QATAR UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

INVESTIGATION OF TEMPORAL VARIABILITY OF CORALS REVEALED BY ROV VIDEOS AT OIL PLATFORMS IN THE ARABIAN GULF.

BY

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ABSTRACT

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Title: Investigation of Temporal Variability of Corals Revealed by ROV Videos at Oil Platforms in the Arabian Gulf.

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The study was conducted at AL-Shaheen oil field within the Arabian Gulf using remotely operated vehicle (ROV) footages in different oil platforms to investigate the impact of platform depth, age, and weight on coral relative cover. The ROV survey implemented in this study signifies the first assessment of soft and hard coral assemblages on AL-Shaheen oil field. For data analysis a generalized linear model (GLM) was implemented within the R programming to describe the relationship between coral cover and the response variables. In this assessment one hard coral species was recorded in Qatari water for the first time. The implemented ROV showed a considerable soft and hard coral cover among different platforms. Corals relative cover was significantly affected by the platform age, depth, and weight. Therefore, platforms with older age and heavier weight should be considered as priority for rig to reef (RTR) approach.

DEDICATION

For my loving family

For coral reefs of the world

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: INTRODUCTION

Coral reefs are considered as one of the most diverse and productive ecosystems on earth and one of the marine ecosystems that support the greatest biodiversity of marine species, estimated to one million of marine species (Fisher et al., 2015), with a significant ecological and economical values (Costanza et al., 2014). They account for only 0.1% of the oceans seafloor, however they provide habitat for around 25% of all marine species such as fish, crustaceans, mollusks, etc. (Titlyanov et al., 2016).

The health of coral reef ecosystems can be inferred through the study of fishes and macroinvertebrates that rely on coral reefs for either food or shelter (Brandl et al., 2019). Various factors could threaten corals worldwide, and particularly in the Arabian Gulf region, including ocean warming, ocean acidification, pollution, fishing, and other anthropogenic activities (Hughes et al., 2017). Accordingly, the recurrent habitat destruction and natural reef loss resulting from bleaching events and coastal reclamation projects, derive the relevance of the existence of artificial substrates for coral recruitment and expansion. Correspondingly, oil and gas offshore platforms in the Gulf, beyond their primary function which is oil and gas production, support various marine species through the provision of hard substratum for species recruitment along the water column (Torquato et al., 2017; 2021).

Studying biodiversity associated with offshore operating oil platforms is a challenging task due to safety and logistical limitations. Regular examination and monitoring surveys using Remotely Operated Vehicles (ROV) are routinely conducted to inspect the integrity and state of the submerged installation units. ROVs have been utilized as an effective technique for biodiversity surveys to investigate and study the organisms inhabiting the region. Implementing this technique allow the researcher to inspect and study large area at all depths (Torquato et al., 2017; 2021; Thomson et al., 2018).

Several platforms are ment to reach their end life and ultimately to be decommissioned in the upcoming years. And when it is no longer in the use, they usually remove the entire submerged structure which results in the loss of valuable ecosystems. Few countries have considerd to convert these platforms into artificial reefs and this is what know as rig to reef programs. To decide about the platform fate, wheather it should be removed or kept in the site as an artifical reefs it is important first to invistigate the biodiversity associated with these platfroms. This option could be relevant in the arabian gulf since 85% of coral reefs in the gulf are threatened (Burke et al., 2011). Therefore, oil and gas platforms as an artificial reef could be a promising way to mitigate the loss in the region.

In our study new hard coral was recorded in Qatari water for the first time (*Cladopsammia spp*). This species was identified according to its morphological characteristics using its micro structure.

Our investigation will provide new data on the environmental importance of oil and gas platforms as artificial reefs in Alshaheen Oil field in the Arabian Gulf. Moreover, it will help the process of making decision whether specific platforms should be kept in the site as an artificial reef or removed after it is being decommissioned. The general aim of this graduate research project is to understand the contribution of oil platforms in providing a substrate to soft and hard corals to thrive and how platform features (such as, age, depth, function, etc.) impact their distribution and abundance.

The specific objectives are:

- To study the temporal and vertical dynamics of corals relative cover on offshore oil platforms.

