were found commonly dwelling within the oil rigs of California (Henry M. Page et al., 2008), explaining the affinity for the rigs by variety of species. Sessile macro-invertebrates are more commonly found on these steel anchors as compared to concrete reef anchors. In a study in Oahu, Hawaii; shallow-water corals preferred colonizing painted steel than concrete or tires (Fitzhardinge et al., 1989), on the other hand, deep-water corals such as *Lophelia pertusa* inhabited steel substrate of the decommissioned platforms in the North Sea inferring steel's suitability to support deep-water corals communities (Bell & Smith, 1999). Nevertheless, communities growing on the artificial habitats are often different than their natural counterparts regardless the age of the rigs (Burt et al., 2009); this difference is likely a consequence of structural and substrate differences. However, for places with extreme habitat destruction and absence of important natural communities nearby, the artificial substrates would offer a valuable opportunity for colonization regardless of the substrate material, resulting in ecosystem rehabilitation and fisheries yield enhancements.

The research into Artificial Reefs (AR) has tremendously expanded from an early basic AR design and deployment aiming from fisheries enhancement to various other beneficial purposes. Other benefits of RTRs to the oil and gas industry is the substantial saving on decommissioning costs (Macreadie et al., 2011). The financial expense of the complete decommissioning is large. It's estimated for the oil and gas platforms in the North Sea at £17.6 billion between 2016 and 2025 whereas for the UK continental shelf to 2050 is £47 billion (Molen et al., 2018). Thus, the prospect of leaving the submerged part in situ is an attractive cost-cutting opportunity (Techera & Chandler, 2015). Therefore, the goals of artificial reefing include human socio-economic aspect along with environmental conservation and is sustainable as it provides economic benefits alongside the social and environmental benefits. The current study near the Al Shaheen oil platforms may provide dual economic benefits of reducing decommissioning costs to oil and gas operators as well as improving the fisheries yield apart from the environmental benefits.

Arabian Gulf

The Arabian/Persian Gulf is a shallow, semi-closed and relatively younger seawater basin originated about 15,000 years ago (Torquato et al., 2017). About 1,000 km in length and 370 km wide at its widest point, the Gulf has an average depth of ca. 35 m making of the Gulf a shallow seawater basin. Along its southeastern side, the Gulf is outlined by the coasts of Qatar, Bahrain and UAE. To the south, it connects with Gulf of Oman through the 56 km wide Strait of Hurmuz (Feary et al., 2011) which allows in the Indian Ocean Surface Water (IOSW). The sources of freshwater are limited to riverine inputs mainly through the now dammed Tigris and Euphrates in Iraq discharging 35-133 km^3 per annum (Quigg et al., 2013) and inadequate precipitation typical of a desert region. The Gulf lies in the sub-tropics within 24° and 30° N and surrounded by deserts making it one of the hottest open sea on Earth. The SSW temperatures exceed 35 - 36 °C in summer and fall below 15 °C during the colder months (Robinson et al., 2013). Water salinity generally stays high >45 psu (Torquato et al., 2017) in addition to marine fauna capable of surviving >48 ppt (Riegl & Purkis, 2012). The high salinity is a result of excessive evaporation and lack of adequate precipitation (Robinson et al., 2013). Qatari territorial waters are also characterized by low precipitation (around 70 mm $year^{-1}$) and high evaporation resulting in high salinities ranging from 40 psu along its northern and eastern coasts up to 70 psu along the southwestern coast (Quigg et al., 2013).

The Arabian (Persian) Gulf experiences a unique seasonal cycle which establishes a gulf-wide cyclonic overturning circulation in the summer. The incoming water through the Strait of Hormuz flowing north along the Iranian coast joins the river plume at Shatt-Al-Arab up north and subsequently, flows back southeastward moving through the coasts of Kuwait, Saudi Arabia and around Qatar before reaching western parts of the Southern coasts. The south-westwards surface currents in the southern Gulf and around the shallow west of Qatar achieve typical speeds of 10 – 20 cm/s. In contrary, the bottom layer attains speeds of 5 – 10 cm/s but increases to 20 – 30 cm/s after it passes through the Strait of Hormuz on its way outwards of the Arabian Gulf (Kämpf & Sadrinasab, 2006). Water circulation and currents are important for larval dispersal (Sammarco et al., 2012) especially for the offshore setting where the currents are stronger relative to the inshore waters.

Artificial reefs have been deployed for over a hundred years in the Arabian Gulf mainly to establish fisheries and improve yields (Feary et al., 2011). Originally, the deployment of the artificial substrates for reef development was intentional using tree trunks, stones, pottery being sunk into coastal waters. Currently, the reefs are unintentional reefs because of other anthropogenic activities such as the oil and gas industry explorations which started in the Gulf after the discovery of oil deposits in 1950s and later coastal development. Such structures are now causing unforeseen consequences for coastal management such as the introduction of invasive species and changes to the natural benthic habitats (Feary et al., 2011).

Oil Platforms of Arabian Gulf

The Arabian Gulf homes around 800 offshore oil and gas platforms (Albano et al., 2016). Oil platforms in the Arabian Gulf are anchored to the sea-bed via pillars that act as supports holding the platforms above the water surface. Hence, these platforms extend along the entire water column, from the sea-surface all the way down to the sea-bed, imitating a simple rocky island. These important hard substrates in the Gulf waters provide a hard substrate to marine wildlife and a medium for sessile taxa to settle, that subsequently allow the growth of mobile organisms as well as attracting other larger organisms for feeding purposes, forming a complete unique habitat.

Several coral communities have been known to grow surrounding the oil and gas platforms in Qatari territorial waters (Maghsoudlou et al., 2008). These production platforms are suitable areas for coral's recruitment and growth. Extensive coral cover has been previously observed in the submerged parts of offshore production platforms in Al Shaheen Oil Field platforms at various depths indicating the importance of artificial reefs in recruiting corals in areas where the sea-bed is naturally soft and corals lack the hard substrates required for anchoring and subsequent life stages (cf. NPRP No.: 7-1129-1-201). Burt et al. (2011) & Burt et al. (2009) found higher coral cover in the artificial mature reefs (>25 years) such as breakwaters than on their natural counterparts in southern Arabian Gulf (UAE). The invertebrate community composition inhabiting offshore platforms in southern Arabian Gulf has been studied by Stachowitsch et al. (2002). This study confirmed the idea that large artificial reefs such as the oil and gas platforms can support diverse and abundant coral and fish communities, despite their structural and functional differences. Furthermore, maturing of artificial reefs would allow the associated benthic communities to develop into similar communities as could be expected on the local natural reefs (Burt et al., 2011).

Al Shaheen Oil Field platforms (northern offshore Qatari waters) provide a great hotspot to the fish assemblages where a highly diverse fish community was recently found comprising of 83 taxa (Torquato et al., 2017). Most of the taxa identified were native to the Arabian Gulf with some new species identified, adding to the currently known Qatari fauna. The findings of this study prove the oil/gas platforms as vital habitat for diverse community of fishes and a candidate of an interesting study of the fish assemblage structure.

Moreover, the offshore setting and protected platforms limits the anthropogenic disturbance significantly. The platforms also act as a shelter for invertebrates and juvenile fishes due to its structural complexity that alters the water currents preventing the planktonic stages from getting drifted away, hence, enhancing their recruitment and subsequent growth. This ultimately contributes positively to commercial fisheries at local or regional scale (Truchon et al., 2015).

Corals of Arabian Gulf

More than 70% of the corals of the Arabian Gulf are degraded or dead and the remaining are considered under the status of threatened species (Burt et al., 2014). Coral reefs have been exposed to environmental and anthropogenic pressures and consequently has led to coral loss and the conversion of coral reefs in broken fragments. Coral loss or recovery has major impacts on the entire marine ecosystem, not only limited to species relevant for fisheries (e.g. snappers, groupers, etc.) or tourism (e.g. angel-fishes and butterfly-fishes), but to the complete trophic chain and the ecosystem functioning (Hoegh-Guldberg et al., 2007).

Arabian Gulf homes highly diverse and abundant macrofaunal invertebrates forming the largest regional marine ecosystem (George, 2012). Also, these invertebrates are a vital source of food for consumers at higher trophic levels. The physical and biological parameters of the Gulf greatly influence the occurrence and distribution of these marine invertebrates. The physical conditions include sediment type, salinity, temperature, depth and physical disturbance and biological conditions include primary productivity and interspecies relationships such as biological competition, commensalism and parasitism. The macro-invertebrates generally comprise of polychaetes, crustaceans and molluscs. Polychaetes are well known to be found in every benthic marine sediment (Naser, 2011). Given that >97% of the sea-bed in the Arabian Gulf is dominated by sand and mud, hence, the dwelling macrobenthos would form a large and diverse marine ecosystem.

The Arabian Gulf is characterized by extreme seawater temperature and salinity limiting the diversity and reefing potential of the native coral species (Rezai et al., 2004). According to the historical records, the tough environmental conditions of the Arabian Gulf and mass coral bleaching events of 1996 and 1998 significantly reduced live coral cover in the shallow waters to less than 1% with a little recovery particularly in the corals of deeper regions or corals subjected to least anthropogenic effect (Wilson et al., 2002). The paper states the biggest threats to the benthic communities are from dredging and land reclamation. Moreover, brine and cooling water discharges from industrial facilities such as power generation, desalination, gas liquefication and more recently district cooling are adding a thermal and high salinity load to an already naturally stressed environment. Anthropogenic effects would arguably be critical for the biodiversity and abundance of macrobenthos living in an environment which is predominantly nature stressed (Naser, 2011).

Contrasting from these coastal environmental and anthropogenic settings, the natural marine conditions several miles off the Qatari coastline provide an appropriate setting for the settlement, recruitment and growth of the local precious offshore reefs. Offshore reef communities have been generally protected and are the least exposed to anthropogenic damage. Northern and Eastern coasts of Qatar provide favorable conditions for coral growth; however, the best growing conditions are found in the offshore waters, far away from brine discharges and coastal developments.

OBJECTIVES

The overall aim of this study is to investigate the level of biological connectivity existing between natural and artificial reefs (i.e., oil platforms) in offshore Qatari waters. The focus will be in assessing the mobile macrofauna recruited in settlement plates deployed offshore along a transect between natural and artificial reefs.

The specific objectives are:

1. Assessing vertical and horizontal spatial variations in recruitment and community structure of mobile macrofauna associated with settlement plates, deployed along a transect between the 'Al Shaheen' oil field and adjacent natural reefs.

2. Assess the association between the mobile epifauna with the sessile (fouling) assemblages.

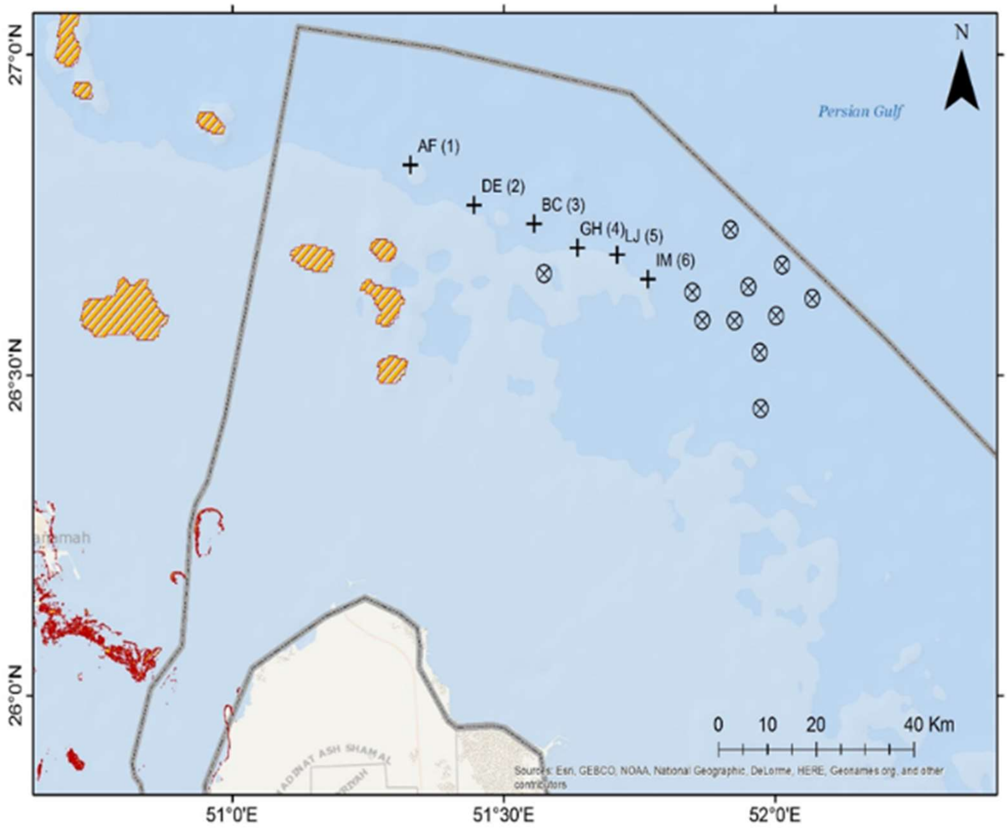
3. Characterization of the most abundant functional groups of the mobile fraction of macrofaunal assemblages

The knowledge gathered in the project is expected to contribute to the planning of the decommissioning stage of the oil platforms, by assessing their capacity to function as artificial reefs, enhancing local productivity and connectivity (as stepping stones) between existing natural reefs.

METHODOLOGY

Study Area

The Al Shaheen field is located ca. 40 miles offshore north from Qatari coast. Figure 1 below depicts the map of the study area, which encompasses the oil platforms at Al Shaheen oil field.



Sources: Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors

Figure 1. Map of the study area showing the six sites of deployment (1-AF to 6-IM), between the Al-Shaheen oil platforms (crossed circles) and the natural reefs (dashed areas)

Several kilometers North-West of Block 5 exists natural coral reefs (Figure 1). At least two reefs have been described around Block 5, and one of them, Umm Al Arshan has been considered one of the most diverse in the southern Arabian Gulf, characterized by a high cover and likely less impacted by earlier coral bleaching events and long-term stress (Burt et al., 2017; Burt et al., 2016). No significant literature is known about these unique offshore reefs inferring the need of extensive field study to determine the coral reefs structure, cover, depth range, connectivity, health status and the associated fauna i.e. fish and invertebrates.

The study area was chosen as a transitional area between natural reefs and artificial reefs i.e. oil platforms in offshore deep waters. Lastly, the area is less exposed to unwanted anthropogenic activities, far from industrial and urban developments and associated dredging works in Qatar coastal regions.

Deployment of the Settlement Plates

In October 2016 the stainless-steel (20x20 cm) settlement plates (abbreviated to SS-Plates) were deployed offshore, at depths ranging from 10-15m (top) and 45-48m (bottom) at six locations between the Al-Shaheen oil platforms and the natural reefs.

Table 1 contains the geo-coordinates of the six sites 1-AF to 6-IM as depicted in Figure 1. This linear arrangement was used to assess the gradient of connectivity between natural reefs and oil platforms.

Several factors such as substratum texture (hard or soft), complexity of the structure, spatial positioning are believed to affect how the benthic invertebrates settle on a substratum (Mckenzie et al., 2011). Accordingly, the stainless-steel plates were chosen to mimic the materials and texture of the pillars of the neighboring oil platforms. Furthermore, they were anchored vertically in the water column to match their spatial orientation to that of platforms. The structural complexity of submerged plates was less sophisticated than the platforms due to logistical considerations.

Each mooring line held 30 plates along the water column, spaced at 1 m depth intervals. This number and spacing of the plates allowed a good representation of recruitment at various depths, while maintaining the total weight of each structure within reasonable operational limits. Mooring lines were secured to the seabed with two concrete anchors (approximately 40 kg each) and attached to the rope via an acoustic release unit, which can be activated from the surface (Figure 2, left & middle). The ropes were kept in vertical orientation though the use of three buoys (4x14 L trawl floats) on the top of each mooring rope (Figure 2, right).

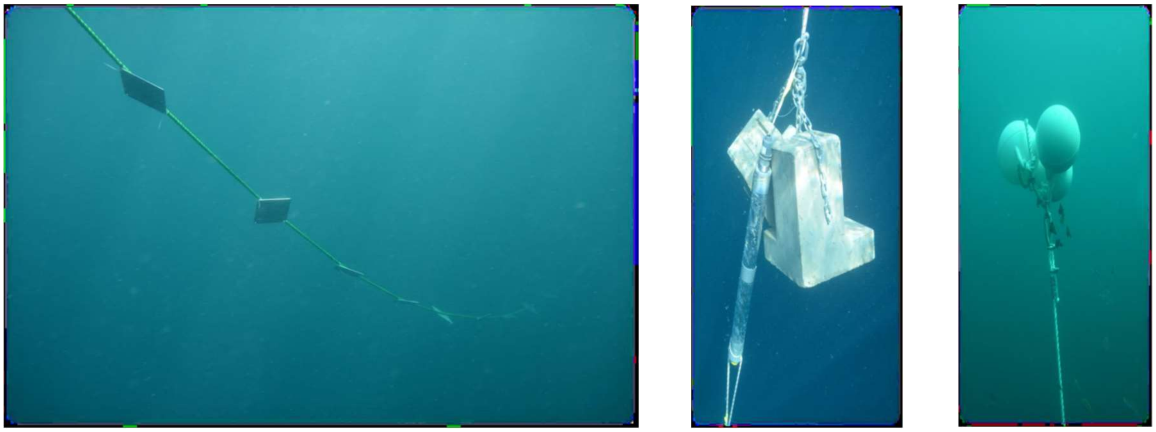


Figure 2. Mooring line (left) supported by two concrete anchors and one acoustic release unit (middle) and; 4x14 L trawl floats (right).

Table 1

Sites and Their Geo-Coordinates as Recorded by Research Vessel Janan Navigation System Upon Sample Retrieval On 3 – 6 Nov 2017

Site	Latitude	Longitude
1 - AF	N26 49 40.1	E51 19 39.8
2 - DE	N26 45 54.8	E51 26 41.8
3 - BC	N26 44 09.8	E51 33 20.8
4 - GH	N26 41 56.0	E51 38 08.5
5 - LJ	N26 41 15.1	E51 42 32.5
6 - IM	N26 38 59.2	E51 45 56.4

Environmental Variables

Vertical profiles were obtained at each site using the Vessel's CTD (Sea-Bird Electronics SBE911plus). Variables measured included Depth, Temperature, Salinity, Density, Dissolved Oxygen, Fluorescence (Table 2), Turbidity, PAR/Irradiance, pH, Oxidation Reduction Potential and Pressure.

Table 2

Date and Time for Fluorescence recorded at each site

Site	Date	Time (GMT)
6-IM	4-Nov-17	6:53
4-GH	4-Nov-17	8:22
2-DE	4-Nov-17	12:22
1-AF	5-Nov-17	5:31
3-BC	5-Nov-17	7:36
5-LJ	5-Nov-17	10:34

Sampling and Retrieval of Substrates

Half of the total deployed plates were collected a year after the initial deployment, during a research cruise with the RV Janan, between 03 and 06 November 2017. Figure 3 depicts a submerged sampling unit totally colonized by invertebrate macrofauna.

Figure 3. Submerged plate covered with invertebrates.

Ropes with the moored SS-Plates were retrieved from the seabed using the acoustic release system (AR-60-E Acoustic Release System – Sub Sea Sonics) to allow the 3 buoys (Figure 4, right) holding the rope in vertical orientation to float to the surface to be collected via the central large crane on RV Janan (Figure 4, left).

Figure 4. Retrieval of fouling plates onboard the RV Janan; detail of crane operation (left) and trawl floats used to support the structure (right).

All the plates retrieved were immediately photographed, on the rear deck of the vessel, using a Nikon D7100 camera with paired Ikelite TTL strobes (Figure 5).

Figure 5. Photo-quadrat of a sampling unit.

All the six structures were removed from the water. and all plates photographed, but only half of them (every other one) were collected from each structure for analysis. Plates (samples) at each depth that lie within each 5 m depth interval were considered as replicates for that depth interval. In some cases, it may be a single sample with no replicates at an interval. Number of samples (depths) from each structure that were used for analysis are depicted in Supplementary Table 8 (Appendix A – Supplementary Tables) The other half of the plates were maintained attached to the rope and re-deployed, with minimal disturbance, in the same locations, to be resampled after a second year of deployment.

Scraping, Pre-Sorting & Preservation

The retrieved plates were transferred to containers into the washing room of the vessel for determining fresh weighing, scraping and sorting the macrofauna and preserving it into containers (Figure 6).

Figure 6. Receiving freshly retrieved samples into the RV Janan washing room for processing

A paint scraper was used to dislodge the settled organisms from the retrieved SS-Plates. Damage to the organisms was minimized by applying the paint scrapper at the contact point between the organisms and the plate to which they were attached. During the scraping each plate was placed in a see-though plastic container and the macrofauna emptied into it.

The collected macrofauna was then washed using a seawater shower and the collected water was filtered through a dual mesh (500 and 50microns) with the first mesh stopping macrofauna and the second mesh stopping or collecting the meiofauna (Figure 7).

The meiofauna fraction was then preserved into falcon tubes, using absolute ethanol and stored in boxes that were refrigerated until they were shipped for taxonomic analysis (data not used in this thesis).