- To investigate the spatial distribution of deep-water hard corals among different platforms within Al Shaheen oilfield.
- To compare between hard corals and soft corals cover and distribution as oil platforms ages.

Chapter 2: REVIEW OF THE LITERATURE

Hard coral Vs. soft corals

Scleractinian corals, also called hard corals (Hamel et al., 2020), develop a solid skeleton built from calcium carbonate named as aragonite that is created in crystal arrangement. They are considered as primary reef creator and could be, or not, light-dependent, depending on their energy source and existence inside their polyps of zooxanthellae, a symbiotic photosynthetic microalgae. Zooxanthellate corals will be found at shallower depths while azooxanthellate counterparts will extend up to 1500m depths. Deep-sea corals represents almost half of the extant Scleractinia species (Cairns, 2007) and establish a vital habitat that support valuable biodiversity (Buhl-Mortensen et al., 2010). Those deep-water corals could be greatly disturbed (Roberts, 2002) due to their slow growth and their tree like morphology (Neves et al., 2015). In fact, there is limited data on sexual and asexual reproduction of deep-sea corals (Hamel et al., 2020).

Soft corals are recognized as Alcyonacea (Larkin et al., 2021) and do not develop a solid calcium carbonate structure, as they are primarily composed of soft colonial tissues. They are present in marine ecosystems worldwide and classified as sessile benthic organisms that mostly reproduce via asexual clonal propagation (Fabricius, 2011). Soft corals are classified in two categories azooxanthellate, and zooxanthellate (Larkin et al., 2021). This classification is built on their energy source and food consumption. Zooxanthellate has a symbiotic algae that relies on photosynthesis as an energy source. Therefore, this type of soft corals is light dependent and restricted to shallow water (Larkin et al., 2021). However, azooxanthellate soft corals depends completely on food acquisition from the surrounding environment as an energy source, consequently present at higher depths. (Grossowicz and Benayahu, 2015).

Artificial reefs

Artificial reefs are defined as submerged structures to simulating some features of the natural reefs, such that in addition to be considered important habitat for marine species, they also provide several advantages to the ecosystem including restoring the degraded communities' reefs, offering food and enrich the benthic community's biomass (Baine, 2001). Nowadays, manmade structures in the marine environment are considered important habitat for sessile marine species (Bishop et al., 2017). The impact of the artificial reefs is not only restricted in changing species distribution and composition but also the functioning of entire ecosystems (Ponti et al., 2015). Nevertheless, several studies have concluded that the artificial structures are not the ideal alternative of natural habitats, and this is attributable to the negative impacts of these structures on marine biodiversity (e.g. Jagerroos and Krause, 2016). For instance, the community and the biodiversity of the recruited species can largely differ from the surrounding natural habitats (Sanabria-Fernández et al., 2018).

In the Arabian Gulf, artificial habitats have been deployed using various materials, including wood and stones (Burt et al., 2012). The primary aim of the use of these artificial structures was to enhance the fish catch (Stone et al., 1991), and to restore degraded habitats (Seaman, 2007). In the Arabian Gulf, deployment of artificial structures is a common methodology, associated mainly to compensation measures when mitigation of coastal habitat destruction is not possible or satisfactory following coastal development projects. These actions are believed to improve the diversity of fish and other marine invertebrates (Burt et al., 2009).

The Arabian Gulf Oil Fields

It is oil wealth that largely determines the geopolitical position of the Arabian Gulf zone on the map of Asia and the world, as a whole. At present, the Arabian Gulf is the richest oil-bearing region in the world, with more than 44% of all the world's proven oil reserves (which is 60% of the oil reserves of the OPEC countries) and about 30% of natural gas (Issa & Vempatti, 2018). The most significant proven oil reserves are in Saudi Arabia, which ranks 1st in the world.

The Arabian Gulf basin stands out in the world not only for the number of giant fields, but also for the quality of oil (mainly light and low-sulfur), as well as for the size of the oil wells flow rate (Sadeghi, 2007). Their average productivity in Saudi Arabia, Iran, Iraq, Kuwait is 800 tons per day, while the average for the world is only 3 tons. At the Gavar and Burgan fields in Kuwait, the average daily well production rate is 700-800 tons, and in some cases reaches 1500-2000 tons (Sparks, 2007). But the world record holder in this respect is the Agha-Jari field in Iran, where many wells produce 3-5 thousand tons, some even up to 10 thousand tons per day (Speight, 2015).