Figure 7. Washing room in RV Janan showing meshed tubes, containers, seawater shower *etc.*

The macrofauna fraction was then placed in a specialized plastic non-reactive food grade sealed containers. Containers of size 1000 ml and 500 ml were used for storage with some samples fitting the entire collected biomass into one 500 ml bottle while some samples with higher biomass required several 1000 ml containers. Different sized containers were used to minimize weight and storage space required. Half the samples retrieved were preserved in absolute ethanol and the other half in 5% buffered formalin solution with seawater. Formalin was used as it preserves samples for longer without any prior distortion to the sample, however, formalin is poisonous and carcinogenic and an irritant even in its vapor form specially to the human eyes and soft tissue in the airways and lungs (Fischer, 1905).

Post-fixation the containers were checked for the double labels (external and internal waterproof labels) and then refrigerated at – 1 ° C until the arrival to the Doha Port (Figure 8).

Figure 8. Left to Right: Refrigeration of preserved samples, Pre-taxonomic sorting using lit magnifiers & Taxonomical identification at ESC, Research Complex, QU.

Upon arrival at Doha Port the sample containers were loaded into large ice boxes that were loaded onto a pickup for immediate transfer to the pre-prepared cold room in Qatar University laboratories, BCR A201. The Principal Investigator enabled our access to the university and the cold room where the ice boxes were unpacked, sorted and loaded onto the shelves.

Lab Sorting

The sample containers were emptied using funnels and sieves of 50 microns while the drained ethanol and formalin waste being poured out into empty bottles for disposal according the Qatar University chemical safety regulations. The ethanol samples were urgently processed to prevent previously mentioned distortion to the samples while the buffered seawater formalin 5% samples were processed later in Environmental Sciences Centre (Research Complex, QU), under a fume-hood, because of the earlier mentioned toxicity.

The samples were then transferred to large plastic trays for study and sorting under large illuminated magnifying glasses (MAGNASCOPE R1-89-01) (Figure 8). The time intensive sorting first separated carefully the sessile portion from mobile part of the macrofauna. Secondly, the mobile macrofauna was further sorting into major taxonomic groups such as Annelids, Mollusks, Crustaceans, Echinoderms etc. and preserved into smaller container such as falcon tubes (5ml, 15ml, 50ml) and eppendorfs with correct labeling prior to their taxonomic identification.

The formalin-fixed samples were first processed inside fume-hood where they were washed thrice with water in meshed sieves after the removal of the buffered formalin seawater into a separate empty and well labelled bottle for disposal purpose. Subsequently, the washed macrofauna was left in trays inside the fume hood for approximately 20-30 minutes to let the toxic chemical evaporate as well as to reduce the smell. This was followed by the routine sorting work.

The sorted samples were preserved back into different vials but with Absolute Ethanol and stored into cold room or refrigerator (-1 °C) for later taxonomical processing. 79 out of 90 sampling units were sorted and processed. This number was chosen for replication purpose i.e. at least 2 replicates per sampling interval of 5 m depth of the water column.

Taxonomic Identification

The mobile assemblages were identified based on their morphology (Figure 8). The taxonomic identification was performed using Zeiss SMZ-168 and Olympus SZ2-ST Stereo Microscopes (Germany). The task was validated by the weeks of daily training received by a taxonomic specialist in the ESC, Research Complex. Several scientific classification books and taxonomic keys were used to identify the taxa to at least the taxonomic level family. These include the following; 1) A Field Guide to THE SEASHORES OF EASTERN AFRICA and the Western Indian Ocean Islands (Richmond, 2002); 2) A FIELD GUIDE TO THE SEASHORES OF KUWAIT AND THE ARABIAN GULF (Jones, 1986); 3) A GUIDE TO POLYCHAETES (ANNELIDA) in Qatar Marine Sediments (Alomari, 2016); 4) Atlas of Crabs of the Persian Gulf (Naderloo, 2017); 5) A Guide to the Marine Sediments Crustaceans of Qatar Marine Zone (Alomari, 2011). Identified Taxa were recorded manually on notebook with their corresponding codes for site, depth and taxa and; subsequently transferred into Microsoft Excel.

Identified samples were preserved back into smaller vials such as eppendorfs, 5 ml and 15 ml falcon tubes labelled for dry biomass processing. Each taxon was assigned a numeric code Supplementary Table 9 (Appendix A – Supplementary Tables) used for labeling purpose to cut on unnecessary time labelling. Simultaneously, reference collections were made for the identified taxa, labelled in and out and stored separately for the purpose for reference photos and later observations when needed. The reference collection was preserved well in absolute ethanol.

Reference Collection

Representative specimens (Supplementary Table 10) of the taxa were chosen and separately preserved for microphotography. Photo-referencing was performed using microphotography equipment LEICA 10450028 and Zeiss 3D Stereo Microscopes (Germany). The photos were further edited using Adobe Photoshop CS5 to remove unwanted bits and enhance the photo quality.

Abundance Records

Individuals of each taxon identified were counted and the abundance recorded on notebook along with their corresponding codes comprising of site, depth and taxon code (Supplementary Table 9).

Biomass Records

Dry weight was determined for each taxon in every sample (SS-Plate). Ethanol and water proof labels were removed from the previously identified sample vials. Vials were well labelled with permanent marker on the outside, caps removed and secured inside racks before placing them into the oven (Gallenkamp Hotbox Oven) at 50 °C. Samples were subjected to either 24 or 48 hours of drying depending on the size and number of organisms in each vial. Echinoderms and Crustaceans were mostly left over for 48 hours because of their relatively bigger body sizes. On retrieval the combined weight of each vial was recorded using Analytical Balance (Denver Instrument SI-234, d = 0.1 mg) followed by emptying of the vials and cleaning with a dry tissue paper wrapped around the edge of forceps. Subsequently, the emptied vial was weighed and recorded on notebook. Trials were performed in the initial stage of the task to make sure if any dried biomass would adhere to the inner walls of the vial and it was not the case. Samples left to dry for 36 hours did not exhibit any biomass sticking into the walls of the containers used. The dry biomass data was later transferred to Microsoft Excel for data analysis.

DATA ANALYSIS

The raw data generated from this research was organized into Microsoft Excel and subjected to statistical analysis. Two orthogonal fixed factors were considered: Site and Depth. The factor Site had 6 levels (geographical positions), defined along a distance gradient between the natural (site 1) and artificial reefs (site 6). The factor Depth had 7 levels, defined at 5 m depth intervals 10-14, 15-19, 20-24, 25-29, 30-34, 35-39 and 40-44 m. Each taxon identified was transformed into operational taxonomic unit (O.T.U) prior to the statistical analysis. This was done because taxa were taxonomically identified to different levels such as to species, genus or family levels and a few to class or order levels.

Non-metric multidimensional scaling (nMDS) and Permutational multivariate analysis of variance (PERMANOVA) were applied based on the Bray-Curtis matrix of similarity.

SIMPER (Similarity Percentages Routine) uses the Bray-Curtis matrix which determine the contribution of each taxon to the observed similarity (or dissimilarity) between samples (or between depth intervals) (Range et al., 2014). A subjective limit of 10 % cumulative contribution was chosen to highlight the taxa that contributed the most to the overall (dis)similarities between sites and between the depth intervals.

Ordination by nMDS was performed as it is considered to be the most robust technique for representing the dataset of biotic communities (Clarke, Warwick, & Laboratory, 2001) allowing us to visualize the epifaunal recruitment patterns between the depths and sites. PERMANOVA with unrestricted of permutations (999) of raw data and Type III (partials) sum of squares was used to test statistically significant differences in the assemblage structure among the sites, depths as well as the interaction between these two factors. PERMANOVA is a highly useful tool specifically designed to analyze the highly variable communities in space and in time (Anderson, 2001; Anderson, 2017).

Number of Taxa (S), Abundance (N), d (diversity *i.e.* measurement of species richness combined with evenness) and J' denotes how well uniformly distributed the individuals across the species or taxa. For these ecological indices the DIVERSE routine was used.

Distance Based Linear Models (DistLM) were used to study the relationship (based on the biological resemblance matrix of densities) of the dependent mobile epifauna to its independent sessile fraction (the response variable to its explanatory variable) (Range et al., 2014). Using the marginal tests (999 permutations) to identify the significantly correlated variables and the BEST procedure which aims at producing all possible combinations of these significant variables ($p<0.05$) were selected and included into the DistLM routine. It generates a multidimensional cloud of points capturing all variation or inertia. It uses the sessile data matrix to explain the variations in mobile dataset or ordinations. Based on the AIC (Akaike Information Criterion) the Distance-based redundancy analysis (dbRDA) was run to ordinate and visualize the best overall DistLM solution (Range et al., 2014). dbRDA has the advantage of using nonparametric permutation methods which do not rely on assumptions of multivariate normality (Nowruzi, Elkamel, Scharer, & Moo-Young, 2009).

Abundance-Biomass Comparison curves (ABC curves) were plotted using the PRIMER-E to determine if the community exhibited a uniformly distributed diversity concluding it's a disturbed or an un-disturbed ecosystem.

All the multivariate analyses were performed using the PRIMER 6 statistical software with PERMANOVA+ add-on (PRIMER-E, Plymouth Marine Laboratory). Statistically significant difference between the means was chosen at $p<0.05$.

Graphs were plotted using SigmaPlot software (V 11.0, Systat System, Inc.).

RESULTS

Macro-Benthic Fauna

Forty-two (42) different operational taxonomic units (OTUs) of macro-benthic recruits were recorded from the samples analyzed at various depths across the six sites comprising of 2302 epibenthic mobile individuals. Amongst the total individuals, including those collected for reference, 1553 specimens were identified at family level. From the remaining, 663 individuals were successfully identified either to genus or species level and 86 individuals identified to higher taxonomic levels, class or order, because of missing or damaged body segments. These included members of Polychaeta, Nudibranchia, Decapoda, Ophiurida and Rhabditophora.

The most diverse group in the study were the annelids belonging to 14 families; Chaetopteridae, Dorvilleidae, Eunicidae, Lumbrineridae, Hesionidae, Nereididae, Phyllodocidae, Polynoidae, Syllidae, Poecilochaetidae, Cirratulidae and the tube worms Terebellidae, Sabellidae and Ampharetidae. Arthropods were the next highly diverse (8 families) Alpheidae, Ampithoidae, Epialtidae, Galatheidae, Pilumnidae, Porcellanidae, Portunidae, Xanthidae followed by echinoderms (5) including three ophiurids (Ophiotrichidae, Ophiocomidae and Ophionereididae) in addition to echinoids (Temnopleuridae and Diadematidae). The molluscs comprised of 2 families Cerithiidae and Cypraeidae along with 3 individuals from the taxonomic order Nudibranchia. Sipunculids belonged to family Phascolosomatidae and the platyhelminthes (polyclads) to Discocelidae and Stylochidae. Phascolosomatidae and Stylochidae were the most abundant mobile taxa. Amongst the identified taxa, the crustacean *Galathea* sp. is believed to be recorded for the first time in Qatari waters.

The list of taxa identified, and their vertical distribution based on their average abundance in every 5 m depth interval across the six sites is summarized in Supplementary Table 1 (Appendix A – Supplementary Tables). Most abundant and well distributed taxa were sipunculid *Phascolosoma* sp .1, platyhelminth Stylochidae, ophiuroids (brittle-stars) Ophiotrichidae and Ophiocomidae and some families of polycheates encompassing largely of Terebellidae, Nereididae, Syllidae, Lumbrineridae, Polynoidae, Eunicidae and Phyllodocidae. Amongst the crustaceans, Pilumnidae was abundant and largely distributed. Amphipods contributed to the abundance at a single site only. Gastropods comprised mainly of *Cerithium* sp. 1 and *Conus* sp.

Distribution of the taxa and their average abundance at 5 m depth intervals at each site (1-AF to 6-IM) is shown in Appendix A – Supplementary Tables (Supplementary Tables 2 – 7). At all sites the sipunculids and polyclads dominated the abundance within the upper layers. Polychaetes were recorded at all sites and depth intervals, usually with high diversity and abundance. Sites 1-AF and 2-DE showed the highest abundance of polychaetes, compared to other sites. Echinoderms were also seen inhabiting the six sites but more diverse and abundant at 4-GH. Crustaceans exhibited high diversity and were dominant in terms of abundance at site 4-GH. Gastropods were found at all sites with *Conus* sp. and *Cerithium* sp. as the most frequent ones. *Conus* sp. was absent in site 5-LJ. Nudibranchs were recorded in two (1-AF and 4-GH) of the six sites at a fixed depth range 20-24 m.

Relationship between abundance and biomass at each depth for each site as discrete points, is reported in Figure 9. The observed general trend shows biomass to increase with abundance. However, there were some outliers for biomass, which are identified in Figure *9*. The three points on left exhibit higher biomass due to decapods, with large body size, found in those samples. The point on the top right of the plot belongs to a sample that contained mostly echinoderms with relatively large body size and numerous Sipunculids.

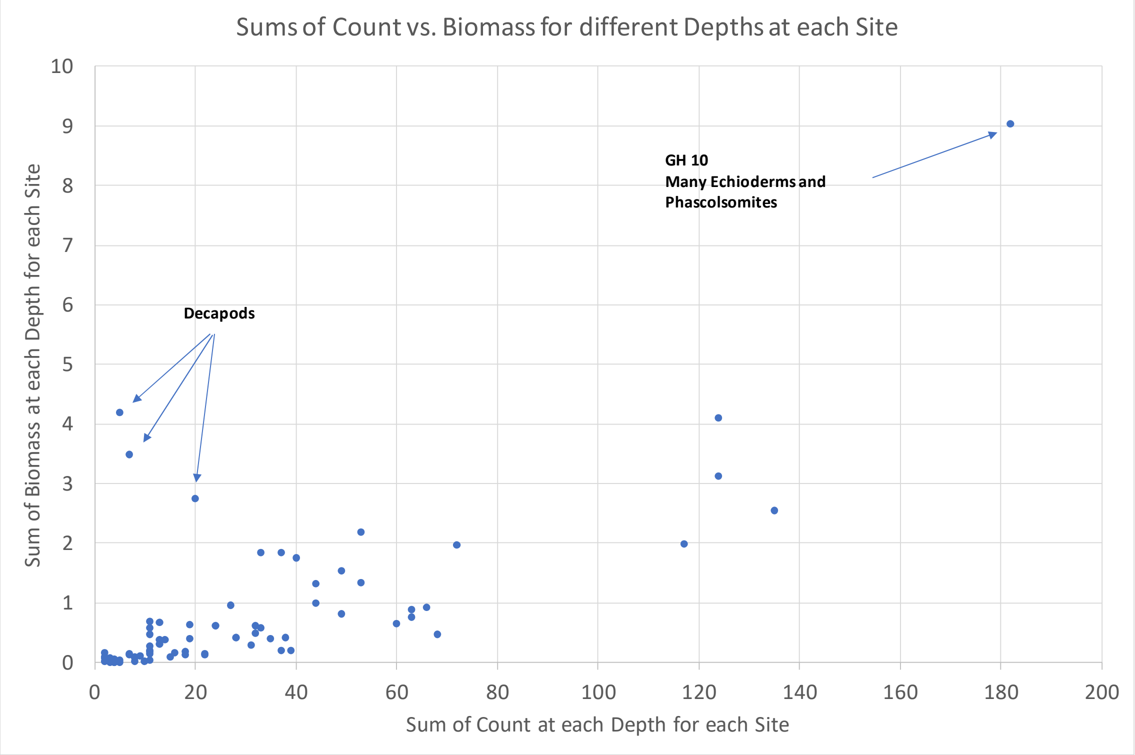


Figure 9. Total abundance vs. total biomass at each depth interval for each site.

The PERMANOVA results for abundance (Table 3) and biomass (

Table 4) show that both the factors considered (Site and Depth), as well as their interaction, had significant effects on the mobile macrofaunal community. The non-metric Multidimensional Scaling (nMDS) plots Supplementary Figure 1 and Supplementary Figure 2 (Appendix B – Supplementary Figures) provide a visual illustration of these results.

Table 3

PERMANOVA on the abundance of all the taxa based on Bray–Curtis resemblance matrix.

(Abbreviations: Si: Site; De: Depth; df: degrees of freedom; SS: sum of squares; MS: mean squares)

PERMANOVA table of results on abundance

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Si	5	29816	5963.2	3.0483	0.001	998
De	6	64691	10782	5.5114	0.001	998
SixDe**	27	71880	2662.2	1.3609	0.001	995
Res	40	78251	1956.3			
Total	78	2.5429E5				

Table 4

PERMANOVA on the biomass of all the taxa based on Bray–Curtis resemblance matrix.

(Abbreviations: Si: Site; De: Depth; df: degrees of freedom; SS: sum of squares; MS: mean squares)

PERMANOVA table of results on biomass

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Si	5	28920	5784	2.5733	0.002	998
De	6	66288	11048	4.9153	0.001	997
SixDe**	27	86604	3207.5	1.4271	0.009	999
Res	37	83164	2247.7			
Total	75	2.7843E5				

The vectors in nMDS plots shown in Supplementary Figure 1 (Appendix B – Supplementary Figures) depict the taxa highlighted by SIMPER (Similarity Percentages - Species Contributions) as the strongest contributors for dissimilarities in terms of abundance among depth intervals at each of the 6 sites. SIMPER highlighted 10 taxa in site 1-AF; 8, 10, 12, 8 and 10 taxa in sites 2-DE, 3-BC, 4-GH, 5-LJ and 6-IM, respectively. Generally, amongst all the sites the sipunculid *Phascolosoma* sp. 1, flatworms of the families of Stylochidae and Discocelidae, along with certain families of polycheates, such as Syllidae, Terebellidae, Lumbrineridae, Ampharetidae, can be seen to dominate the community at shallower to moderate vertical layers (i.e. 10-29 m depth). The families Terebellidae, Lumbrineridae, Ampharetidae failed to contribute >10% (contribution to dissimilarity) in one sites *i.e.* 6-IM and furthermore, the site 2-DE had high relative abundance of Terebellidae and Lumbrineridae in the deeper depths (35-39 m) in contrast with other sites where they were numerous in the upper layers. Taxonomic groups with some notable exceptions in horizontal distribution include polychaetes Polynoidae, Syllidae that were abundant only in sites 1-AF and, the polyclad Discocelidae in 1-AF and 5-LJ. In contrary, the taxa *Phascolosoma* sp. 1 and Stylochidae exhibited a strong positive correlation with shallow layers throughout all the sites. On the other hand, the ophiuroids Ophiotrichidae and Ophiocomidae are seen to have settled in higher numbers mainly at the intermediate depth intervals (i.e. 20-34 m depth), however, at sites 1-AF, 2-DE and 4-GH they are more abundant in shallow to intermediate depth range (10-34 m). Other families of polycheates (*i.e.* Eunicidae, Nereididae, Polynoidae), as well as the crustaceans Pilumnidae, Epialtidae, *Hyastenus brockii* were abundant mainly in the greater depths ranging from 30-44 meters. Population members of family Nereididae showed a strong positive correlation with the deep layers throughout all the sites, so did the Pilumnidae but in sites 3-BC, 4-GH, 5-LJ and 6-IM only. The gastropod *Cerithium* sp. 1 was found to be particularly well represented at larger depths in site 3-BC. In the same site (3-BC), the vectors for the polycheate Eunicidae and the crustacean *Hyastenus brockii* are totally overlaid, demonstrating a strong correlation in their depth distribution. *Ampithoe* sp. and *Etisus demani* inhabited higher abundance within moderate to deep layers, respectively, of the vertical profile of site 4-GH.

The nMDS plots for biomass (Supplementary Figure 2 - Appendix B – Supplementary Figures) exhibit a similar general trend to the ones for abundance. *Phascolosoma* sp. 1 and Stylochidae can be seen at all sites and contribute most of the biomass at shallower depths (10-19 m). The biomass contributions of ophiurids Ophiocomidae and Ophiotrichidae are mainly represented at intermediate depths such (20-34 m), so do the marine worms Eunicidae and Nereididae but at greater depths (35-44 m). The crustaceans; Epialtidae, Pilumnidae, *Hyastenus brockii*, *Etisus demani* and Decapoda (broken decapods) added to the biomass (>10% contribution) while inhabiting the greater depth intervals. However, *Etisus demani* and Decapoda overlaid each other at depth 35-39 m in site 4-GH illustrating a strong positive correlation at their depth distribution with respect to their biomass. Gastropods *Cerithium* sp. 1 has shown highest biomass at the larger depths (30-34 m) in sites 3-BC and 5-LJ whereas *Cypraea turdus* generally found in upper layers but contributed to the overall biomass more at site 4-GH. Rhabditophora (distorted polyclads) were considered as part of taxa contributing the most to biomass at depth 34 m recorded only in site 6-IM.

The abundance pattern of the taxa (OTUs) amongst all depths sampled across the horizontal distribution from site (1) through site (6) is reported in an nMDS plot (Figure 10). The taxonomic groups Stylochidae and *Phascolosoma* sp.1 dominated (abundance) at the top layers 10-19 m. Other groups such as Terebellidae, Ophiotrichidae, Ophiocomidae were generally abundant at the intermediate depths (20-34 m) whereas the bristle worms from families Eunicidae, Nereididae and the decapods Pilumnidae were found existing at high abundances at greater depths 30-44 m.