Qatar’s Oil fields

Proved oil reserves in Qatar amount to about 2.8 billion tons (2% of world reserves). Most of these deposits are concentrated within the continental fields, the largest of which is Dukhan. Major offshore fields include: Idd al-Shargi North Dome, Bul Hanine, Maydan Mahzam, al-Shaheen, al-Rayyan and al-Khalij (Speight, 2015). The central position in the hydrocarbon industry of Qatar's economy is held by the state-owned company Qatar Energy (QE), previously denominated Qatar Petroleum (QP), which is responsible for all operations with oil and gas, including prospecting, production, processing, storage, and transportation of raw materials (Speight, 2015). The company is also responsible for the marketing of fuels and refined products in the domestic and foreign markets.

Oil and gas platforms as artificial reefs

All over the world's oceans, offshore oil and gas platforms are established chiefly over the continental shelves. These offshore structures, beyond the actual aim of oil and gas production, have significant ecological function for several marine species (Friedlander et al., 2014). These platforms constitute a habitat for various marine species such as fishes and sessile invertebrates. They offer the sessile species including corals and sponges with hard substrate that support their recruitment and growth. Moreover, they provide shelters and/or feeding ground for other marine creatures such as fish and megafauna, including whales (Todd et al., 2016). When platforms are fixed, the occurrence of an associated biological community arises rapidly, with fish coming within hours (Bohnsack, 1989), and within five to six years the ecological succession results in a climax community, with a complex reef-type habitat (Driessen, 1986). Nevertheless, these hard substrates that are provided by the offshore platforms can similarly offer invasive species a habitat (Pajuelo et al., 2016). Even though their principal objective is not associated to enhance the marine biodiversity, these units have been demonstrated to enrich the ecosystem components and functions (Torquato et al., 2017; 2021).

There are thousands of offshore oil and gas platforms spread across the seas, contributing to around one third of the extracted oil and gas worldwide (World Ocean Review, 2014). Although they are not primarily planned to enhance the biodiversity of the marine environment, they gradually develop into ecologically valuable artificial reefs that support various marine species and productivity (Torquato et al., 2017; Thomson et al., 2018). Indeed, these offshore platforms, and their combined marine life, change the local environment from the previous state that existed prior to the platform establishment. In these situations, a novel ecosystem has appeared with potentially considerable ecological importance.

Worldwide, several platforms are meant to reach their end of life and ultimately to be decommissioned in the upcoming years (Fowler et al., 2018). When a platform is no longer in use, it is decommissioned, which usually entails removing the entire submerged structure from the water, destroying the artificial reef that has been evolving and potentially resulting in the loss of valuable ecosystem services (Verbeek, 2013). Alternatively, few countries considered to convert these platforms into artificial reefs (i.e., Rigs-to-Reefs – RTR approach), though numerous stakeholders are still reticent towards the adoption and implementation of RTR programs (Fowler et al., 2018).

To decide about offshore platforms decommissioning, the biodiversity established on the platforms should be studied and compared with the natural habitats in the surroundings, thus recognizing the actual importance of these artificial habitats, concerning the local and regional marine biodiversity and productivity (Verbeek, 2013).

Since the 1950s, the installation of oil and gas offshore platforms started in the Arabian Gulf, and more than 800 platforms have been operating since then (Sheppard et al., 2010). These platforms' vertical structure provides substrate to the sessile organisms to be settled at appropriate depths and at distinct lifespan. While a significant portion of these platforms is approaching the end of their respective production lifetime, they consequently constitute a great source of RTR materials via reefing the existing platforms. However, the biological community occupying these artificial habitats is mostly unstudied, making it uncertain whether these platform jackets must be removed during decommissioning or kept in the site as artificial reefs. This option is particularly relevant in the Arabian Gulf due to the loss of natural reefs throughout the previous decades, attributable to ocean warming, leading to coral bleaching, and other anthropogenic activities. According to Burke et al. (2011), more than 85% of the corals in the region are threatened. Thus, the artificial habitats including platforms are considered a promising way to substitute the loss of coral reefs in the Gulf region.

Types of oil and gas platforms

The total area of the oil and gas fields of the Arabian Gulf is nearly 1.5 million square kilometers (Beadnall & Moore, 2021). The first Arabian Gulf oil field was discovered in 1908, and gas field in 1965. At present, almost 300 oil and natural gas fields with reserves ranging from 100 million to 10 billion tons have been identified in the basin (Beadnall & Moore, 2021). Offshore oil and natural gas production in the Arabian Gulf is currently dominating in countries such as Saudi Arabia, United Arab Emirates, Kuwait and others (Brki, 2021). Most of the offshore fields in the Gulf are exploited using fixed (template-type) platforms (Ben-Hamadou et al., 2022). Fixed platforms are made with steel (sometimes concrete) supports attached to the bottom, an oil rig, along with a subsurface production, drilling and when applicable, accommodation modules (Kharade & Kapadiya, 2014). Such platforms are installed for long production times at a depth of 14 to 500 meters. Support piles of stationary platforms are driven into the bottom and concreted (Kharade & Kapadiya, 2014). Other offshore structures, commonly found in the Arabian Gulf and in Qatari waters, are drilling jackup platforms/rigs (a kind of a drilling barges with steel legs lowered until they rest on the sea bottom) and Floating Storage and Offloading (FSO) platforms (ship-shaped platforms with a steel hull structures secured to the seabed via a variety of mooring systems).

Coral reefs in the Arabian Gulf

The Arabian Gulf is a semi closed distinctive marine environment with a severe values of water temperatures that ranges from 11.4 in winter to 36.2 °C in summer (Lin et al., 2021). The average depth of this subtropical shallow water is 35 meters. Various habitats including seagrasses, oyster beds, coral reefs, algal bed and non-accreting coral communities are found on the sedimentary seabed in Arabian Gulf (western region) (Sheppard et al., 2010).

Coral reefs ecosystems are communities of distinct species that interact with their surrounding environment. The abundance of organisms associated with coral reefs are primarily determined by availability of food, space, and light. Corals in the Arabian Gulf considered to be persistent to the severe temperature and salinity that could negatively impact corals in elsewhere locations (Bauman et al., 2014). Corals in the Arabian Gulf have been deteriorated by various anthropogenic and natural stressors (Lin et al., 2021), including one of the greatest oil spills in history in 1991 resulting from the Gulf War (Downing and Roberts, 1993). These anthropogenic disturbances motivated numerous coastal reclamation projects (Burt et al., 2011). Additionally, coral reefs have experienced various bleaching events in 1996, 1998, 2010 and 2016/17 (Burt et al., 2019), contributing to a severe decline of the coral cover in the region (Krishnakumar and Lindo, 2019) and particularly in the Qatar coastal zone (Bouwmeester et al., 2022).

Coral recruits on oil and gas platforms

Zooxanthellate corals' vertical distribution is limited by sunlight penetration. Light is the main energy source to derive photosynthesis of the symbiotic zooxanthellae, a microalga that grows inside corals. Limestone basis is the main hard substratum for coral growth. Moreover, underwater rocks and stones are solid substrata that are occupied by hermatypic corals forming coral reefs. Furthermore, corals can colonize artificial substrate including oil and gas platforms and other underwater manmade structures (Titlyanov et al., 2016).

Prior to the expansion of platforms installation, hard substrates were limited especially in deep waters where light penetration is low limiting the occurrence of photosynthetic and light – dependent encrusting and sessile organisms. These man-made structures offer extensive areas as artificial reefs, providing suitable substrates, from the seabed up to the surface, in poorly biodiverse marine regions. Coral is a sessile epibenthic organism that manage to colonize different region through larval dispersal (Sammarco, 2013). Oil and gas platforms are typically isolated by several kilometers from surrounding coral reefs. These neighboring natural reefs could serve as coral larvae source. There are two major modes of sexual reproduction of corals, the first is by brooding and the second through broadcast spawning (Sammarco, 2013). Brooders involves internal fertilization of eggs and sperm that results in developing planula larvae, this type of fertilization involves higher tendency of reef self-seeding. While the broadcast spawners involve release of both male and female gametes into the water with an external fertilization and larvae stay for longer period in the plankton and this type of fertilization typically leads to a wider dispersal, with lower chance of self-seeding.