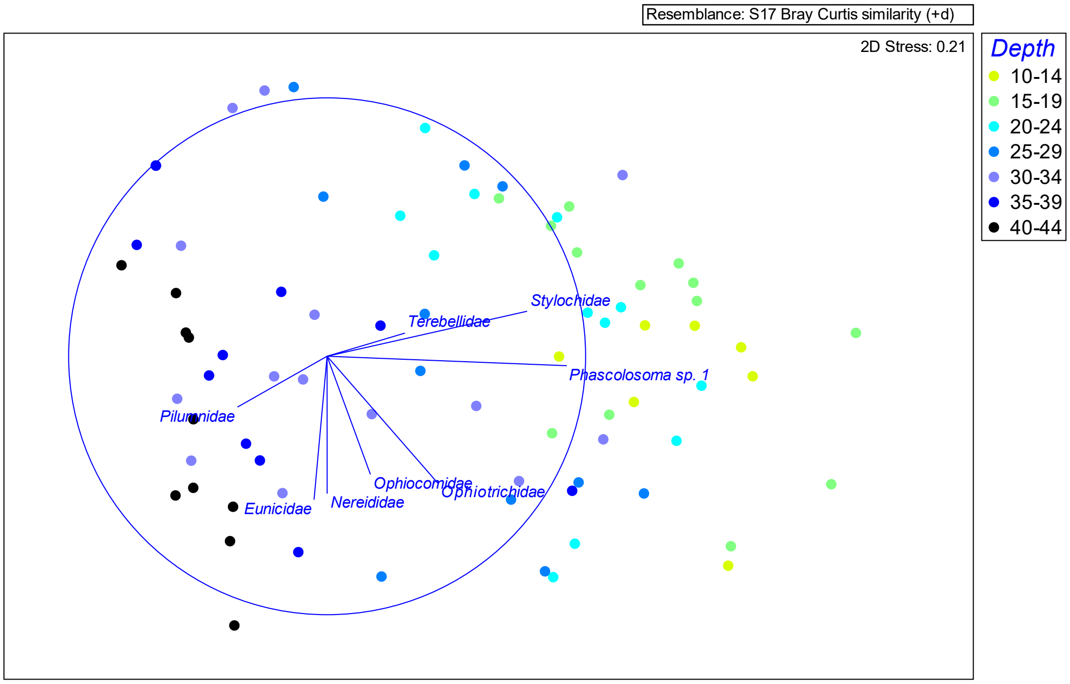


Figure 10. Non-metric multi-dimensional scaling (nMDS) on abundances of all OTUs from all depth intervals

Forty-two operational taxonomic groups (OTUs) contributed to the total biomass at all sites through the 79 sampled water depths (SS-Plates). The total biomass summed up to 63.4 g, where the upper layers contributed the most (32.7 g at 10-19 m) due to higher number of taxa settled and their corresponding abundance as compared to the greater depths (14.2 g for depths below 30 m). This trend is supported by the earlier pattern for abundance across the vertical layers of the six sites. The taxa dominating the biomass values at different depth layers were mentioned earlier (Supplementary Figure 2 - Appendix B – Supplementary Figures) where sipunculid *Phascolosoma* sp. 1 and polyclad Stylochidae were the main representatives at 10-19 m followed by the ophiuroids at intermediate layers and decapods (*e.g.* Pilumnidae) at greater depths along with members of polychaetes Eunicidae and Nereididae.

There is a general trend of total abundance decreasing with depth (Figure 11). There are, however, notable exceptions to this pattern. Indeed, in sites 1-AF and 2-DE abundance peaks at intermediate depths 15-19 m and 25–29 m, respectively, and then decreases again further down the water column. Site 3-BC exhibited very low abundances below 25 m. In 5-LJ and 6-IM the trend reverses from15-19 m to 20-24 m and 20–24 m to 25-29 m, respectively, followed by the previous general decreasing trend until the last interval. It is important to note, however, that not all depth intervals in each site are represented by the same number of plates, which may explain part of the variation in the general, decreasing trend.

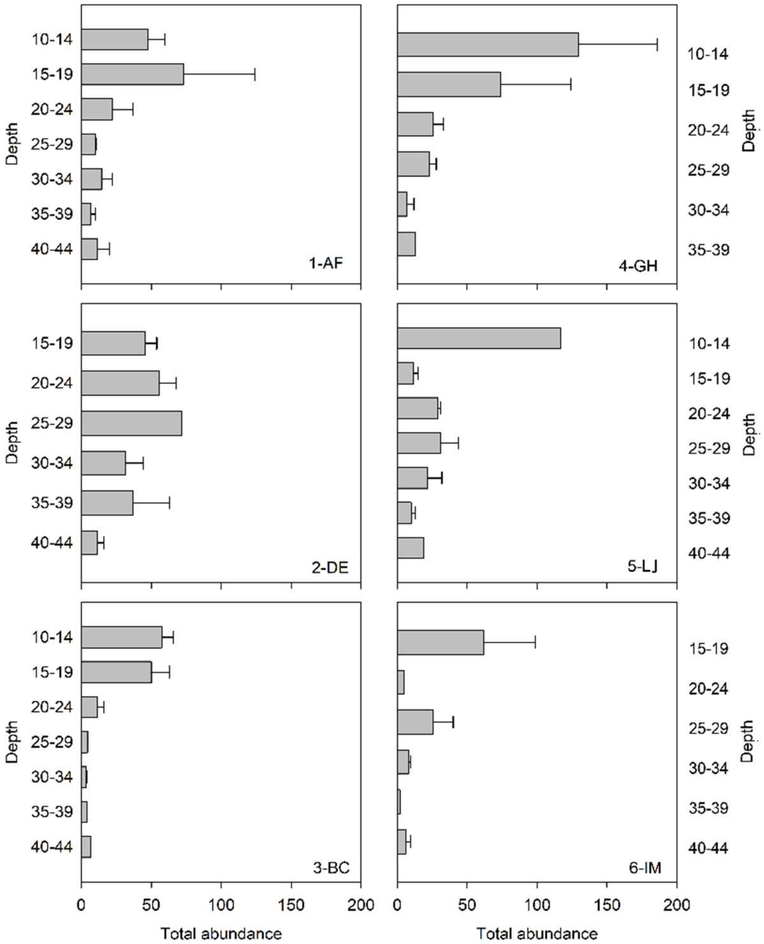


Figure 11. Total Abundance per plate (mean + SE) at each Site and Depth Interval.

The average number of taxa is also generally decreasing with depth (Figure 12). However, sites 5-LJ and 6-IM show fluctuations in this trend. It is not a linear trend, but the max. S at these sites was consistently at the shallower depth. In site 3-BC the average number of taxa decreased until 34 m below which it increased by twofold up to 44 m. At site 1-AF the trend reversed slightly at 25-29 m to 30-34 m and then it followed the same general decreasing trend. Similar fluctuation took place in 2-DE from 30-34 m to 35-39 m.

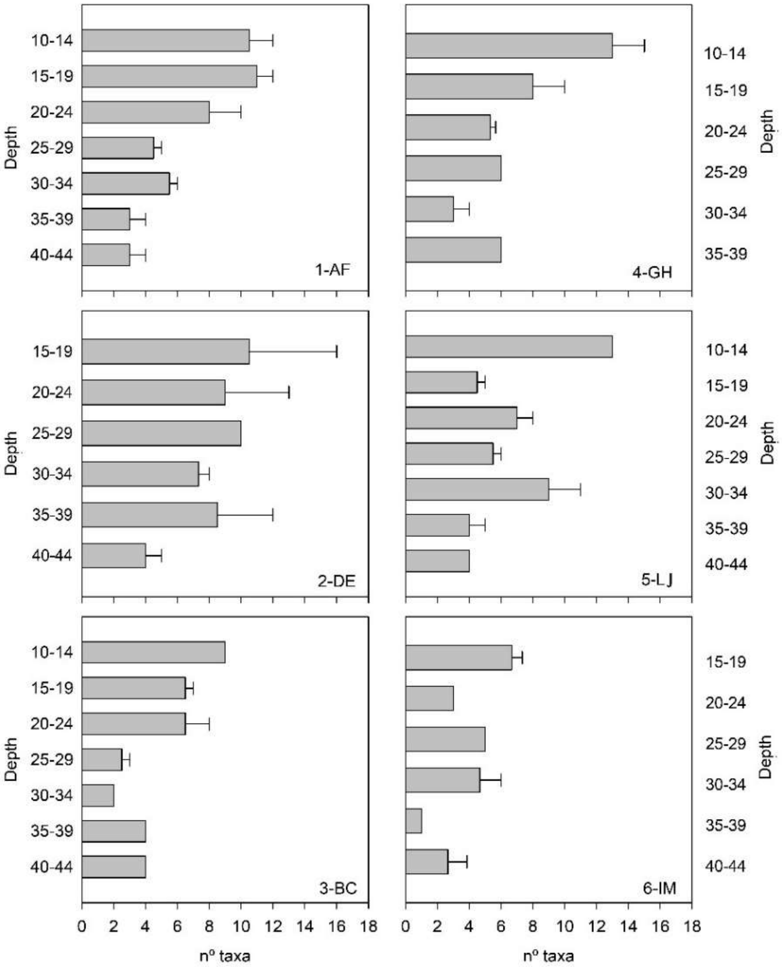


Figure 12. Number of Taxa per plate (mean + SE) at each Site and Depth Interval.

Diversity Indices

Number of Taxa (S) and Abundance (N) were analyzed. Other indices (d, J’) were calculated but were only included in the Supplementary Table 11 (Appendix A – Supplementary Tables).

Based on Diversity data (Supplementary Table 11) in the site 1-AF the highest number of taxa (S) were found at depth interval 10-19 m totaling 241 individuals followed by 20-24 m with 45 individuals. In 2-DE, organisms were more diverse and abundant at 15 m down to 29 m summing up to 276 settlers. Site 3-BC had highest abundance within 10-19 m (215 individuals); however, the depth interval 20-24 m exhibited a low abundance value while accommodating higher number of taxa (diversity). 4-GH had the upper depth interval 10-14 m rich in diversity with plentiful mobile invertebrates (259) followed by 148 individuals down at 15-19 m lower in species richness, relatively. Site 5-LJ is more abundant and diverse at 10-14 m (117) followed by a deeper layer at 30-34 m (5-LJ) but with lower abundance, contrasting with an immediately shallower layer higher in species richness i.e. 25-29 m. The last site 6-IM has the upper layer 15-19 m as the most abundant throughout its vertical profile. This concludes to the fact the top vertical layers within 10-19 m were consistently more diverse and highly abundant across all the sites. Site 2-DE showed a similar richness and abundance but further deep to 29 m. Some irregular trends were noted in 3-BC and 5-LJ within their deeper intervals. Regarding the greater depths the abundance and diversity both generally represented low values except for site 2-DE which failed to depict a linear decreasing trend.

Mobile – Sessile Relationships

The overall best DistLM solution included 8 sessile taxa, as explanatory variables: The bivalves *Malleus regula, Modiolus barbatus, Pinctada radiata* and *Pinna bicolor*; the barnacles *Amphibalanus Amphitrite* and dead barnacles; sponges of the Class Hexactinellida and; tube polychaetes. The effect of each of these taxa on the dbRDA ordination is expressed by the vectors' overlays in Figure 13. The length of the vectors is proportional to the contribution of the corresponding variable for the dbRDA axes. Seven mobile taxa (response variables) also showed particularly strong correlations to the dbRDA ordination: the sipunculids *Phascolosoma* sp. 1, the ploYclads Stylochidae and the polychaetes Polynoidae, Syllidae and Lumbrineridae showed a strong positive correlation to Bivalves (*Malleus regula, Modiolus barbatus, Pinctada radiata* and *Pinna bicolor*) and tube polychaetes, at shallow to moderate depths. The decapods Pilumnidae and *Etisus demani* were also positively correlated to Dead Barnacles, but at greater depths. The strongest correlations were between *Phascolosoma* sp. 1 - *Pinna bicolor* (Pearson's r = 0.80); Pilumnidae - Dead Barnacles (Pearson's r = 0.78) and *Etisus demani* - *Amphibalanus Amphitrite* (Pearson's r = 0.73).

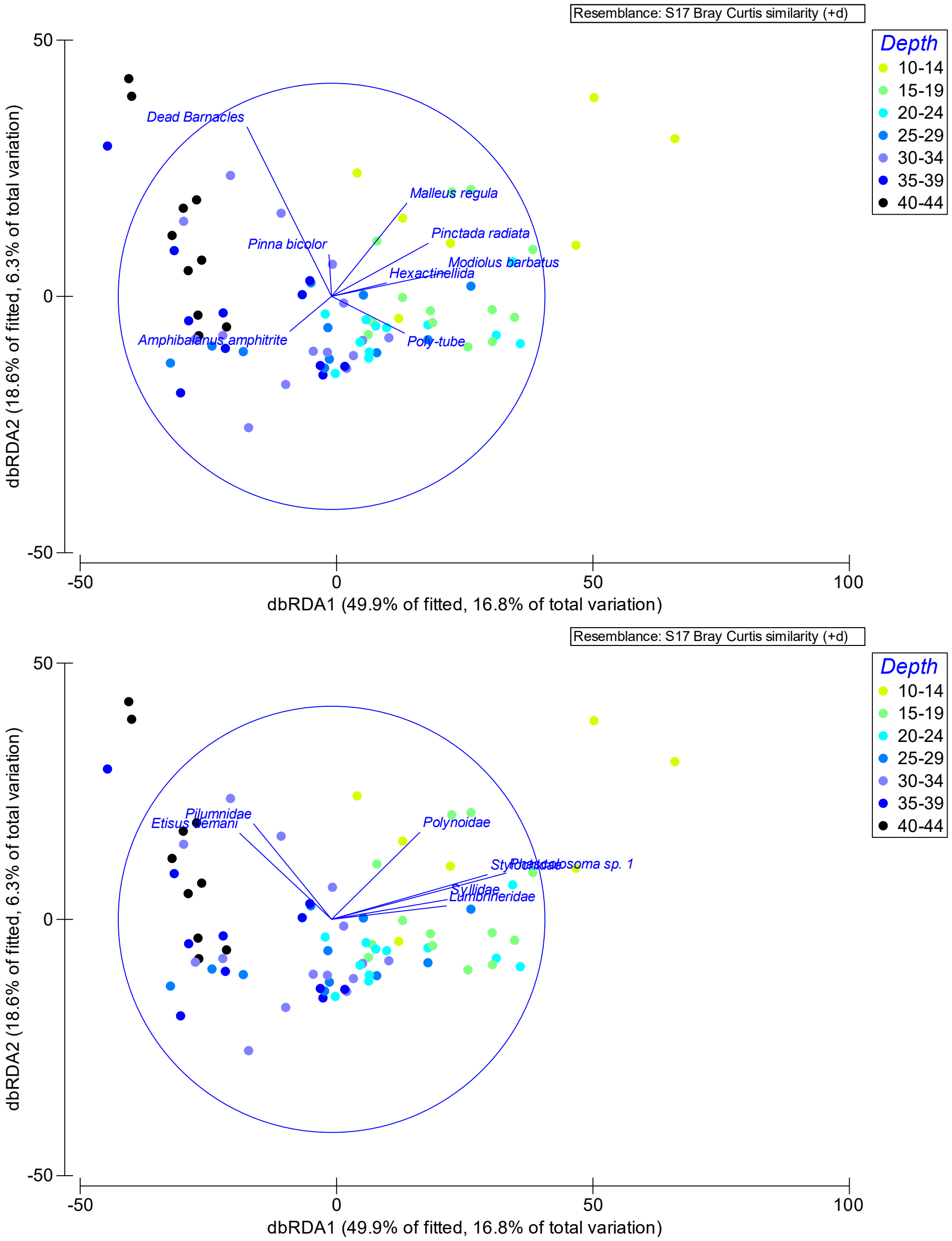


Figure 13. Distance-based redundancy analysis (dbRDA) on untransformed data on the entire macrofaunal assemblage. For Mobile fraction (top) and Sessile habitat (bottom) vectors represent the correlations between the dbRDA ordination and densities in each depth interval (Count per 20x20 cm Plate) of taxa contributing >10% to overall dissimilarities.

The crabs, sipunculids and polyclads (flatworms) were seen to be strongly correlated. The low dimension 2-D bubble plots (Figure 14) exhibit how with increasing count of Dead Barnacles down the deeper depths shows increasing abundance of crabs (Pilumnidae). Similarly, highly abundant bivalves at shallower depths exhibit the high abundance of sipunculids and platyhelminthes (polyclads) as compared to greater depths where lower light penetration restrict the productivity, thus, the minimal presence of bivalves accommodating a few of these two mobile assemblages mentioned earlier.

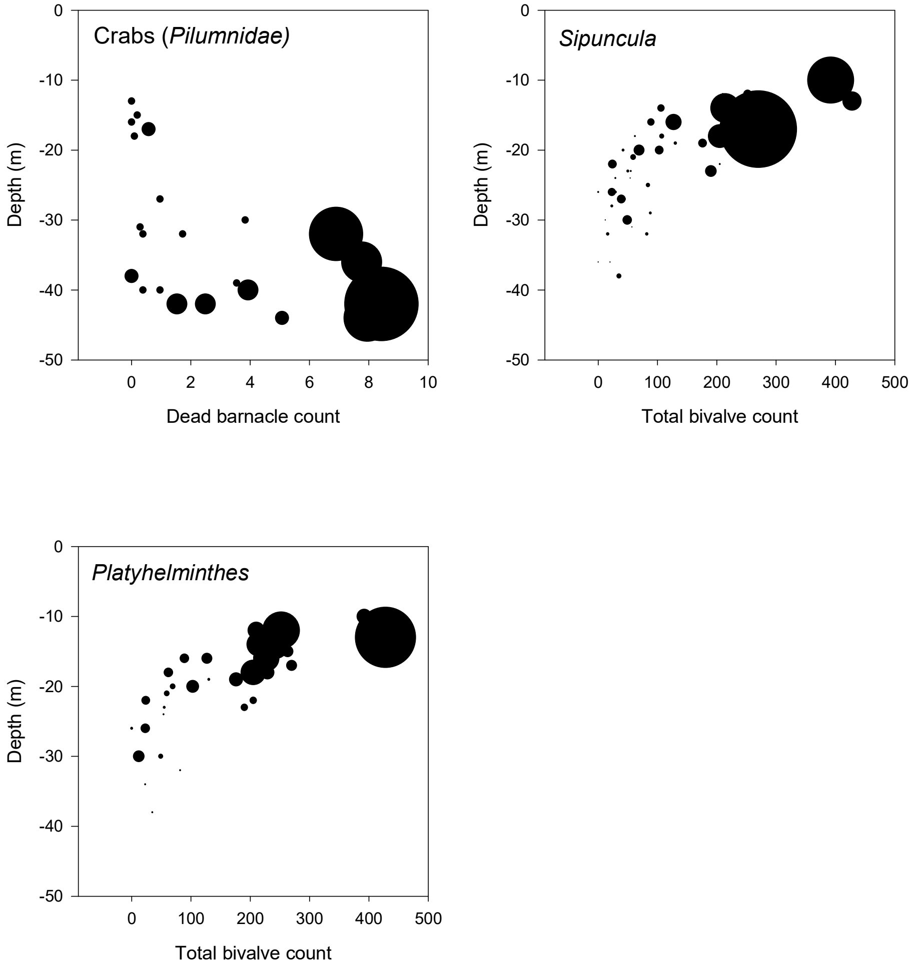


Figure 14. Most Abundant Mobile Taxa Groups association to Sessile Groups.

ABC Curves

Cumulative dominance is consistently larger for biomass, relatively to abundance, at all depths (Supplementary Figure 3 and Supplementary Figure 4 - Appendix B – Supplementary Figures), resulting in positive values of the W statistic (Table 5 & Table 6), suggesting a non-disturbed system. The same general pattern is observed among sites, except in site 6-IM, where the dominant taxon *Phascolosoma* sp. 1 shows a larger fraction of the cumulative total for abundance than for biomass (Supplementary Figure 5). The dominance curves saturate faster in site 3-BC, relative to other sites, particularly for biomass.

All the taxa are making a small and gradual contribution to the Abundance in the curve exhibiting a uniformly distributed diversity. The W statistics of ABC curves for sites are also consistently positive, but there is an increasing trend with distance from the oil platforms, with the minimum at the site closest to the platforms (6-IM). In contrast, no trend is apparent for the W statistic values of ABC curves for depths intervals.

Table 5

W Statistic values for Sites

Sites	W
1-AF	0.188906
2-DE	0.125604
3-BC	0.159406
4-GH	0.10208
5-LJ	0.112859
6-IM	0.07377

Table 6

W Statistic values for Depths

Depth (m)	W
10-14	0.121596
15-19	0.0843
20-24	0.181818
25-29	0.207
30-34	0.233926
35-39	0.160195
40-44	0.172416

Environmental Variables

The chlorophyll inferred through fluorescence across the water column (0 to 60 m) was recorded during the cruise with the RV Janan. The chlorophyll concentrations can be seen to peak between the 10 to 20 meters (Figure 15) and at their minimum in the greater depths.