Impacts of oil and gas

Oil and gas exploration and production govern a fundamental role in improving the economic sector of a country, therefore it is considered as one of the activities that enhances significantly the economic growth. On the other hand, oil and gas activities have various serious environmental consequences, particularly on the marine environment. Indeed, the offshore and coastal activities associated with oil and gas industry trigger a variety of physical, chemical and biological stressors on marine ecosystems (Legrenzi & Lawson, 2017).

The severity of these impacts and their spatial and temporal scale will greatly vary depending on the intensity of the disturbance, the level of exposure and vulnerability of the ecosystems (Singh, 1983). Impacts are therefore characterized as acute or chronic, with for instance, accidental oil spills or sediment dredging during construction work on the seabed are acute stress situations (Aldosari, 2019). They are characterized by a sudden onset and a sharp rise in the intensity of exposure, followed by a more or less rapid decline (Johnson et al., 2018). While accumulation of oil hydrocarbons in bottom sediments in areas of systematic discharge from platforms of drilling and field work waste, are considered a situation of chronic stress (Difiglio, 2014). Despite the fact that oil and gas production brings great benefits to mankind, its implementation through extraction, transportation, processing and use brings serious environmental consequences (Hvidt, 2011).

The drilling activities of oil and gas could directly or indirectly influence the marine ecosystem at each stage of either oil and gas exploration, production or decommissioning. Oil drilling wastewater and crude oils contain a variety of pollutants, ranges from trace metals to diverse amounts of polycyclic aromatic hydrocarbons (PAHs), alkanes, mono-aromatic chemicals and phenols with toxic implications (Schifter et al., 2015). Trace metals often form a major pollutant of the offshore oil explorations as it is produced in considerably high quantities during the drilling processes.

Trace metals are poisonous and cannot be degraded by microorganisms, these toxic constituents can build up in the marine environment (Ghani, 2015). As a result of their existence in crude oil and sediments around oil and gas production areas, they have arisen as a potential hazard to the organisms in the surrounding habitats, besides the risk posed by the oil and gas wells themselves. Production and exploration processes of oil and gas have been conducted in the offshore regions of more than half of the world's countries (Speight, 2014), and these processes have been found to have significant socio-ecological consequences on the surrounding marine environment. It has also been confirmed that continuous discharge of various chemicals related with oil and gas production processes have substantial ecological influences. Over the last few decades, many studies have examined the effects of oil and gas exploration activities on marine ecosystems (Bakke et al., 2013). The adverse consequences of these exploration activities derived notable management practices to conserve the environment.

Chapter 3: RESEARCH METHODOLOGY

Study Site

The study was conducted at the Al Shaheen oil field, within the Arabian Gulf, which is an area of oil and gas production works of North Oil Company (NOC) known as block 5. Located in the north of Qatar exclusive economic zone (EEZ), the area is located about 90 kilometers offshore from the Qatari coast (Figure 1). The first discovery of AL-Shaheen oil field was in the mid-70s (Thomasen et al., 2005), though production from the field commenced only in 1992 including the world's longest horizontal well (Hoch et al. 2010). In 2010, the Al Shaheen field was producing 300,000 barrels of oil per day and exceeded 1 billion barrels (Hoch et al. 2010). Currently, 33 platforms for oil and gas production are encompassed in Al Shaheen oil field within 9 locations (A-I) as illustrated in Figure 1. These platforms vary based on platform age of installation, height and platform function as illustrated in Figure 3.

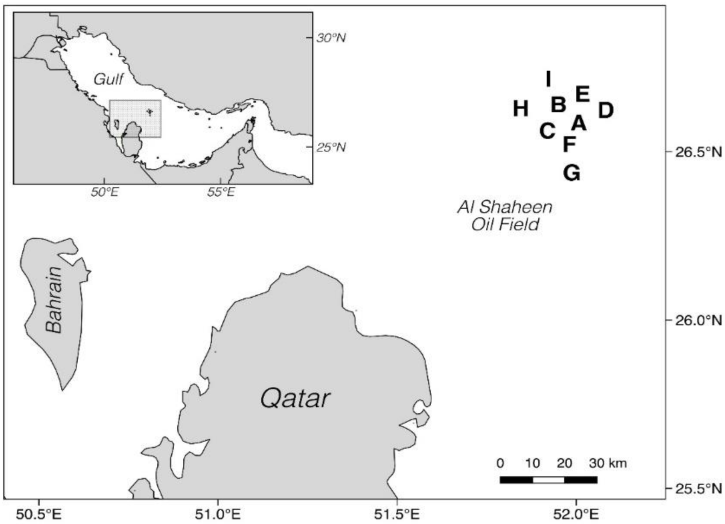

Figure 1. Map of the study area presenting the locations of oil platforms at Block 5.

Al-Shaheen Oil Fields

In the mid-seventies, the oil reservoir at AL-Shaheen oil field, block 5 was discovered (Thomasen et al., 2005). In 1992, Qatar petroleum and Maersk oil Qatar AS held an agreement for exploration and production (Thomasen et al., 2005). In 1994 AL-

Shaheen oil field started the production of oil (*Al-Shaheen - North Oil Company*, 1994). The field is located off the northeast coast of the country. It is considered as one of the greatest oil fields in the world. And located north of Ras Laffan 80 Km inside the Qatari waters. There are more than 300 wells and 33 platforms in this field (*Al-Shaheen - North Oil Company*, 1994).

With regard to the Al-Shaheen field specifically, in 2017 oilmen produced here 300 thousand barrels of oil per day (*Al-Shaheen - North Oil Company*, 1994). Qatar produced 670 thousand barrels of oil daily. Thus, this field alone covers almost 45% of all oil production in the country (*Al-Shaheen - North Oil Company*, 1994). The well is 12,290 meters long, making it the longest in the world until 2011.

Note that Qatar is the largest exporter of liquefied gas in the world. The country sells large quantities of oil and petroleum products. The export proceeds of these products provide a significant portion of government revenues. So, according to the National Bank of Qatar, over the past five years, funds from the hydrocarbon sector provide 60% of the state budget.

Remotely operated vehicle (ROV)

Oil and gas platforms are restricted locations within the marine domain with a prohibited region of a minimum of 500 m around the platforms (Kashubsky & Morrison, 2013). Terrorism or insider threats are not the only risks that threaten the security of this zone but also the recreational activities and commercial shipping and fishing. Traditional biological survey approaches such as scuba diving and snorkeling are firmly prohibited in the oil and gas platform exclusion zone. However, routine monitoring and maintenance surveys are regularly performed to examine the condition of submerged structures. These surveys are primarily conducted via video footage filmed by remotely operated vehicle (ROV) (Torquato et al., 2017), that is operated by authorized professionals. ROV-based surveys allow investigators to study broader and deeper zones compared to other monitoring techniques including the conventional scuba diving (Torquato et al., 2017). For example, the ROV technique has been implemented to determine the sessile species distribution and abundance however there are some limitations that could restrict the efficiency of this technique including remoteness, depth and intense currents (Teixidó et al., 2011). Moreover, the use of ROVs have lower impacts on most of fish behaviors (Patterson et al., 2009).

In our study, ROV footages from inspection were opportunistically investigated to survey deep-sea coral relative coverage at Al-Shaheen oilfield with different oil platforms to investigate the impact of platform depth, age, weight, location on soft and hard corals cover.

Video Analysis and sampling design

Since oil and gas platforms are top-security regions, the study area is inaccessible due to Qatar Energy and NOC regulations. The research methodology was opportunistically relied on videos of the ROV's surveillance footage. From the 4510 videos provided by Mærsk Oil Qatar, back in 2015, a total number of 96 videos were selected randomly from 2007 to 2014 to investigate the coverage as ROVs shifts vertically along the platform. Based on previous studies, hard corals were not recorded along upper layers and thus we focused our surveying below 30 meters depth (Torquato et al. 2021). Coral presence and relative cover was determined from the selected videos that encompass platforms with different ages, depths, locations, functions and weight (**Error! Reference source not found.**). To do so, we selected videos where the ROV moved vertically from 30 meters to the sea floor and a screenshot was taken every 1 meter, which represent our sampling unit. Soft coral and hard coral relative cover were estimated using CoralNet by plotting 50 points per screenshot and classified as hard corals, soft corals, other sessile invertebrates, fish, mobile invertebrates, water, transect.