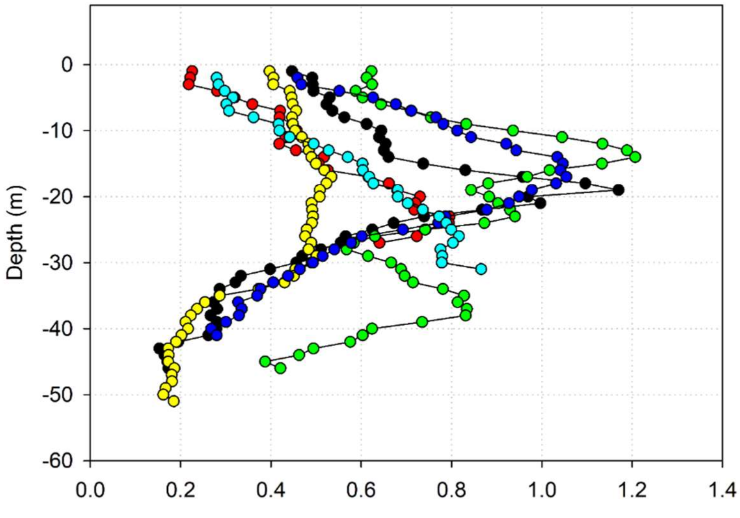


Figure 15. Chlorophyll-fluorescence (mg/m^3) across the vertical profile (0 – 60 m).

Sea-water temperature records from the data loggers deployed along the first deployment of the substrates. Temperature fluctuations at the shallow depths 10-15 m (red) and 45-50 m (blue) across all the six sites are shown in Figure 16. A clear thermal stratification is seen to develop starting around March 2017 and intensifying in the following months until November 2017 when the samples were retrieved. A daily thermocline gradient of 5 – 6 °C on average could be observed with a maximum of about 10 °C observed in September 2017.

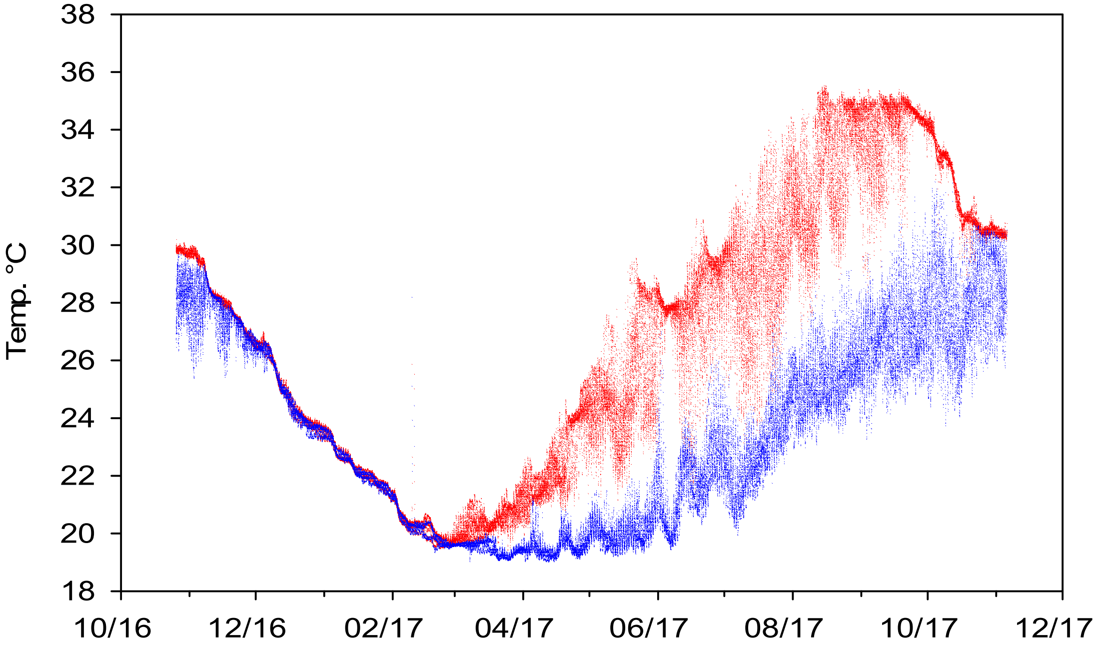


Figure 16. Seawater temperature records from Hobbo© data loggers deployed at 10-15 m (red) and 45 – 50 m (blue) in each of the 6 vertical structures.

DISCUSSION

To investigate the spatial dynamics of the recruits of the mobile community in offshore artificial reefs, the current study attempted to imitate the ecological importance of offshore oil platforms, acting as artificial reefs, by deploying stainless-steel plates at six sites along a transect extending between natural reefs to a group of oil platforms. The used material was the same as the submerged sections of the platforms (extending throughout the water column). Indeed, scarce information is available about the ecological significance of oil platforms in offshore Qatari waters and the Arabian Gulf. Most literature is focused on the coastal region and on sessile macrofauna. In fact, the sessile fraction is easier to study since it is normally comprising a larger biomass in the fouling communities and may also serve as a source of commercial commodity. The mobile fraction of the assemblage is relatively difficult to study since the organisms are in continuous motion and are generally expected to be affected by seasonal variations. Hence, this study tackled the often ignored mobile epifauna and its recruitment in offshore Qatari waters.

Thirty-two taxonomical families were recorded in this study (Supplementary Table 1). As background to the findings of the current study, oyster reefs in Qatari waters were found to have highly diverse associated biota which included a sipunculid, a decapod and an amphipod, two taxa of gastropods, three polychaetes and three ophiuroids (Al-Khayat & Al-Ansi, 2008; Khayat, 2005). Additionally, Mohammed & Al-Ssadh (1996) reported similar taxa to this study belonging to annelids, crustaceans, gastropods including *Cypraea turdus* and *Cerithium* sp. and echinoderms in the Arabian Gulf while studying the effects of Gulf war's oil spill (1991) on the coral reefs and their associated biota. Furthermore, Mohammed & Al-Ssadh (1996) stated that the abundance and diversity of the coral associated biota was richest in the north-east of Qatar, likewise this study that was performed in the northern Qatari waters in proximity of the Al Shaheen Oil Field which is 40 miles away from coast.

The spatial variations along the considered factors; depths (vertical) and sites (horizontal), and their interaction exhibited significant effects on the mobile epifaunal community structure with respect to their abundance and biomass (Table 3 & Table 4). Specific patterns were observed in the vertical distribution (depth) of the recruits as compared to the horizontal gradient amongst the six sites (Figure 10, Supplementary Figure 1 & Supplementary Figure 2). The motile macrofauna assemblages of the current study were largely dominated by the sipunculids (*Phascolosoma* sp. 1) and polyclads (Stylochidae) as these species were found in larger abundances at shallower depths 10-19 m (Supplementary Figure 1). Other species such as the ophiuroids and decapods tend to occupy moderate to deeper depths and polychaetes having a wide range vertical distribution (Supplementary Table 1, Supplementary Figure 1 and Supplementary Figure 2) suggesting their dependency on the types of habitats, which in terms of the motile organisms refers to the host sessile communities as habitat provider. To support the current findings on depth-dependent recruitment, the study by Khayat (2005) recorded similar taxa such as Pilumnidae at depths 27 - 36 m, the genus Alpheus at 36 - 40 m, *Amphipoda* sp. in depths 10 - 55 m, Eunice at 19 - 55 m, *Nereis* sp. 10 - 55 m, *Lumbrineris* 11 - 55 m, *Ophiothrix* sp. (fam. Ophiotrichidae) at 10 - 23 m and *Ophionereis* sp. (fam. Ophionereididae) at 10 & 11 m. The study by Vedenin et al. (2018) in the Central Arctic Ocean recorded 10,117 individuals attributed to 440 taxa from 37 stations. Authors found similar negative correlation with depth as our study on the same parameters where the abundance, diversity and biomass were all negatively correlated with depth. Furthermore, polychaetes were most abundant and diverse in our study and so was the case for Vedenin et al. (2018). However, Jacobucci & Leite (2002) noticed that the gastropods, polychaetes and ophiuroids tended to dominate as depth increased, whereas in the current study polychaetes were abundant throughout the vertical column.

Despite having a significant effect on the horizontal distribution of the mobile macrofaunal community, no clear patterns were found in relation to the geographical location of the structures. Therefore, studying the population structure (not analyzed in the current study) in addition to the community structure studied may allow the visualization of the patterns and recruitment rates along the gradient between the natural and artificial reefs.

Ecological mechanisms that may play a role in the spatial distribution include the feeding guilds (Gambi et al., 1992) of the mobile macro-fauna and the biological competition that most likely have caused the bivalves to exclude the barnacles from colonizing the 20x20 cm plates at the upper layers (Hardin, 1960). According to an unpublished study performed by an undergraduate student titled "Characterization of sessile benthic communities associated with the platforms in Al Shaheen oil field from a ROV surveillance video footage" studied the benthic communities on these platforms and found the first 10 m depth from the sea-surface dominated by encrusting organisms from phyla Bryozoa and Porifera. Biological competition is likely the explanation for their scarcity down the water column.

Feeding types may explain the vertical distribution of sipunculids (*Phascolosoma* sp. 1) and polyclads (Stylochidae) dominating the upper layers. Sipunculids extract organic food from the sediments surface (Jumars et al., 2015) and the polyclads are active predators with parasitic capabilities (Cannon, 2003).

Bivalves are filter-feeders largely dependent on phytoplankton and suspended organic particulates. Figure 15 depicts the chlorophyll levels, which peak between a depth of 10 and 20 m, which indeed corresponds to a maximum abundance of bivalves at (10-19 m). According to Fehling et al. (2012) "Phytoplankton underpin the marine food web", so we can say without doubt that all the organisms that are the focus of this study are further up the food chain and are reliant on these phytoplanktons. Higher primary productivity is, therefore, believed to be the main driver for bivalves occurrence (*Malleus regula, Modiolus barbatus, Pinctada radiata* and *Pinna bicolor*) contributing a large biomass in the upper layers of the sampled sites (Plutchak et al., 2010). A parallel study on the sessile hosts of the studied mobile epifauna found that Bivalves were dominating at the same shallow depths (Figure 13). This dominance of bivalves may have been the reason for the abundance of these two reported worms, through an interspecies relationship mediated by their feeding type such as predation by the flatworm (Stylochidae) and commensalism for the sipunculids (*Phascolosoma* sp .1).

A significant relationship has been observed between the mobile assemblage and their sessile pre-cursors (Figure 14). Sipunculids (peanut worms) feed on organically rich surface sediment deposits from which they extract their plant and animal organic matter. Accordingly, the excreted waste of bivalves (i.e., feces and pseudo-feces) is the main food source for deposit-feeders , which is easily retained within the network of bivalve abyssal threads (Kędra et al., 2018; Murina, 1984). Phascolosomites have been reported living in the subtidal reefs of Qatar amongst the pearl oysters (Al-Khayat & Al-Ansi, 2008). This explains their high abundance amongst the oysters' dominated plates.

Polyclads, on the other hand, are generally carnivores preying on a range of sessile colonial macro-invertebrates including corals, bryozoans, ascidians, small gastropods, bivalve molluscs and barnacles that are plentiful in SE Arabian Gulf (Riegl & Purkis, 2012). One of their favorite preys is bivalves including rock and pearl oysters, scallops, mussels and even the giant clams (Cannon, 2003). Polyclads may exhibit a parasitic feeding behavior and oysters are known to be their preferred host, hence, some species of polyclads are known as oyster leech. (Landers & Rhodes, 1970) found the polyclad *S. ellipticus* primarily attacked small oysters whereas the larger (2+ cm long) could kill oysters of length reaching more than 6 cm. This leech has significantly reduced the productivity of oyster beds on the Atlantic and Gulfs coasts of USA, in addition, these leeches have caused considerable damage to oyster beds of Indian River, Cedar Key, Port Inglis, Tampa and Apalachichola Bay (Pearse & Wharton, 1938). Polyclads feeding on oysters and barnacles is supported by studies (Merory & Newman, 2005; Pearse & Wharton, 1938) and may therefore explain their high association with bivalves at lower depth ranges.

Page & Hubbard (1987) found similar findings to the current study mussels, when considering the vertical distribution of the mussel *Mytilus edulis*, in an offshore oil platform. The study found that this bivalve was most abundant in the 0 – 20 m depth range due to high concentration of particulate organic carbon which was like our findings regarding bivalves' abundance at 10-19 m. Sipunculids and platyhelminths in the current study depended on these bivalves at for habitat food availability. Bivalves are in turn dependent on primary producers that are abundant in shallower depths (Plutchak et al., 2010). Based on the inferred chlorophyll fluorescence the highest primary productivity was found in 10 – 19 m.

Crustaceans are known to have many marine representatives of many different forms on the reefs of the SE Gulf commonly called as shrimps, crabs and lobsters. Families Pilumnidae, Xanthidae, and the less abundant Portunidae, Epialtidae, Porcellanidae, Alpheidae and Ampithoidae have been reported in SE Gulf, associated to coral reefs (George, 2012). The hairy crabs, Pilumnidae, are small crabs closely related to the Xanthidae and usually found hiding in crevices, beneath coral boulders, and amongst coral rubble during the daylight on the reefs of SE Gulf. The hairy crabs emerge during night to feed on a variety of other macroinvertebrates including sponges and polychaetes as well as on pieces of algae using their large claws. The crab-barnacles association is likely due to crabs finding a refuge in those barnacles to hide themselves from predators. Invertebrate larvae of decapods are sensitive to the diel light cycle fearing predation (Torres, 2015). This could be the reason that most crustaceans found were in the deeper depths where they could conveniently hide in the colonies of barnacles.

On the other hand, the broad range of feeding types in ophiuroids and polycheates (Jumars et al., 2015; Stöhr et al., 2012) have enabled them to exist at wider range of depths. Sea-urchins have an omnivorous nature feeding on algae, decaying matter and other animals such as sponges, barnacles and bryozoans (Chrism, 2013). The distribution of their preys could be the cause of their uneven vertical distribution. Similarly, the major trophic role of the gastropods determines their spatial distribution seen as inhabiting the upper layers 10-34 m in the current study (Supplementary Table 1). The cone gastropod *Conus* sp. part of reef community is a primary carnivore feeding on herbivores (e.g. bivalves) and deposit-feeders (e.g. sipunculids) (Kohn, 2001), both of which were abundant at shallower layers. Other shell gastropods found were a small reef-safe Cerith snail *Cerithium* sp. eating primarily on algae and a cowrie *Cypraea turdus* (accepted as *Naria turdus* ("WoRMS - World Register of Marine Species," n.d.) that are known to feed on sessile sponges (Wilson & Clarkson, 2000). (Jenkins et al., 1988) reported the cowry (Cypraeidae) inhabiting the coral reefs in the Gulf waters and the Red Sea.

An environmental disturbance may cause an alteration in the community composition and structure. Feeding strategies as an indicator of disturbance was first mentioned by (Fauchald & Jumars, 1979) and further studied by Metcalfe and Glasby (2008) where the feeding guilds were used to study the human disturbance on the composition, abundance and diversity of the mangrove associated polychaetes species. The study found significant differences in the diversity indices of the different groups (feeding guilds) between the disturbed and undisturbed sites. The highly diverse assemblage (Supplementary Table 1 & Supplementary Table 10 & Supplementary Table 11) and evenly distributed (Supplementary Figure 3, Supplementary Figure 4, Supplementary Figure 5) across the studied spatial dimensions is a clear indication of undisturbed healthy ecosystem in the offshore waters.

Polychaetes have been well utilized as an indicators of environmental conditions, for example, in determining the general health of benthic communities, occurrence of organic pollution and a mix of other pollutants such as heavy metals and pesticides (Dean, 2008). This is because polychaetes have a range of diverse reproductive and feeding strategies allowing them a flexibility in responding to anthropogenic disturbances and inhabiting wider range of habitat distribution. The dominant groups of polychaetes found in the current study include families of deposit feeders (Ampharetidae), omnivores (Eunicidae & Nereididae) and carnivores (Lumbrineridae & Polynoidae) (Jumars et al., 2015). All the 14 families of polychaetes found in this study were also reported by (DiBattista et al., 2016) in the Arabian Gulf and by (Wehe & Fiege, 2002) around the seas of Arabian Peninsula, *i.e.* the Red Sea, Gulf of Aden, Arabian Sea, Gulf of Oman and Arabian Gulf. The greater depths referring to 35-44m were mainly occupied by families Nereididae and Eunicidae across all the sites (Supplementary Table 1). Both taxa form a large group of families and highly diverse in Gulf waters as the associates of reef platforms (George, 2012). The high diversity and wide spatial distribution are indication of the little to none anthropogenic disturbance to the studied area.

The purpose of using the abundance-biomass comparison curves (Supplementary Figure 3**,** Supplementary Figure 4 **&** Supplementary Figure 5**)** was to assess their usefulness as tools to estimate ecological integrity and quality of the study area.

Cumulative dominance was consistently larger for biomass relative to abundance at all depths resulting in positive values of the W statistic (Table 5 & Table 6) which is interpreted as an undisturbed system classifying the environment as unpolluted. Such assemblage is likely to be dominated by slow growing “k” strategist species with one or two species at high biomass levels while showing generally low species abundance compared to biomass (Yemane et al., 2005). Generally, all taxa made a small and gradual contribution to the abundance curve and the corresponding biomass. This is also reflected in the generally uniformly distributed values of the equability index (Supplementary Table 11) except for an outlier at site 6-IM. The W statistic showed a minimum at site 6-IM where the dominant taxon *Phascolosoma* sp. 1 represents a larger fraction of the cumulative total for abundance (44.76 %) than for biomass (21.61%), implying a change in population structure of this sipunculid and thereby causing both curves to intersect

(Supplementary Figure 5**)**. However, in the closest site to the oilfield (6-IM), the disturbance could may not be explained to biological competition on the food sources, but it is more likely due to delayed recruitment rather than pollution or competition. This is confirmed by the occurrence, in this site, of numerous small individuals rather than well-developed big specimens. In the delayed recruitment scenario, the "k" species are being replaced by "r" species, which demonstrate faster growth and are more dominant in terms of abundance rather than biomass (Yemane et al., 2005). The dominance curves saturate faster particularly for biomass in site 3-BC compared to other sites (Supplementary Figure 5) due to the taxa Stylochidae having larger-bodied individuals causing a disproportional increase in the biomass when compared to abundance.

Ocean currents have been considered as the main mechanism for larval horizontal dispersal since the invertebrate larvae are relatively poor swimmers (Daigle & Metaxas, 2011). The current speed and direction generally vary with depth. In the deeper waters, the currents are weaker resulting in the observed smaller number of recruits. Greater depths had relatively lesser taxa totaling 18 taxa at 35-39 m and 12 taxa at 40-44 m (compared to 32 taxa at 10-19 m with average abundance 6.18) and corresponding average abundance of 3.02 and 2.62, respectively (Supplementary Table 1 and for each site; Supplementary Tables 2 – 7 in Appendix A – Supplementary Tables).

The recruitment in the study area most likely occurred in the winter months immediately after the plates were deployed as there was no thermocline so there was significant mixing during those months. This mixing and tidal currents brought the planktonic stage of these organisms to the recruitment sites (Verspagen et al., 2004) as the thermocline plus the shallow density driven surface currents would have prevented recruitment in other parts of the year. A clear thermal stratification (average gradient of 5 – 6 °C) was observed at all sites starting from around March 2017 and extending until winter (Figure 16). This temperature stratification may have prevented species migrating to shallower depths or vice versa, except for species which have wider tolerance to change in temperature. However, according to (McConnaughey & Sulkin, 1984) naturally occurring thermoclines should seldom influence dispersal characteristics.

Limited information is available on the communities of epibenthic mobile macrofauna dwelling inside the sessile assemblages recruited by the numerous and wide spread offshore oil platforms. Indeed, this study is believed to establish a baseline for further similar studies for potential commissioning and decommissioning of the oil and gas platforms. Moreover, it may also contribute to a feasibility study aiming to build and deploy artificial reefs in the deep waters aiming to enhance local productivity and connectivity between natural reefs.

CONCLUSION

The 20x20 cm stainless-steel settlement plates deployed in depths ranging 10 – 44 m at six different sites located between the Al Shaheen Oil Platforms and offshore natural reefs in Qatari EEZ exhibited clear patterns in the vertical spatial distribution of mobile epifaunal assemblages. Taxa clearly dominant in the shallower depths such as polyclads and sipunculids were generally scarce from the deeper sections of the water column. The abundance, diversity and biomass were all negatively correlated with depth. No clear patterns were observed in the horizontal gradients between the reefs, hence, studying also population structure would allow in examining these missing patterns. Moreover, more samplings at short time intervals needed to identify the patterns of recruitment. Another limitation of the study was the size of the stainless-steel plates deployed and not very accurate vertical orientation of the plates on the slightly moving line might not have allowed a very accurate mimicking of the oil platforms and may affect the larval settlement due to lesser current energy harvested by the plates. The mobile epifaunal assemblages suggest undisturbed ecosystem based on the ABC curves. Analyzed data shows deployed substrates fulfilling role of stepping stones because similar species composition, abundance and biomass vertical patterns were found at all the sites exhibited high connectivity amongst the six structures. Eight (8) of the sessile taxa were strongly associated to seven (7) mobile taxa with sipunculids and platyhelminths exhibiting strongest association to the bivalves in the shallow depths and the crabs with the dead barnacles in the greater depths. The most dominant functional groups included surface deposit feeders, carnivorous flatworms and others such as polychaetes and ophiuroids exhibited a broad range of feeding types.