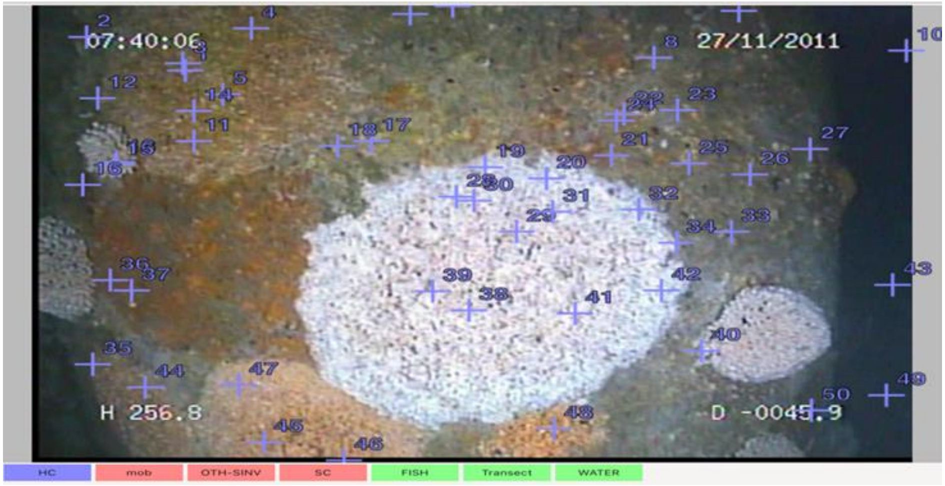

Figure 2. CoralNet screenshot with 50 plotted dots.

Name	Depth (m)	Year of installation	Weight with piles (t)	Platform function	Sampling year 2007	2009	2010	2011	2012	2014
AS-A-C	60·0	1997	774	Flare platform						+
AS-A-D	62·0	1998	2078	Accommodation platform						+
AS-B-A	61·0	1998	3610	Wellhead platform	+	+	+	+		+
AS-B-B	61·0	1997	671	Flare platform						+
AS-B-C	61·0	2004	1098	Accommodation platform				+		+
AS-B-D	61·0	2007	3536	Wellhead platform				+		+
AS-B-E	61·0	2009	8131	Process platform				+		+
AS-B-F	61·0	2009	916	Accommodation platform						+
AS-B-G	61·0	2009	7986	Utility platform				+		+
AS-C-A	56·5	1998	3590	Wellhead platform	+	+		+	+	
AS-C-B	56·5	1997	659	Flare platform					+	
AS-C-C	56·0	2004	1088	Accommodation platform					+	
AS-C-D	56·5	2007	3322	Wellhead platform					+	
AS-D-A	65·0	2004	4610	Wellhead platform						+
AS-D-B	65·0	2004	941	Flare platform						+
AS-E-A	66·5	2004	4474	Wellhead platform						+
AS-E-B	66·5	2004	958	Flare platform						+
AS-E-C	66·5	2004	1101	Accommodation platform						+
AS-E-D	66·5	2009	6061	Process platform						+
AS-E-F	66·5	2009	913	Accommodation platform						+
AS-F-A	55·0	2004	4440	Wellhead platform	+	+	+			+
AS-F-B	55·5	2004	916	Flare platform					+	+
AS-G-A	51·0	2007	3129	Wellhead platform		+				
AS-G-D	50·5	2009	7210	Wellhead–Process platform		+			+	+
AS-H-A	57·0	2007	3407	Wellhead platform					+	
AS-H-B	57·0	2009	NA	Flare platform		+	+			+
AS-I-A	69·5	2007	4139	Wellhead platform						+
AS-G-A	51·0	2007	3129	Wellhead platform		+			+	+

Figure 3. AL-Shaheen oil platforms included in the study (Torquato et al., 2017).

Data Analysis

Generalized linear model

To evaluate the effect of the predictor variables (**Error! Reference source not found.**) on coverage of soft and hard corals on platforms, a Generalized Linear Model (GLM) was used within the R programming platform (R Development Core Team, 2019). GLMs extend Linear Models in the sense that the response variable (i.e., coral coverage) can assume any distribution family (McCullagh & Nelder, 1989). Thus, distributions other than the normal distribution can be used to fit better the data at hand. Given that coral coverage is a proportion and therefore range between a continuous scale from 0 to 1, a Beta distribution with a log-log link function was used. (Ferrari & Cribari-Neto, 2004). In addition, 56% of the data was zero, and therefore a zero-inflated analysis was required. To do so, the *gamlss* R-package was used (Stasinopoulos et al. 2022).