A total of 2302 individuals were identified across 42 operational-taxonomic-units. The crustacean *Galathea* sp. is believed to be recorded for the first time in Qatari waters.

This study will allow future research on the recruitment of macro-benthic communities on artificially deployed structures in offshore waters such as through comparisons based on spatial distribution of taxa, abundance and biomass with regards to competition on scarce resources such as substrate. This and subsequent studies will allow the development of best practices on commissioning and decommissioning lifecycles of oil and gas platforms. However, further investigations are needed to determine, in a comprehensive and precise manner, the environmental effects on the mobile macro-faunal recruitment and community structure. Indeed, this study establishes a baseline information on mobile communities associated to offshore artificial reefs in Qatari waters. Moreover, it may contribute to the design, construction and deployment of offshore artificial reefs, to facilitate the rehabilitation of natural reefs and improve fisheries yields.

REFERENCES

Albano, P. G., Filippova, N., Steger, J., Kaufman, D. S., Tomašových, A., Stachowitsch, M., & Zuschin, M. (2016). Oil platforms in the Persian (Arabian) Gulf: Living and death assemblages reveal no effects. *Continental Shelf Research*, Assessing marine ecosystems health, in an integrative way, *121*, 21–34.

Al-Khayat, J. A., & Al-Ansi, M. A. (2008). Ecological features of oyster beds distribution in Qatari waters, Arabian Gulf. *Asian Journal of Scientific Research*, *1*, 544–561.

Alomari, N. (2016). Guide to Polychaetes Annelida in Qatar Marine Sediments.

Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, *26*(1), 32–46.

Anderson, M. J. (2017). Permutational Multivariate Analysis of Variance (PERMANOVA). *Wiley StatsRef: Statistics Reference Online* (pp. 1–15). American Cancer Society. Retrieved October 8, 2018, from https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118445112.stat07841

Bell, N., & Smith, J. (1999). Coral growing on North Sea oil rigs. *Nature*, *402*(6762), 601.

Bram, J. B., Page, H. M., & Dugan, J. E. (2005). Spatial and temporal variability in early successional patterns of an invertebrate assemblage at an offshore oil platform. *Journal of Experimental Marine Biology and Ecology*, *317*(2), 223–237.

Burt, J. A., Ben-Hamadou, R., Abdel-Moati, M. A. R., Fanning, L., Kaitibie, S., Al-Jamali, F., Range, P., et al. (2017). Improving management of future coastal development in Qatar through ecosystem-based management approaches. *Ocean & Coastal Management*, *148*, 171–181.

Burt, J. A., Smith, E. G., Warren, C., & Dupont, J. (2016). An assessment of Qatar's coral communities in a regional context. *Marine Pollution Bulletin*, *105*(2), 473–479.

Burt, J., Bartholomew, A., & Sale, P. F. (2011). Benthic development on large-scale engineered reefs: a comparison of communities among breakwaters of different age and natural reefs. *Ecological Engineering*, *37*(2), 191–198.

Burt, J., Bartholomew, A., Usseglio, P., Bauman, A., & Sale, P. F. (2009). Are artificial reefs surrogates of natural habitats for corals and fish in Dubai, United Arab Emirates? *Coral Reefs*, *28*(3), 663–675.

Burt, J., Van Lavieren, H., & Feary, D. (2014). Persian Gulf Reefs: An Important Asset for Climate Science in Urgent Need of Protection. *Ocean Challenge*, *Vol.20*.

Cannon, L. R. G. (2003). *Marine Flatworms: The World of Polyclads*. Csiro Publishing.

Chrism. (2013, July 9). The Echinoblog: What (and How) do Sea Urchins Eat? Sea Urchin Feeding Roundup! *The Echinoblog*. Retrieved October 17, 2018, from http://echinoblog.blogspot.com/2013/07/what-and-how-do-sea-urchins-eat-sea.html

Claisse, J. T., Pondella, D. J., Love, M., Zahn, L. A., Williams, C. M., Williams, J. P., & Bull, A. S. (2014). Oil platforms off California are among the most productive marine fish habitats globally. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(43), 15462–15467.

Clarke, K. R., Warwick, R. M., & Laboratory, P. M. (2001). *Change in marine communities : an approach to statistical analysis and interpretation* (2nd ed.). Plymouth, U.K. : Primer-E Ltd. Retrieved September 13, 2018, from https://trove.nla.gov.au/work/20554767

Coral reefs | WWF. (n.d.). . Retrieved October 17, 2018, from http://wwf.panda.org/our_work/oceans/coasts/coral_reefs/

Daigle, R. M., & Metaxas, A. (2011). Vertical distribution of marine invertebrate larvae in response to thermal stratification in the laboratory. *Journal of Experimental Marine Biology and Ecology*, *409*, 89–98.

Dauterive, L. (2000). Rigs-To-Reefs policy, progress, and perspective. Retrieved April 27, 2017, from http://dspace.rubicon-foundation.org:8080/xmlui/handle/123456789/8995

Dean, H. (2008). The use of polychaetes (Annelida) as indicator species of marine pollution: a review. *Rev Biol Trop*, *56*.

DiBattista, J. D., Roberts, M. B., Bouwmeester, J., Bowen, B. W., Coker, D. J., Lozano-Cortés, D. F., Choat, J. H., et al. (2016). A review of contemporary patterns of endemism for shallow water reef fauna in the Red Sea. *Journal of Biogeography*, *43*(3), 423–439.

Fauchald, K., & Jumars, P. A. (1979). The diet of worms: a study of polychaete feeding guilds.

Feary, D. A., Burt, J. A., & Bartholomew, A. (2011). Artificial marine habitats in the Arabian Gulf: Review of current use, benefits and management implications. *Ocean & Coastal Management*, *54*(10), 742–749.

Fischer, M. H. (1905). THE TOXIC EFFECTS OF FORMALDEHYDE AND FORMALIN. *The Journal of Experimental Medicine*, *6*(4–6), 487–518.

Fitzhardinge, R. C., & Bailey-Brock, J. H. (1989, March). Colonization of Artificial Reef Materials by Corals and Other Sessile Organisms. Text, . Retrieved October 21, 2018, from https://www.ingentaconnect.com/content/umrsmas/bullmar/1989/00000044/00000002/art00004

Friedlander, A. M., Ballesteros, E., Fay, M., & Sala, E. (2014). Marine Communities on Oil Platforms in Gabon, West Africa: High Biodiversity Oases in a Low Biodiversity Environment. *PLOS ONE*, *9*(8), e103709.

Gambi, M. C., Lorenti, M., Russo, G. F., Scipione, M. B., & Zupo, V. (1992). Depth and Seasonal Distribution of Some Groups of the Vagile Fauna of the Posidonia oceanica Leaf Stratum: Structural and Trophic Analyses. *Marine Ecology*, *13*(1), 17–39.

García, C. B., & Salzwedel, H. (1993). Recruitment patterns of sessile invertebrates onto fouling plates in the bay of Santa Marta, colombian Caribbean. *Boletín de Investigaciones Marinas y Costeras-INVEMAR*, *22*(1), 30–44.

George, J. D. (2012). Reef-Associated Macroinvertebrates of the SE Gulf. In B. M. Riegl & S. J. Purkis (Eds.), *Coral Reefs of the Gulf: Adaptation to Climatic Extremes*, Coral Reefs of the World (pp. 253–308). Dordrecht: Springer Netherlands. Retrieved October 23, 2018, from https://doi.org/10.1007/978-94-007-3008-3_13

Hardin, G. (1960). The Competitive Exclusion Principle. *Science*, *131*(3409), 1292–1297.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., et al. (2007). Coral reefs under rapid climate change and ocean acidification. *Science (New York, N.Y.)*, *318*(5857), 1737–1742.

Jenkins, M., Sheppard, C., & Wells, S. (1988). *Coral reefs of the world. Vol. 2 : Indian Ocean, Red Sea and gulf*. Retrieved October 23, 2018, from https://portals.iucn.org/library/node/8973

Jones, D. A. (1986). *A field guide to the sea shores of Kuwait and the Arabian Gulf*. University of Kuwait.

Jumars, P. A., Dorgan, K. M., & Lindsay, S. M. (2015). Diet of worms emended: an update of polychaete feeding guilds. *Annual Review of Marine Science*, *7*, 497–520.

Kaiser, M. J., & Pulsipher, A. G. (2005). Rigs-to-Reef Programs in the Gulf of Mexico. *Ocean Development & International Law*, *36*(2), 119–134.

Kämpf, J., & Sadrinasab, M. (2006). The circulation of the Persian Gulf: a numerical study. *Ocean Sci.*, *2*(1), 27–41.

Kędra, M., Grebmeier, J. M., & Cooper, L. W. (2018). Sipunculan fauna in the Pacific Arctic region: a significant component of benthic infaunal communities. *Polar Biology*, *41*(1), 163–174.

Khayat, A. L., & الخياط, J. A. [2005) (جاسم ع. ا.). Some Macrobenthic Invertebrates in the Qatari Waters, Arabian Gulf. Retrieved October 23, 2018, from http://qspace.qu.edu.qa/handle/10576/10054

Kohn, A. (2001). Maximal species richness in Conus: diversity, diet and habitat on reefs of northeast Papua New Guinea. *Coral Reefs*, *20*(1), 25–38.

Landers, W. S., & Rhodes, E. W. (1970). Some factors influencing predation by the flatworm,Stylochus ellipticus (Girard), on oysters. *Chesapeake Science*, *11*(1), 55–60.

Lee, M. O., Otake, S., & Kim, J. K. (2018). Transition of artificial reefs (ARs) research and its prospects. *Ocean and Coastal Management*, *154*, 55–65.

Louisiana Aims to Turn Shut-Down Oil Rigs into Reefs. (2017). *Salt Water Sportsman*, *78*(8), 12–12.

Macreadie, P. I., Fowler, A. M., & Booth, D. J. (2011). Rigs-to-reefs: will the deep sea benefit from artificial habitat? *Frontiers in Ecology and the Environment*, *9*(8), 455–461.

Maghsoudlou, A., Eghtesadi Araghi, P., Wilson, S., & Taylor, O. (2008). Status of Coral Reefs in the ROPME Sea Area (The Persian Gulf, Gulf of Oman and Arabian Sea) (pp. 79–90).

McConnaughey, R. A., & Sulkin, S. D. (1984). Measuring the effects of thermoclines on the vertical migration of larvae of Callinectes sapidus (Brachyura: Portunidae) in the laboratory. *Marine Biology*, *81*(2), 139–145.

Mckenzie, R., Lowry, M., Folpp, H., & Gregson, M. (2011). Fouling assemblages associated with estuarine artificial reefs in new South Wales, Australia. *Brazilian Journal of Oceanography*, *59*(SPE1), 107–118.

Merory, M., & Newman, L. J. (2005). A new stylochid flatworm (Platyhelminthes, Polycladida) from Victoria, Australia and observations on its biology. *Journal of Natural History*, *39*(28), 2581–2589.

Metcalfe, K. N., & Glasby, C. J. (2008). Diversity of Polychaeta (Annelida) and other worm taxa in mangrove habitats of Darwin Harbour, northern Australia. *Journal of Sea Research*, Mangrove Macrobenthos Special Issue, *59*(1), 70–82.

Mohammed, S. Z., & Al-Ssadh, S. (1996). Coral reef grounds and its associated biota in the western side of the Arabian Gulf (ROPME Sea Area) with respect to 1991 Gulf war oil spill. *IJMS Vol.25(1) [March 1996]*. Retrieved October 23, 2018, from http://nopr.niscair.res.in/handle/123456789/36401

Molen, J. van der, García-García, L. M., Whomersley, P., Callaway, A., Posen, P. E., & Hyder, K. (2018). Connectivity of larval stages of sedentary marine communities between hard substrates and offshore structures in the North Sea. *Scientific Reports*, *8*. Retrieved October 20, 2018, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6170480/

Munday, P. L. (2004). Habitat loss, resource specialization, and extinction on coral reefs. *Global Change Biology*, *10*(10), 1642–1647.

Murina, G. V. V. (1984). Ecology of Sipuncula. *Marine ecology progress series. Oldendorf*, *17*(1), 1–7.

Naderloo, R. (2017). *Atlas of Crabs of the Persian Gulf*. Springer International Publishing. Retrieved October 7, 2018, from //www.springer.com/br/book/9783319493725

Naser, H. (2011). Human Impacts on Marine Biodiversity: Macrobenthos in Bahrain, Arabian Gulf.

Nowruzi, K., Elkamel, A., Scharer, J. M., & Moo-Young, M. (2009). A Computational Intelligent Based Approach for the Development of a Minimal Defined Medium: Application to Human Interleukin-3 Production by Streptomyces lividans 66. In M. do Carmo Nicoletti & L. C. Jain (Eds.), *Computational Intelligence Techniques for Bioprocess Modelling, Supervision and Control*, Studies in Computational Intelligence (pp. 215–236). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved October 27, 2018, from https://doi.org/10.1007/978-3-642-01888-6_8

Page, H. M., & Hubbard, D. M. (1987). Temporal and spatial patterns of growth in mussels Mytilus edulis on an offshore platform: relationships to water temperature and food availability. *Journal of Experimental Marine Biology and Ecology*, *111*(2), 159–179.

Page, Henry M., Culver, C. S., Dugan, J. E., & Mardian, B. (2008). Oceanographic gradients and patterns in invertebrate assemblages on offshore oil platforms. *ICES Journal of Marine Science*, *65*(6), 851–861.

Page, Henry M., Dugan, J. E., & Piltz, F. (2009). Fouling and Antifouling in Oil and Other Offshore Industries. In S. Dürr & J. C. Thomason (Eds.), *Biofouling* (pp. 252–266). Wiley-Blackwell. Retrieved November 12, 2015, from http://onlinelibrary.wiley.com/doi/10.1002/9781444315462.ch18/summary

Pearse, A. S., & Wharton, G. W. (1938). The Oyster "Leech," Stylochus inimicus Palombi, Associated with Oysters on the Coasts of Florida. *Ecological Monographs*, *8*(4), 605–655.

Perkol-Finkel, S., Shashar, N., Barneah, O., Ben-David-Zaslow, R., Oren, U., Reichart, T., Yacobovich, T., et al. (2005). Fouling reefal communities on artificial reefs: does age matter? *Biofouling*, *21*(2), 127–140.

Perry, C. T., Murphy, G. N., Graham, N. A. J., Wilson, S. K., Januchowski-Hartley, F. A., & East, H. K. (2015). Remote coral reefs can sustain high growth potential and may match future sea-level trends. *Scientific Reports*, *5*, 18289.

Plutchak, R., Major, K., Cebrian, J., Foster, C. D., Miller, M.-E. C., Anton, A., Sheehan, K. L., et al. (2010). Impacts of Oyster Reef Restoration on Primary Productivity and Nutrient Dynamics in Tidal Creeks of the North Central Gulf of Mexico. *Estuaries and Coasts*, *33*(6), 1355–1364.

Polovina, J. J., & Sakai, I. (1989, March). Impacts of Artificial Reefs on Fishery Production in Shimamaki, Japan. Text, . Retrieved October 20, 2018, from https://www.ingentaconnect.com/content/umrsmas/bullmar/1989/00000044/00000002/art00043

Proposed law could jumpstart California's rigs-to-reefs program: Converting oilrigs into artificial reefs could become easier if SB 588 becomes law. (n.d.). .

Quigg, A., Al-Ansi, M., Nour Al Din, N., Wei, C.-L., Nunnally, C., Al-Ansari, E., Rowe, G., et al. (2013). Phytoplankton along the coastal shelf of an oligotrophic hypersaline environment in a semi-enclosed marginal sea: Qatar (Arabian Gulf). *Continental Shelf Research*, *60*, 1–16.

Range, P., Martins, M., Cabral, S., Piló, D., Ben-Hamadou, R., Teodósio Chícharo, M., Leitão, F., et al. (2014). Relative sensitivity of soft-bottom intertidal macrofauna to increased CO2 and experimental stress. *Marine Ecology Progress Series*, *509*, 153–170.

Reaka, M. (2005). Biodiversity of Caribbean coral reefs (pp. 259–276).

Relics to Reefs. (n.d.). .

Rezai, H., Wilson, S., Claereboudt, M., & Riegl, B. (2004). Coral Reef Status in the ROPME Sea Area: Arabian/Persian Gulf, Gulf of Oman and Arabian Sea. *Status of Coral Reefs of the World: 2004*, 155–170.

Rezek, R. J., Lebreton, B., Palmer, T. A., Stunz, G. W., & Beseres Pollack, J. (2018). Structural and functional similarity of epibenthic communities on standing and reefed platforms in the northwestern Gulf of Mexico. *Progress in Oceanography*, *168*, 145–154.

Richmond, M. D. (Ed.). (2002). *Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands* (2nd edition.). Dar es Salaam: Sida.

Riegl, B. M., & Purkis, S. J. (Eds.). (2012). *Coral reefs of the Gulf: adaptation to climatic extremes*. Coral reefs of the world. Dordrecht ; New York: Springer.

Robinson, D. P., Jaidah, M. Y., Jabado, R. W., Lee-Brooks, K., El-Din, N. M. N., Malki, A. A. A., Elmeer, K., et al. (2013). Whale Sharks, Rhincodon typus, Aggregate around Offshore Platforms in Qatari Waters of the Arabian Gulf to Feed on Fish Spawn. *PLOS ONE*, *8*(3), e58255.

Rule, M. J., & Smith, S. D. A. (2007). Depth-associated patterns in the development of benthic assemblages on artificial substrata deployed on shallow, subtropical reefs. *Journal of Experimental Marine Biology and Ecology*, *345*(1), 38–51.

Sammarco, P. W., Brazeau, D. A., & Sinclair, J. (2012). Genetic Connectivity in Scleractinian Corals across the Northern Gulf of Mexico: Oil/Gas Platforms, and Relationship to the Flower Garden Banks. *PLOS ONE*, *7*(4), e30144.

Sanabria-Fernandez, J. A., Lazzari, N., Riera, R., & Becerro, M. A. (2018). Building up marine biodiversity loss: Artificial substrates hold lower number and abundance of low occupancy benthic and sessile species. *Marine Environmental Research*, *140*, 190–199.

Sandin, S. A., Smith, J. E., DeMartini, E. E., Dinsdale, E. A., Donner, S. D., Friedlander, A. M., Konotchick, T., et al. (2008). Baselines and degradation of coral reefs in the northern Line Islands. *PloS one*, *3*(2), e1548.

Stachowitsch, M., Kikinger, R., Herler, J., Zolda, P., & Geutebrück, E. (2002). Offshore oil platforms and fouling communities in the southern Arabian Gulf (Abu Dhabi). *Marine pollution bulletin*, *44*(9), 853–860.

Stap, T. van der, Coolen, J. W. P., & Lindeboom, H. J. (2016). Marine Fouling Assemblages on Offshore Gas Platforms in the Southern North Sea: Effects of Depth and Distance from Shore on Biodiversity. *PLOS ONE*, *11*(1), e0146324.

Stöhr, S., O'Hara, T. D., & Thuy, B. (2012). Global Diversity of Brittle Stars (Echinodermata: Ophiuroidea). *PLOS ONE*, *7*(3), e31940.

Stuart-Smith, R. D., Brown, C. J., Ceccarelli, D. M., & Edgar, G. J. (2018). Ecosystem restructuring along the Great Barrier Reef following mass coral bleaching. *Nature*, *560*(7716), 92–96.

Techera, E. J., & Chandler, J. (2015). Offshore installations, decommissioning and artificial reefs: Do current legal frameworks best serve the marine environment? *Marine Policy*, *59*, 53–60.

Torquato, F., Jensen, H. M., Range, P., Bach, S. S., Ben-Hamadou, R., Sigsgaard, E. E., Thomsen, P. F., et al. (2017). Vertical zonation and functional diversity of fish assemblages revealed by ROV videos at oil platforms in The Gulf. *Journal of Fish Biology*, *91*(3), 947–967.

Torres, A. P. (2015). Decapod crustacean larvae inhabiting offshore balearic sea waters (western mediterranean): taxonomy and ecology. *Dialnet*. http://purl.org/dc/dcmitype/Text, . Retrieved October 26, 2018, from https://dialnet.unirioja.es/servlet/tesis?codigo=59536

Truchon, S. P., Brzuzy, L. P., Fawcett, D., & Fonseca, M. (2015). Innovative Assessments for Selecting Offshore-Platform-Decommissioning Alternatives. *Oil and Gas Facilities*, *4*(05), 47–55.

Vedenin, A., Gusky, M., Gebruk, A., Kremenetskaia, A., Rybakova, E., & Boetius, A. (2018). Spatial distribution of benthic macrofauna in the Central Arctic Ocean. *PloS one*, *13*(10), e0200121.

Veron, J. E. N., Hoegh-Guldberg, O., Lenton, T. M., Lough, J. M., Obura, D. O., Pearce-Kelly, P., Sheppard, C. R. C., et al. (2009). The coral reef crisis: The critical importance of< 350ppm CO 2. *Marine pollution bulletin*, *58*(10), 1428–1436.

Verspagen, J. M. H., Snelder, E. O. F. M., Visser, P. M., Huisman, J., Mur, L. R., & Ibelings, B. W. (2004). Recruitment of Benthic Microcystis (cyanophyceae) to the Water Column: Internal Buoyancy Changes or Resuspension?1. *Journal of Phycology*, *40*(2), 260–270.

Wehe, T., & Fiege, D. (2002). Annotated checklist of the polychaete species of the seas surrounding the Arabian Peninsula: Red Sea, Gulf of Aden, Arabian Sea, Gulf of Oman, Arabian Gulf. *Fauna of Arabia*, *19*, 7–238.

Williams, T. (2006). Sinking Poor Decision-Making with Best Practices: A Case Study of Artificial Reef Decision-Making in the Florida Keys. *Theses and Dissertations*. Retrieved from https://scholarscompass.vcu.edu/etd/838

Wilson, B. R., & Clarkson, P. (2000). *Australia's spectacular cowries : a review and field study of two endemic genera : Zoila and Umbilia* (1st ed.). California, USA : Odyssey. Retrieved October 17, 2018, from https://trove.nla.gov.au/version/24549552

Wilson, S., Fatemi, seyed mohammad reza, Shokri, M. R., & Claereboudt, M. (2002). Status of coral reefs of the Persian/Arabian Gulf and Arabian Sea region. *Status of Coral Reefs of the World: 2002*.

Wilson, S. K., Graham, N. A., Pratchett, M. S., Jones, G. P., & Polunin, N. V. (2006). Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? *Global Change Biology*, *12*(11), 2220–2234.

WoRMS - World Register of Marine Species. (n.d.). . Retrieved October 17, 2018, from http://www.marinespecies.org/index.php

Yemane, D., Field, J. G., & Leslie, R. W. (2005). Exploring the effects of fishing on fish assemblages using Abundance Biomass Comparison (ABC) curves. *ICES Journal of Marine Science*, *62*(3), 374–379.

Zintzen, V., Norro, A., Massin, C., & Mallefet, J. (2008). Spatial variability of epifaunal communities from artificial habitat: Shipwrecks in the Southern Bight of the North Sea. *Estuarine, Coastal and Shelf Science*, *76*(2), 327–344.

APPENDIX

Appendix A – Supplementary Tables

Supplementary Table 1 Distribution of Average Abundance of each taxon at 5 m depth intervals across the Six Sites.

(Note: For operations O.T.U 2 was used due to some taxa identified to higher taxonomic levels in column O.T.U were reduced to family level as shown in O.T.U. 2 to increase the confidence level of the taxonomic identification and subsequent data analysis performed on the taxonomic identification)

All Sites				**Depth Intervals (5 m)**						
Phylum	**Order**	**O.T.U**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Annelida	**-**	Polychaeta	Polychaeta	4.00	4.33		12.50	3.33	3.00	6.00
	Canalipalpata	Chaetopteridae	Chaetopteridae	2.00		5.00			1.00	
	Eunicida	Dorvilleidae	Dorvilleidae	3.00	1.00	1.00				
		Eunice antennata	Eunicidae	1.50	1.00	1.00	2.50	1.40	1.33	4.75
		Eunicidae	Eunicidae	1.00		2.00			5.50	
		Lumbrineridae	Lumbrineridae	2.25	2.89	2.80	2.00	2.33	9.00	
		Lumbrineris gracilis	Lumbrineridae	4.00	3.00					
	Phyllodocida	Hesionidae	Hesionidae	4.00	1.50	1.00				
		Lepidontus carinulatus	Polynoidae	2.00	3.00			1.00		
		Lepidontus sp. 1	Polynoidae	1.00						
		Nereididae	Nereididae	5.40	2.20	2.00	6.00	3.00	3.17	2.67
		Nereiphylla castanea	Phyllodocidae	1.50						
		Nereis denhamensis	Nereididae						2.00	2.25
		Nereis sp. 1	Nereididae				1.00	2.00		
		Paralepidonotus ampulliferus	Polynoidae	2.00			4.00	1.00		
		Perinereis nigropunctata	Nereididae	8.33	2.00		1.00			6.00
		Phyllodocidae	Phyllodocidae	2.33	2.00	1.00	2.00	1.00		1.00
		Polynoidae	Polynoidae	5.00	1.83	1.67	2.00	2.00	1.00	
		Syllidae	Syllidae	7.00	3.80	1.71	2.00	1.67		
		Syllis cornuta	Syllidae	3.50	1.00	1.00		1.00		
		Syllis sp. 1	Syllidae	1.00						
		Typosyllis sp. 1	Syllidae	1.00	1.00	2.00				
		Typosyllis sp. 2	Syllidae	1.00	13.00					
	Sabellida	Sabellidae	Sabellidae			1.00			1.00	
	Spionida	Poecilochaetidae	Poecilochaetidae		1.00	1.50				
	Terebellida	*Amage* sp. 1	Ampharetidae	3.00						
		Ampharetidae	Ampharetidae	1.50	3.50	1.80	4.00	2.00	2.50	1.00
		Cirratulidae	Cirratulidae		5.00		1.00	1.00		1.00
		Cirriformia tentaculata	Cirratulidae				1.00			3.00
		Polycirrus aurantiacus	Terebellidae	1.00						
		Terebellidae	Terebellidae	1.00	2.00	6.67	2.00	8.80	9.67	

Supplementary Table 1 Distribution of Average Abundance of each taxon at 5 m depth intervals across the Six Sites.

(Note: For operations O.T.U 2 was used due to some taxa identified to higher taxonomic levels in column O.T.U were reduced to family level as shown in O.T.U. 2 to increase the confidence level of the taxonomic identification and subsequent data analysis performed on the taxonomic identification)

All Sites				Depth Intervals (5 m)						
Phylum	**Order**	**O.T.U**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Arthropoda	**Amphipoda**	*Ampithoe* sp. 1	*Ampithoe* sp. 1		64.00	1.00				
	Decapoda	*Alpheus* sp.	*Alpheus* sp.						1.00	
		Decapoda	Decapoda							
		Epialtidae	Epialtidae			1.00		1.00		1.00
		Etisus demani	*Etisus demani*					1.00	1.50	1.25
		Galathea sp. 1	*Galathea* sp. 1							1.00
		Hyastenus brockii	*Hyastenus brockii*					1.00		1.00
		Pachycheles sp. 1	*Pachycheles* sp. 1	1.00	2.75				1.00	
		Pilumnidae	Pilumnidae		1.00				1.00	4.67
		Pilumnus sp. 1	Pilumnidae	1.00	1.33		1.00	2.40	4.00	2.29
		Pilumnus sp. 2	Pilumnidae							1.00
		Thalamita sp.	*Thalamita* sp.		1.00	1.00			1.00	
		Tiarinia sp. 1	*Tiarinia* sp. 1							1.00
		Xanthidae	Xanthidae		1.00					
Echinodermata	**Camarodonta**	*Salmacis* sp.1	*Salmacis* sp.1	1.00						
	Diadematoida	*Echinothrix* sp. 1 juvenile	*Echinothrix* sp. 1 juvenile	2.00	1.00		1.50			
	Ophiurida	*Ophiocoma* sp. 1	Ophiocomidae	11.00	2.00	6.50	14.50	2.00		
		Ophiocoma sp. 2	Ophiocomidae				1.00			
		Ophiocoma sp. 3	Ophiocomidae			1.00				
		Ophiocoma sp. 4	Ophiocomidae	3.00						
		Ophiocomidae	Ophiocomidae	4.00	2.00	3.80	5.83	3.83	2.00	
		Ophionereididae	Ophionereididae		1.00					
		Ophioneries sp. 1	Ophionereididae	1.00						
		Ophiothrix savignyi	Ophiotrichidae	5.00		4.00	1.00			
		Ophiothrix sp. 1	Ophiotrichidae	9.00	10.00	9.50	1.00	1.00		
		Ophiothrix sp. 2	Ophiotrichidae	18.00	1.00	1.00	1.00			
		Ophiothrix sp. 3	Ophiotrichidae			1.00				
		Ophiothrix sp. 4	Ophiotrichidae	1.00	1.00					
		Ophiotrichidae	Ophiotrichidae	4.50	34.67	5.67	8.40	2.20	3.67	
		Ophiurida	Ophiurida	2.33	1.00		1.00	2.00		

Supplementary Table 1 Distribution of Average Abundance of each taxon at 5 m depth intervals across the Six Sites.

(Note: For operations O.T.U 2 was used due to some taxa identified to higher taxonomic levels in column O.T.U were reduced to family level as shown in O.T.U. 2 to increase the confidence level of the taxonomic identification and subsequent data analysis performed on the taxonomic identification)

All Sites				Depth Intervals (5 m)						
Phylum	**Order**	**O.T.U**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Mollusca	**Caenogastropoda**	*Cerithium* sp. 1	*Cerithium* sp. 1		2.00	1.00	2.00	1.25		
	Littorinimorpha	*Conus* sp.	*Conus* sp.	1.50	1.75	1.00				
	Littorinimorpha	*Cypraea turdus*	*Cypraea turdus*	1.00	1.00					
	Nudibranchia	Nudibranchia	Nudibranchia			1.00				
Platyhelminthes	**-**	Rhabditophora	Rhabditophora					1.00		
	Polycladida	*Adenoplana* sp. 1	Discocelidae	4.25	3.00					
		Adenoplana sp. 2	Discocelidae	1.00						
		Discocelidae	Discocelidae	3.00	4.00			2.50		
		Stylochidae	Stylochidae	11.17	9.90	5.43	2.00	3.33	1.00	
		Stylochus sp. 1	Stylochidae	17.75	5.00	5.00	8.00			
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	*Phascolosoma* sp. 1	22.86	17.15	6.08	4.78	4.40	2.67	
		Phascolosoma sp. 2	*Phascolosoma* sp. 2		1.00					

Supplementary Table 2 Taxa and their Average Abundance at 5 m Depth Interval at Site 1-AF

Site 1-AF			Depths (5 m intervals)						
Phylum	**Order**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Annelida	**-**	Polychaeta	3.00						
	Canalipalpata	Chaetopteridae	2.00					1.00	
	Eunicida	Dorvilleidae	3.00	1.00					
		Eunicidae					2.00	1.00	16.00
		Lumbrineridae	5.00	1.00	4.00	2.00	1.00		
	Phyllodocida	Hesionidae		1.00	1.00				
		Nereididae	7.00	2.00	2.00		1.00	4.50	2.00
		Phyllodocidae	3.50	2.00		2.00			1.00
		Polynoidae	7.00		1.00			1.00	
		Syllidae	4.33	4.00	2.00	1.00	1.00		
	Spionida	Poecilochaetidae		1.00	1.50				
	Terebellida	Ampharetidae	3.00		1.00			2.00	
		Cirratulidae				1.00			
		Terebellidae	1.00	3.00	1.00	3.00	5.50		
Arthropoda	**Decapoda**	Decapoda							
		Epialtidae							1.00
		Etisus demani							1.00
		Pachycheles sp. 1		1.00					
		Pilumnidae		1.00					
		Thalamita sp.		1.00					
Echinodermata	**Ophiurida**	Ophiocomidae				4.00	1.00		
		Ophiotrichidae	1.00	90.00		1.00	1.00		
		Ophiurida	2.00						
Mollusca	**Littorinimorpha**	*Conus* sp.		3.00					
	Nudibranchia	Nudibranchia			1.00				
Platyhelminthes	**Polycladida**	Discocelidae	4.50	3.00			4.00		
		Stylochidae	3.00	6.50	6.50		6.00		
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	5.50	5.50	6.50	3.00	1.00		

Supplementary Table 3 Taxa and their Average Abundance at 5 m Depth Interval at Site 2-DE

Site 2-DE			Depths (5 m intervals)					
Phylum	**Order**	**O.T.U 2**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Annelida	-	Polychaeta	3.00		19.00			6.00
	Canalipalpata	Chaetopteridae		5.00				
	Eunicida	Dorvilleidae		1.00				
		Eunicidae		2.00	2.00	1.50	2.50	1.00
		Lumbrineridae	5.00	5.00		2.00	9.00	
	Phyllodocida	Nereididae	1.50		1.00	1.67	6.00	3.20
		Phyllodocidae		1.00				
		Polynoidae	1.50		4.00		1.00	
		Syllidae	3.33	4.00		2.00		
	Sabellida	Sabellidae					1.00	
	Terebellida	Ampharetidae					3.00	
		Cirratulidae			1.00			2.00
		Terebellidae		25.00		15.00	14.00	
Arthropoda	**Decapoda**	Epialtidae				1.00		
		Etisus demani						1.00
		Pachycheles sp. 1	1.00				1.00	
		Pilumnidae						1.50
		Thalamita sp.	1.00	1.00			1.00	
		Tiarinia sp. 1						1.00
Echinodermata	**Diadematoida**	*Echinothrix* sp. 1 juvenile			1.00			
	Ophiurida	Ophiocomidae	2.50	2.33	11.50	6.67	1.00	
		Ophionereididae	1.00					
		Ophiotrichidae	6.00	7.33	1.00	3.00	5.00	
		Ophiurida	1.00					
Mollusca	**Caenogastropoda**	*Cerithium* sp. 1				1.00		
	Littorinimorpha	*Conus* sp.	1.00	1.00				
Platyhelminthes	**Polycladida**	Discocelidae	3.00			1.00		
		Stylochidae	6.00	6.00	8.00	3.00	1.00	
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	12.50	12.50	10.00	8.00	3.50	
		Phascolosoma sp. 2	1.00					

Supplementary Table 4 Taxa and their Average Abundance at 5 m Depth Interval at Site 3-BC

Site 3-BC			**Depths (5 m intervals)**						
Phylum	**Order**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Annelida	**Eunicida**	Eunicidae							1.00
		Lumbrineridae	2.00	2.00	1.50				
	Phyllodocida	Hesionidae	4.00	2.00	1.00				
		Nereididae	7.00	3.00				1.00	2.00
		Phyllodocidae	1.00						
		Polynoidae	2.00		2.00			1.00	
		Syllidae	2.00		1.00				
	Sabellida	Sabellidae			1.00				
	Terebellida	Ampharetidae	1.50	4.00	2.00	2.50	2.00		
		Terebellidae	1.00		1.00	1.00		1.00	
Arthropoda	**Decapoda**	*Hyastenus brockii*							1.00
		Pilumnidae		1.00					1.50
		Xanthidae		1.00					
Echinodermata	**Ophiurida**	Ophiocomidae				2.00			
		Ophiotrichidae	1.00					1.00	
Mollusca	**Caenogastropoda**	*Cerithium* sp. 1					1.50		
	Littorinimorpha	*Conus* sp.	1.00						
Platyhelminthes	**Polycladida**	Discocelidae	4.00	5.00					
		Stylochidae	18.33	20.00	3.50				
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	11.50	18.50	1.50	1.00			

Supplementary Table 5 Taxa and their Average Abundance at 5 m Depth Interval at Site 4-GH

Site 4-GH			**Depths (5 m intervals)**					
Phylum	**Order**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**
Annelida	-	Polychaeta	2.00	2.00		6.00		
	Eunicida	Eunicidae	1.33	1.00	1.00	3.00		1.00
		Lumbrineridae	1.00	5.00				
	Phyllodocida	Nereididae	5.50			1.00	2.00	2.00
		Phyllodocidae	1.00					
		Polynoidae	1.67	2.00				
		Syllidae	8.50	7.00	1.33			
	Terebellida	Ampharetidae				3.00		
		Terebellidae			5.00			
Arthropoda	**Amphipoda**	*Ampithoe* sp. 1		64.00	1.00			
	Decapoda	*Alpheus* sp.						1.00
		Decapoda						
		Etisus demani						2.00
		Pachycheles sp. 1	1.00	1.00				
		Pilumnidae					4.50	6.00
Echinodermata	**Diadematoida**	*Echinothrix* sp. 1 juvenile	2.00					
	Ophiurida	Ophiocomidae	5.50	1.00	5.20	7.50	1.00	
		Ophionereididae	1.00					
		Ophiotrichidae	8.17	5.00	4.50	3.33		
		Ophiurida	2.50			1.00	1.00	
Mollusca	**Caenogastropoda**	*Cerithium* sp. 1		3.00				
	Littorinimorpha	*Conus* sp.	2.00					
	Littorinimorpha	*Cypraea turdus*	1.00	1.00				
	Nudibranchia	Nudibranchia			1.00			
Platyhelminthes	**Polycladida**	Discocelidae	3.33					
		Stylochidae	8.00			2.00		
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	50.50	13.50	2.33	2.00		1.00

Supplementary Table 6 Taxa and their Average Abundance at 5 m Depth Interval at Site 5-LJ

Site 5-LJ			**Depths (5 m intervals)**						
Phylum	**Order**	**O.T.U 2**	**10-14**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Annelida	-	Polychaeta	7.00				3.00	3.00	
	Eunicida	Eunicidae					1.00	8.00	
		Lumbrineridae	2.50	1.50	2.00		4.00		
	Phyllodocida	Nereididae	6.50		2.00	6.00	5.50	1.50	5.00
		Phyllodocidae	1.00				1.00		
		Polynoidae	1.00		2.00	2.00	2.00	1.00	
		Syllidae	2.00	2.00	1.00	3.00			
	Terebellida	Ampharetidae		3.00	2.00	8.00			1.00
		Cirratulidae					1.00		
		Terebellidae	1.00		3.00		3.00		
Arthropoda	**Decapoda**	*Etisus demani*					1.00	1.00	2.00
		Hyastenus brockii					1.00		
		Pilumnidae	1.00				1.00	1.00	11.00
Echinodermata	**Camarodonta**	*Salmacis* sp.1	1.00						
	Diadematoida	*Echinothrix* sp. 1 juvenile	2.00			2.00			
	Ophiurida	Ophiocomidae				1.00		3.00	
		Ophiotrichidae			9.00	16.00			
		Ophiurida					3.00		
Mollusca	**Caenogastropoda**	*Cerithium* sp. 1		1.00	1.00	2.00	1.00		
Platyhelminthes	**Polycladida**	Discocelidae	1.00						
		Stylochidae	26.50	3.50	5.50		1.00		
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	25.00	3.50	11.00	8.00	4.00		

Supplementary Table 7 Taxa and their Average Abundance at 5 m Depth Interval at Site 6-IM

Site 6-IM			**Depths (5 m intervals)**					
Phylum	**Order**	**O.T.U 2**	**15-19**	**20-24**	**25-29**	**30-34**	**35-39**	**40-44**
Annelida	-	Polychaeta	8.00			3.50		
	Eunicida	Eunicidae			2.00			1.00
	Phyllodocida	Nereididae			1.00	4.00		2.00
		Polynoidae	2.33		2.00	1.00		
		Syllidae	1.00			1.00		
	Terebellida	Cirratulidae	5.00					
		Terebellidae	1.00					
Arthropoda	**Decapoda**	Epialtidae		1.00				
		Etisus demani						1.00
		Galathea sp. 1						1.00
		Pachycheles sp. 1	8.00					
		Pilumnidae	1.50		1.00	1.00	2.00	2.75
Echinodermata	**Diadematoida**	*Echinothrix* sp. 1 juvenile	1.00					
	Ophiurida	Ophiocomidae			10.00	2.00		
		Ophiotrichidae		1.00	8.50	1.00		
Mollusca	**Caenogastropoda**	*Cerithium* sp. 1	2.00					
	Littorinimorpha	*Conus* sp.	1.50					
Platyhelminthes	-	Rhabditophora				1.00		
	Polycladida	Stylochidae	10.33					
Sipuncula	**Phascolosomatida**	*Phascolosoma* sp. 1	38.67	3.00	4.00	1.00		

Supplementary Table 8 *Number of samples (shaded green) from various depths analyzed*

(Please note the symbols represent size of the vials samples were preserved in □ 1 L and Δ 500 ml)

PRESERVED IN ETHANOL						PRESERVED IN FORMALIN					
IM		GH		DE		AF		BC		LJ	
DEPTH (m)	VIALS	DEPTH (m)	VIALS	DEPTH (m)	VIALS	DEPTH (m)	VIALS	DEPTH (m)	VIALS	DEPTH (m)	VIALS
10		10	□□□	10		10		10		10	
11		11		11		11		11		11	
12		12		12		12	Δ□	12	□□	12	
13		13		13		13		13		13	□□
14		14	□□	14		14	□	14	□□	14	
15	□□	15		15		15		15		15	
16		16	Δ□	16	Δ□	16	□	16	□	16	
17	□ΔΔ	17		17		17		17		17	□
18		18	□	18	□	18	□	18	□	18	
19	□	19		19		19		19		19	□
20		20	□	20	□	20	□	20		20	
21		21		21		21		21		21	□
22		22	□	22	□	22		22	□	22	
23	□	23		23		23	Δ	23		23	□
24		24	□	24		24		24	□	24	
25		25		25		25		25		25	Δ
26		26	□	26	□	26	Δ	26	Δ	26	
27	□	27		27		27		27		27	□
28		28	□	28		28	Δ	28	Δ	28	
29	□	29		29		29		29		29	
30		30	□	30	Δ	30	Δ	30	Δ	30	
31	□	31		31		31		31		31	
32	□	32	□	32	Δ	32	Δ	32	Δ	32	□
33		33		33		33		33		33	
34	Δ	34		34	Δ	34		34	Δ	34	□
35		35		35		35	Δ	35		35	
36	Δ	36	□	36	Δ	36		36	Δ	36	□
37		37		37		37		37		37	
38	Δ	38		38	Δ□	38		38	□	38	
39		39		39		39	Δ	39		39	Δ
40	Δ	40		40	Δ	40		40	□	40	
41		41		41		41	Δ	41		41	
42	□	42		42	Δ	42		42		42	□
43		43		43		43	Δ	43		43	
44	□	44		44	Δ	44		44		44	

Supplementary Table 9 Taxa Codes used for labelling during taxonomy

O.T.U	Code	O.T.U	Code	O.T.U	Code
Perinereis nigropunctata	**P1**	*Thalamita sp.*	**C1**	*Conus sp.*	**M1**
Syllis cornuta	**P2**	*Pilumnus sp. 1*	**C2**	*Cypraea turdus*	**M2**
Polynoidae	**P3**	*Tiarinia sp. 1*	**C3**	*Cerithium sp. 1*	**M3**
Paralepidonotus ampulliferus	**P4**	*Pilumnus sp. 2*	**C4**	Nudibranchia	**M4**
Eunice antennata	**P5**	*Hyastenus brockii*	**C6**	*Phascolosoma sp. 1*	**W1**
Cirriformia tentaculata	**P6**	*Eitsus demani*	**C8**	*Phascolosoma sp. 2*	**W2**
Nereis denhamensis	**P7**	*Alpheus sp.*	**C9**	*Adenoplana sp. 1*	**W3**
Cirratulidae	**P8**	*Ampithoe sp. 1*	**C10**	*Stylochus sp. 1*	**W4**
Nereididae	**P9**	*Pachycheles sp. 1*	**C11**	Stylochidae	**W5**
Nereis sp. 1	**P10**	*Galathea sp. 1*	**C12**	*Adenoplana sp. 2*	**W6**
Lepidontus carinulatus	**P11**	Pilumnidae	**C13**	Rhabditophora	**W7**
Syllis sp. 1	**P12**	Decapoda	**C14**	Discocelidae	**W8**
Polychaeta	**P13**	Epialtidae	**C15**		
Polycirrus aurantiacus	**P14**	Xanthidae	**C16**		
Nereiphylla castanea	**P15**	*Ophiothrix savignyi*	**E1**		
Typosyllis sp. 2	**P16**	*Ophiocoma sp. 1*	**E2**		
Lumbrineris gracilis	**P17**	*Ophiocoma sp. 2*	**E3**		
Lumbrineridae	**P18**	*Ophiothrix sp. 1*	**E4**		
Lepidontus sp. 1	**P19**	*Ophiothrix sp. 2*	**E5**		
Typosyllis sp. 1	**P20**	*Echinothrix sp. 1 juvenile*	**E6**		
Terebellidae	**P21**	*Ophioneries sp. 1*	**E7**		
Amage sp. 1	**P22**	*Ophiocoma sp. 3*	**E8**		
Phyllodocidae	**P23**	*Ophiothrix sp. 3*	**E9**		
Syllidae	**P24**	*Ophiocoma sp. 4*	**E10**		
Ampharetidae	**P25**	Ophiurida	**E11**		
Eunicidae	**P26**	*Salmacis sp.1*	**E13**		
Hesionidae	**P28**	*Ophiothrix sp. 4*	**E14**		
Sabellidae	**P29**	Ophiocomidae	**E15**		
Dorvilleidae	**P30**	Ophiotrichidae	**E16**		
Chaetopteridae	**P31**				
Poecilochaetidae	**P32**				

Supplementary Table 10 *Reference Collection of Specimens*

Specimens for Reference Collection			Specimens for Reference Collection		
Code	**O.T.U**	**Total**	**Code**	**O.T.U**	**Total**
C1	*Thalamita sp.*	1	**P1**	*Perinereis nigropunctata*	5
C10	*Ampithoe sp. 1*	6	**P11**	*Lepidontus carinulatus*	3
C11	*Pachycheles sp. 1*	3	**P12**	*Syllis sp. 1*	1
C12	*Galathea sp. 1*	1	**P14**	*Polycirrus aurantiacus*	1
C13	Pilumnidae	1	**P15**	*Nereiphylla castanea*	2
C15	Epialtidae	1	**P16**	*Typosyllis sp. 2*	1
C16	Xanthidae	1	**P17**	*Lumbrineris gracilis*	2
C2	*Pilumnus sp. 1*	7	**P18**	Lumbrineridae	4
C4	*Pilumnus sp. 2*	1	**P19**	*Lepidontus sp. 1*	1
C6	*Hyastenus brockii*	1	**P2**	*Syllis cornuta*	2
C8	*Etisus demani*	3	**P20**	*Typosyllis sp. 1*	3
C9	*Alpheus sp.*	1	**P21**	Terebellidae	4
E1	*Ophiothrix savignyi*	1	**P23**	Phyllodocidae	4
E10	*Ophiocoma sp. 4*	1	**P24**	Syllidae	10
E13	*Salmacis sp.1*	1	**P25**	Ampharetidae	2
E14	*Ophiothrix sp. 4*	2	**P28**	Hesionidae	3
E15	Ophiocomidae	7	**P29**	Sabellidae	1
E16	Ophiotrichidae	20	**P3**	Polynoidae	6
E2	*Ophiocoma sp. 1*	5	**P30**	Dorvilleidae	2
E3	*Ophiocoma sp. 2*	1	**P31**	Chaetopteridae	3
E4	*Ophiothrix sp. 1*	2	**P4**	*Paralepidonotus ampulliferus*	4
E5	*Ophiothrix sp. 2*	5	**P5**	*Eunice antennata*	6
E6	*Echinothrix sp. 1 juvenile*	2	**P7**	*Nereis denhamensis*	4
E8	*Ophiocoma sp. 3*	1	**P8**	Cirratulidae	1
E9	*Ophiothrix sp. 3*	1	**P9**	Nereididae	8
M1	*Conus sp.*	2	**W1**	*Phascolosoma sp. 1*	14
M3	*Cerithium sp. 1*	3	**W3**	*Adenoplana sp. 1*	7
M4	Nudibranchia	3	**W4**	*Stylochus sp. 1*	11
			W5	Stylochidae	5
			W6	*Adenoplana sp. 2*	1
			W8	Discocelidae	3

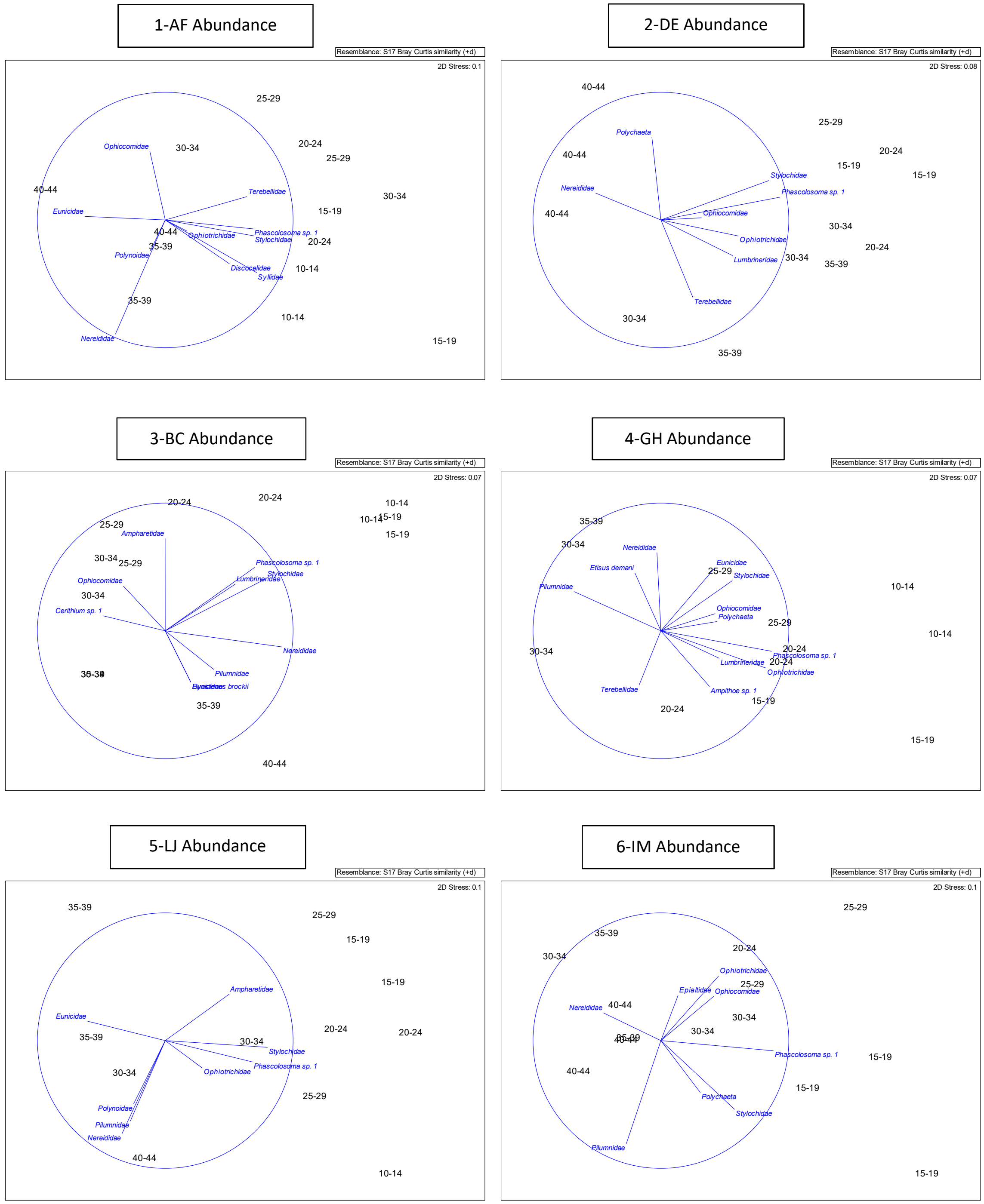
Supplementary Table 11 *Diversity Data*

Diversity Data

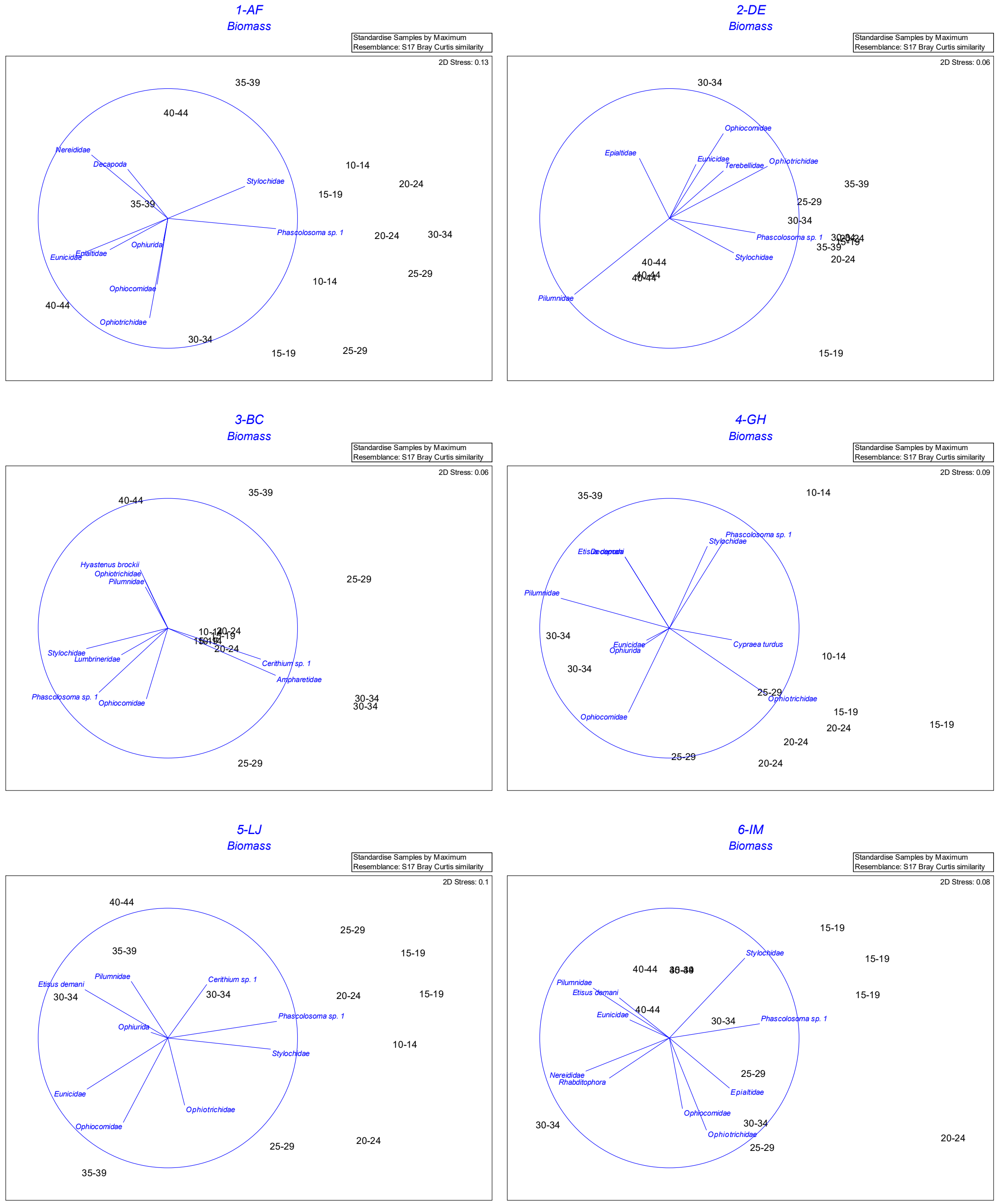
Site	Depth	SiteDepth	sample	S	N	d	J'
1-AF	10-14	1-AF10-14	1-AF-12	9	35	2.25013	0.92266
1-AF	10-14	1-AF10-14	1-AF-14	12	60	2.68663	0.90211
1-AF	15-19	1-AF15-19	1-AF-16	12	124	2.28202	0.47249
1-AF	15-19	1-AF15-19	1-AF-18	10	22	2.91164	0.85654
1-AF	20-24	1-AF20-24	1-AF-20	10	37	2.49244	0.81268
1-AF	20-24	1-AF20-24	1-AF-23	6	8	2.40449	0.96713
1-AF	25-29	1-AF25-29	1-AF-26	4	9	1.36536	0.87636
1-AF	25-29	1-AF25-29	1-AF-28	5	11	1.66813	0.96096
1-AF	30-34	1-AF30-34	1-AF-30	6	22	1.61758	0.81008
1-AF	30-34	1-AF30-34	1-AF-32	5	7	2.05559	0.96296
1-AF	35-39	1-AF35-39	1-AF-35	4	10	1.30288	0.78548
1-AF	35-39	1-AF35-39	1-AF-39	2	4	0.72135	0.81128
1-AF	40-44	1-AF40-44	1-AF-41	2	3	0.91024	0.9183
1-AF	40-44	1-AF40-44	1-AF-43	4	20	1.00142	0.51096
2-DE	15-19	2-DE15-19	2-DE-16	16	54	3.76036	0.88035
2-DE	15-19	2-DE15-19	2-DE-18	5	38	1.09963	0.88144
2-DE	20-24	2-DE20-24	2-DE-20	5	44	1.05703	0.82938
2-DE	20-24	2-DE20-24	2-DE-22	13	68	2.84393	0.79055
2-DE	25-29	2-DE25-29	2-DE-26	10	72	2.10444	0.78397
2-DE	30-34	2-DE30-34	2-DE-30	8	49	1.79864	0.8097
2-DE	30-34	2-DE30-34	2-DE-32	8	39	1.91071	0.84258
2-DE	30-34	2-DE30-34	2-DE-34	6	7	2.56949	0.9755
2-DE	35-39	2-DE35-39	2-DE-36	5	11	1.66813	0.80435
2-DE	35-39	2-DE35-39	2-DE-38	12	63	2.65499	0.80085
2-DE	40-44	2-DE40-44	2-DE-40	2	3	0.91024	0.9183
2-DE	40-44	2-DE40-44	2-DE-42	5	18	1.38391	0.91948
2-DE	40-44	2-DE40-44	2-DE-44	5	14	1.51569	0.70058
3-BC	10-14	3-BC10-14	3-BC-12	9	66	1.90947	0.75031
3-BC	10-14	3-BC10-14	3-BC-14	9	49	2.05559	0.65597
3-BC	15-19	3-BC15-19	3-BC-16	6	37	1.38469	0.82663
3-BC	15-19	3-BC15-19	3-BC-18	7	63	1.44818	0.63397
3-BC	20-24	3-BC20-24	3-BC-22	8	16	2.52472	0.88521
3-BC	20-24	3-BC20-24	3-BC-24	5	7	2.05559	0.96296
3-BC	25-29	3-BC25-29	3-BC-26	3	4	1.4427	0.94639
3-BC	25-29	3-BC25-29	3-BC-28	2	5	0.62133	0.72193
3-BC	30-34	3-BC30-34	3-BC-30	2	3	0.91024	0.9183

3-BC	30-34	3-BC30-34	3-BC-32	2	4	0.72135	0.81128
3-BC	35-39	3-BC35-39	3-BC-36	4	4	2.16404	1
3-BC	40-44	3-BC40-44	3-BC-40	4	7	1.5417	0.92119
4-GH	10-14	4-GH10-14	4-GH-10	15	186	2.67904	0.73267
4-GH	10-14	4-GH10-14	4-GH-14	11	73	2.33075	0.62361
4-GH	15-19	4-GH15-19	4-GH-16	10	124	1.86711	0.66395
4-GH	15-19	4-GH15-19	4-GH-18	6	24	1.57329	0.82009
4-GH	20-24	4-GH20-24	4-GH-20	6	33	1.43	0.80624
4-GH	20-24	4-GH20-24	4-GH-22	5	33	1.144	0.75808
4-GH	20-24	4-GH20-24	4-GH-24	5	11	1.66813	0.87874
4-GH	25-29	4-GH25-29	4-GH-26	6	28	1.50051	0.9152
4-GH	25-29	4-GH25-29	4-GH-28	6	18	1.72988	0.81448
4-GH	30-34	4-GH30-34	4-GH-30	2	2	1.4427	1
4-GH	30-34	4-GH30-34	4-GH-32	4	12	1.20729	0.70915
4-GH	35-39	4-GH35-39	4-GH-36	6	13	1.94936	0.85096
5-LJ	10-14	5-LJ10-14	5-LJ-13	13	117	2.51986	0.66354
5-LJ	15-19	5-LJ15-19	5-LJ-17	5	15	1.47708	0.96138
5-LJ	15-19	5-LJ15-19	5-LJ-19	4	8	1.4427	0.875
5-LJ	20-24	5-LJ20-24	5-LJ-21	6	27	1.51707	0.88599
5-LJ	20-24	5-LJ20-24	5-LJ-23	8	31	2.03845	0.76846
5-LJ	25-29	5-LJ25-29	5-LJ-25	5	18	1.38391	0.84817
5-LJ	25-29	5-LJ25-29	5-LJ-27	6	44	1.32129	0.82077
5-LJ	30-34	5-LJ30-34	5-LJ-32	11	32	2.88539	0.92215
5-LJ	30-34	5-LJ30-34	5-LJ-34	7	11	2.50219	0.90845
5-LJ	35-39	5-LJ35-39	5-LJ-36	3	13	0.77974	0.84209
5-LJ	35-39	5-LJ35-39	5-LJ-39	5	7	2.05559	0.91652
5-LJ	40-44	5-LJ40-44	5-LJ-42	4	19	1.01887	0.7644
6-IM	15-19	6-IM15-19	6-IM-15	6	19	1.69812	0.7887
6-IM	15-19	6-IM15-19	6-IM-17	8	135	1.42704	0.45278
6-IM	15-19	6-IM15-19	6-IM-19	6	32	1.4427	0.78963
6-IM	20-24	6-IM20-24	6-IM-23	3	5	1.24267	0.86497
6-IM	25-29	6-IM25-29	6-IM-27	5	11	1.66813	0.87874
6-IM	25-29	6-IM25-29	6-IM-29	5	40	1.08434	0.72207
6-IM	30-34	6-IM30-34	6-IM-31	6	11	2.08516	0.88972
6-IM	30-34	6-IM30-34	6-IM-32	6	8	2.40449	0.93063
6-IM	30-34	6-IM30-34	6-IM-34	2	5	0.62133	0.72193
6-IM	35-39	6-IM35-39	6-IM-38	1	2	0	
6-IM	40-44	6-IM40-44	6-IM-40	2	2	1.4427	1
6-IM	40-44	6-IM40-44	6-IM-42	1	3	0	
6-IM	40-44	6-IM40-44	6-IM-44	5	13	1.55948	0.78513

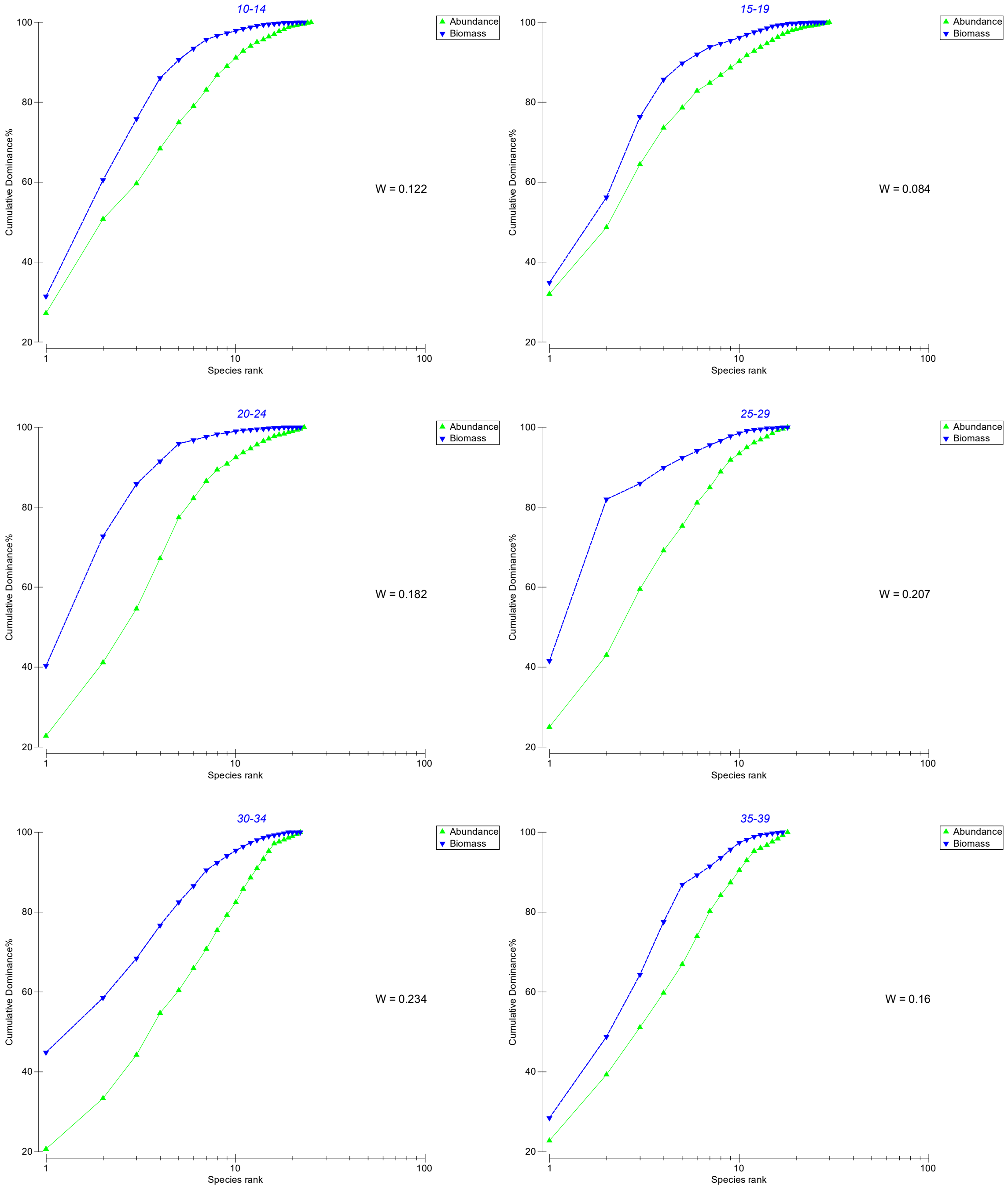
Appendix B – Supplementary Figures



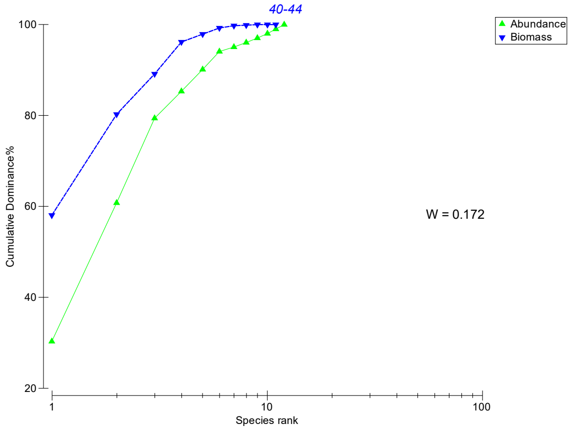
Supplementary Figure 1 Non-metric Multi-dimensional scaling (nMDS) ordination of the sampling units i.e. artificial plates based on Bray-Curtis dissimilarities of all the mobile assemblages in terms of abundance classified by depths in sites 1-AF to 6-IM



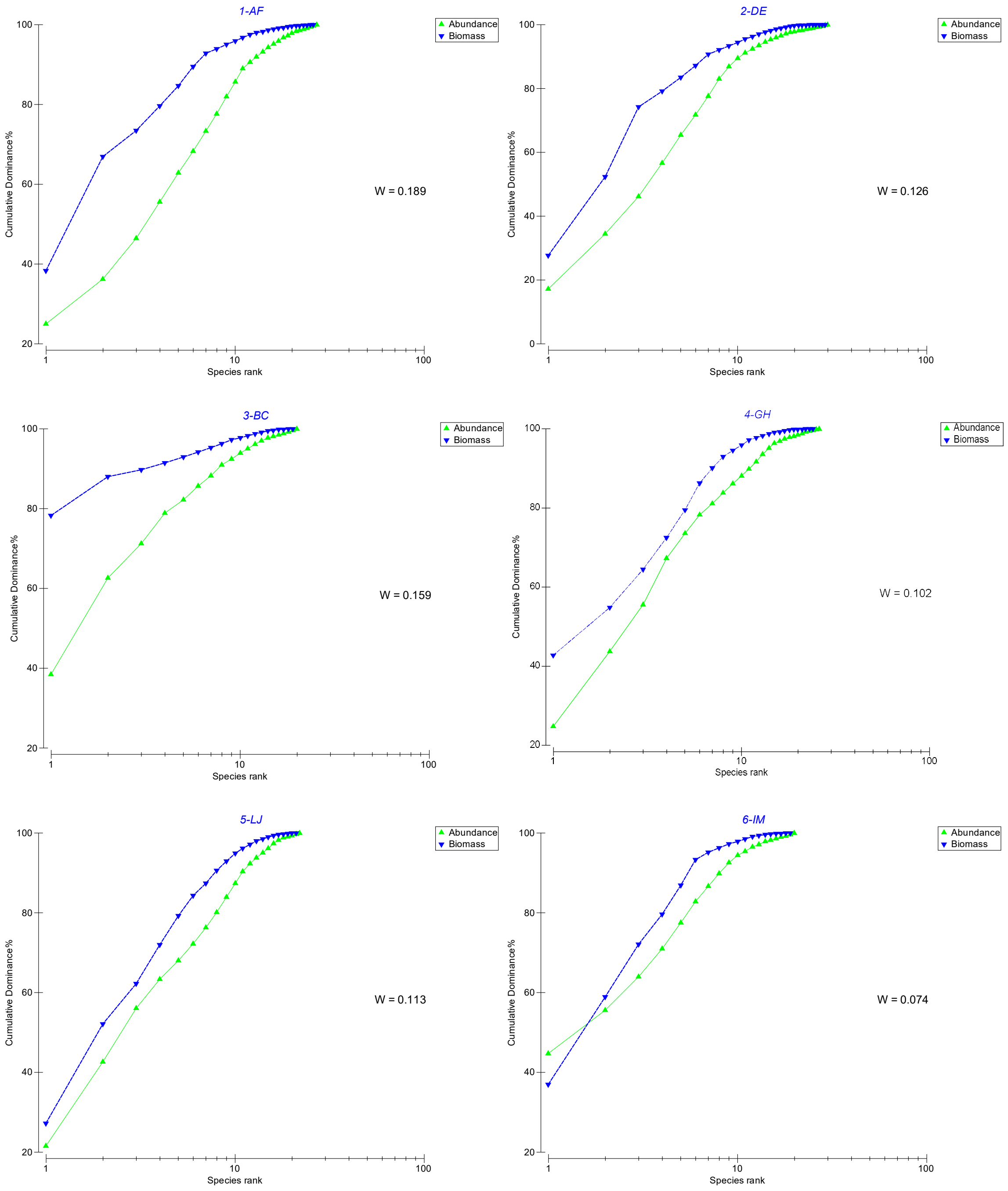
Supplementary Figure 2 Non-metric Multi-dimensional scaling (nMDS) ordination of the sampling units i.e. artificial plates based on Bray-Curtis dissimilarities of all the mobile assemblages in terms of biomass classified by depths in site 1-AF to 6-IM



Supplementary Figure 3 ABC Curve for Depths 10-14 to 30-39 m

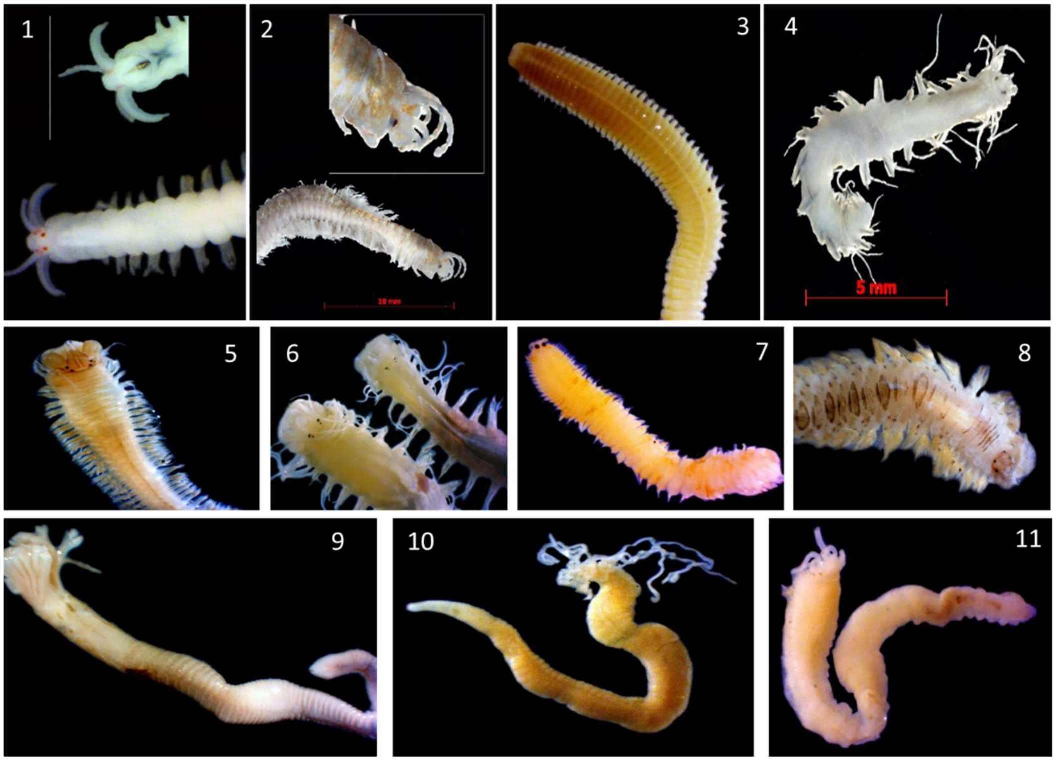


Supplementary Figure 4 ABC Curve for Depths 40-44 m



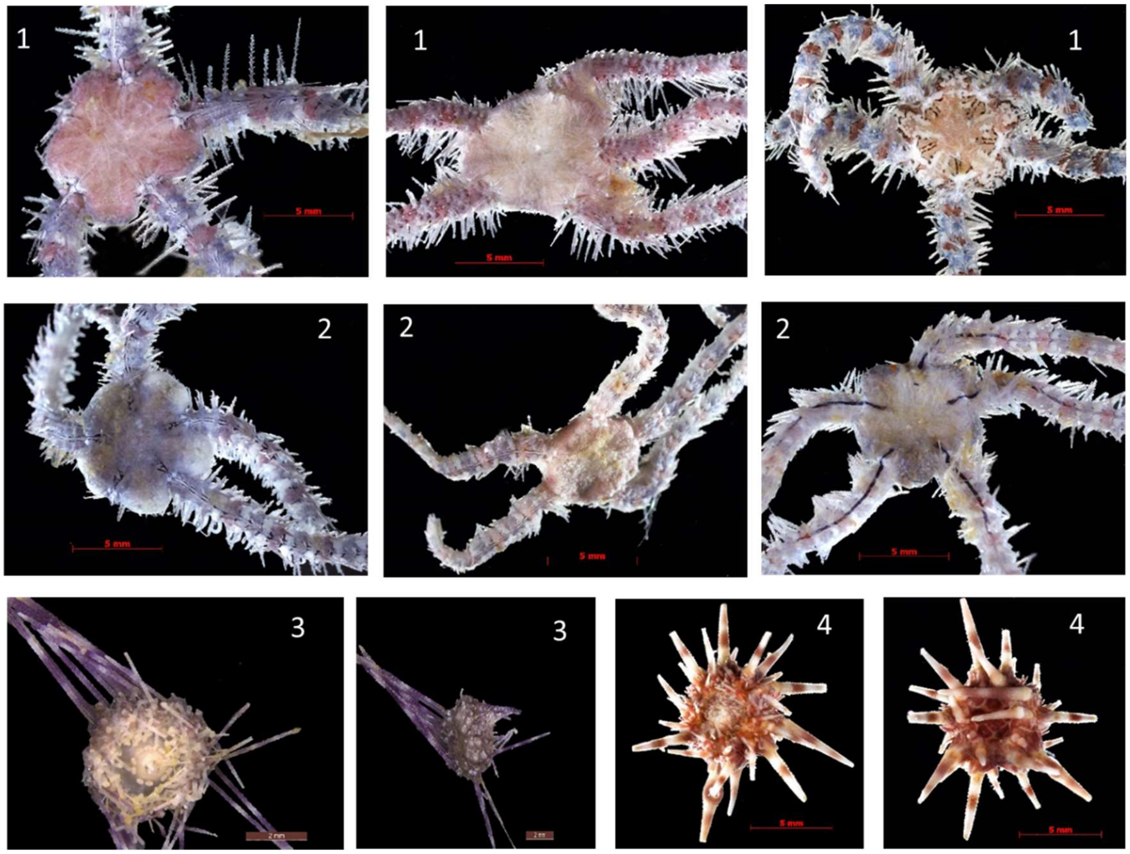
Supplementary Figure 5 ABC Curve Sites 1-AF to 6-IM

Appendix C – Reference Pictures

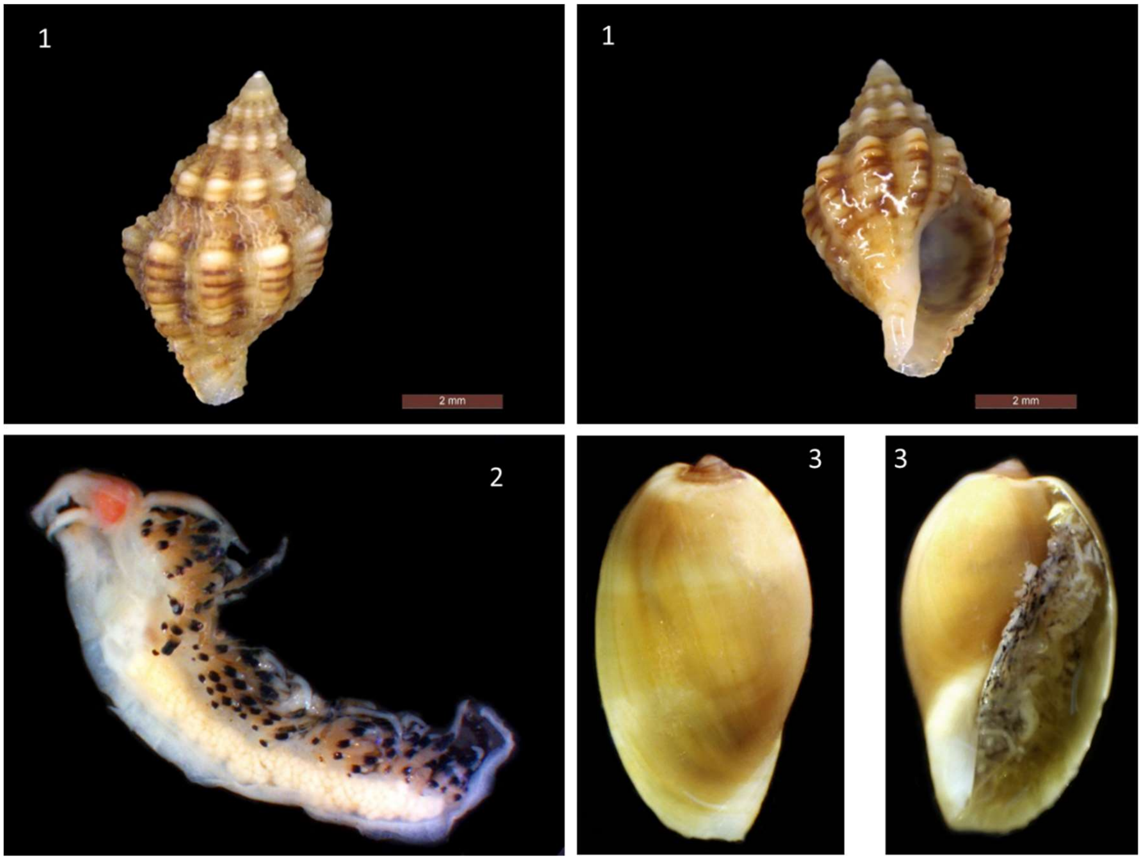


Supplementary Figure 6 Polychaetes: Dorvilleidae *(1),* Eunicidae *(2),* Lumbrineridae *(3),* Syllidae *(4),* Nereididae *(5),* Hesionidae *(6),* Phyllodocidae *(7),* Polynoidae *(8),* Sabellidae *(9),* Terebellidae *(10)* & Ampharetidae *(11)*

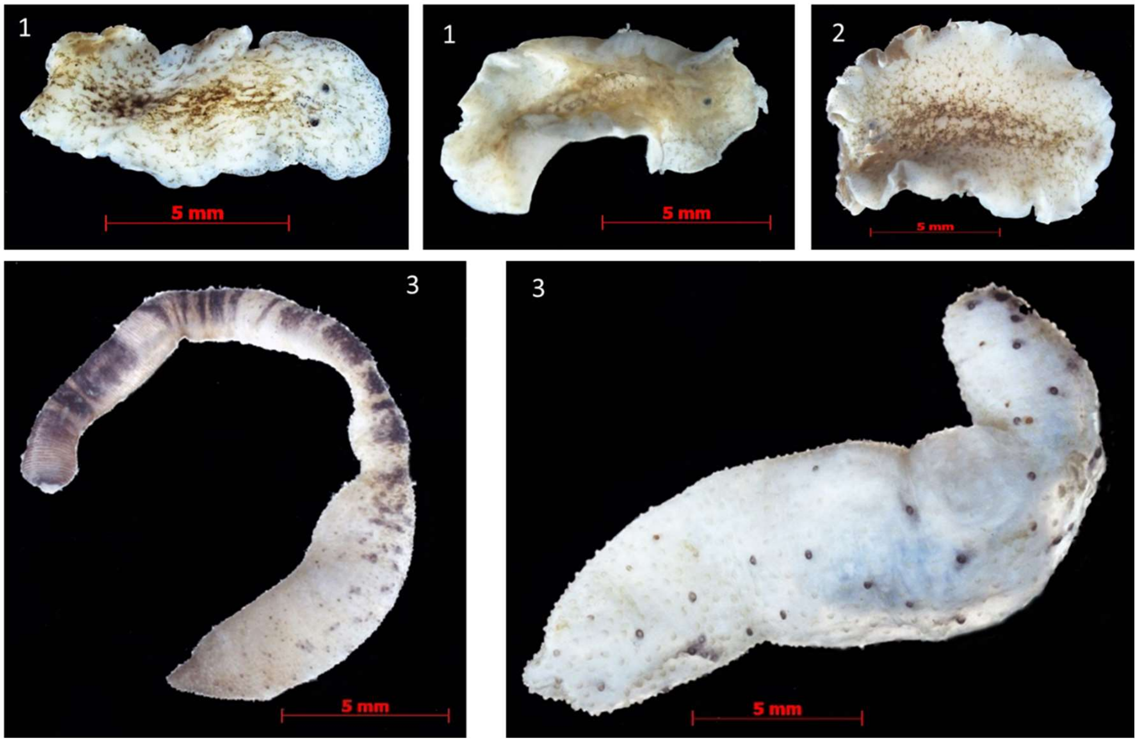
Supplementary Figure 7 Crustaceans: Ampithoe sp. 1 *(1), Galathea* sp. 1 *(2), Thalamita* sp. *(3),* Pilumnidae *(4), Etisus demani (5) & Pachycheles* sp. 1 *(6)*



Supplementary Figure 8 Ophiuroids: Ophiotrichidae *(1),* Ophiocomidae *(2) & Echinoderms: Salmacis* sp.1 *(3), Echinothrix* sp. 1 juvenile *(4)*



Supplementary Figure 9 Gastropods: Cerithium sp. 1 *(1),* Nudibranchia *(2) & Conus* sp. *(3)*



Supplementary Figure 10 Polyclads and Sipunculid: Discocelidae *(1),* Stylochidae *(2) &* *Phascolosoma* sp. 1 *(3)*