The model validation was performed by means of residual diagnostic plots following recommendations from Zuur et al. (2010), Quantile-Quantile plots, and by contrasting the residuals against the predicted values. Furthermore, the coefficient of determination (R^2) was retrieved to check for observed *vs.* estimated values, with values typically ranging from 0 to 1. The closer to 1, the better the predictive quality of the model.

Chapter 4: RESULTS

This study represents the first assessment of hard and soft corals inhabiting oil and gas platforms in Qatar. In this assessment one hard coral species was recorded in Qatari water for the first time (*Cladopsammia ssp*). The implemented ROV technology in this study showed a considerable soft and hard coral cover recorded among different platforms at Al-Shaheen oil field, with evident variability among platform age, depth, weight, and locations.

Figure 4. ROV while surveying AL-Shaheen platforms

Figure 5. Sample of the newly recorded hard coral species.

Platform age

The ROV survey showed that the greatest average of hard coral cover occurred at platforms greater than 10 years old (**Error! Reference source not found.**). According to GLM analysis, hard coral cover significantly increases as the platform age increases (GLM, $\rho < 0.05$; Table 1). On the other hand, the ROV survey showed a notable occurrence of soft corals at an early age of different platforms (**Error! Reference source not found.**). These results were clearly highlighted in as-b-a and as-b-b platform whose data was collected during five years. The age of those two platforms in 2014 were 16 and 17 years old respectively and the hard coral average cover was greater than 40% in both platforms (**Error! Reference source not found.**). However, the age of as-b-e and as-b-f in 2014 was only five years old and the average coral cover was close to zero (**Error! Reference source not found.**). Based on GLM analysis, there was significant negative relationship between increasing the platform age and soft coral cover (GLM, $\rho < 0.05$; **Error! Reference source not found.**). The average of soft corals cover in as-b-e and as-b-f platforms was greater than 60% in 2014 and the age of those platforms in that year was only five years old (**Error! Reference source not found.**).

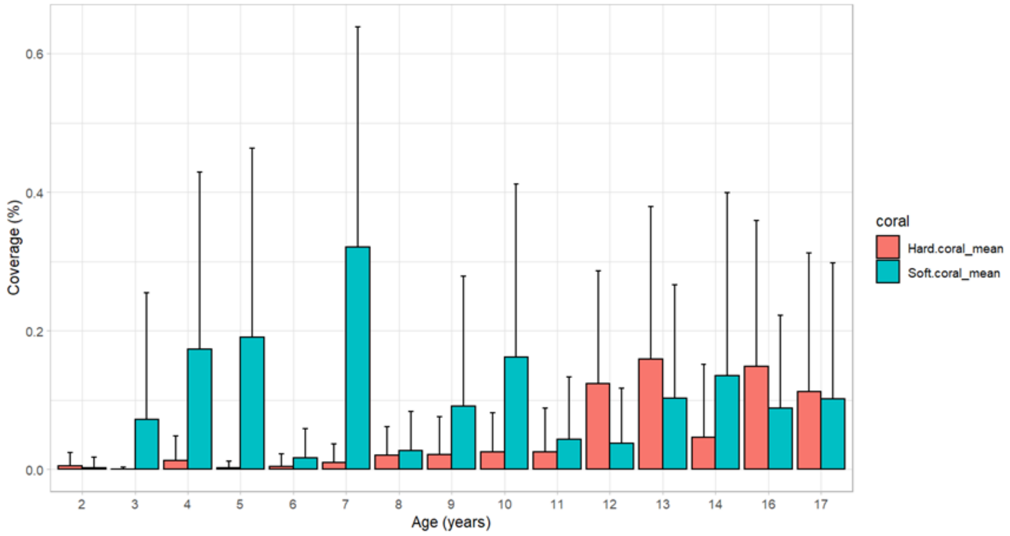

Figure 6. Mean+sd of relative coverage by platform age.

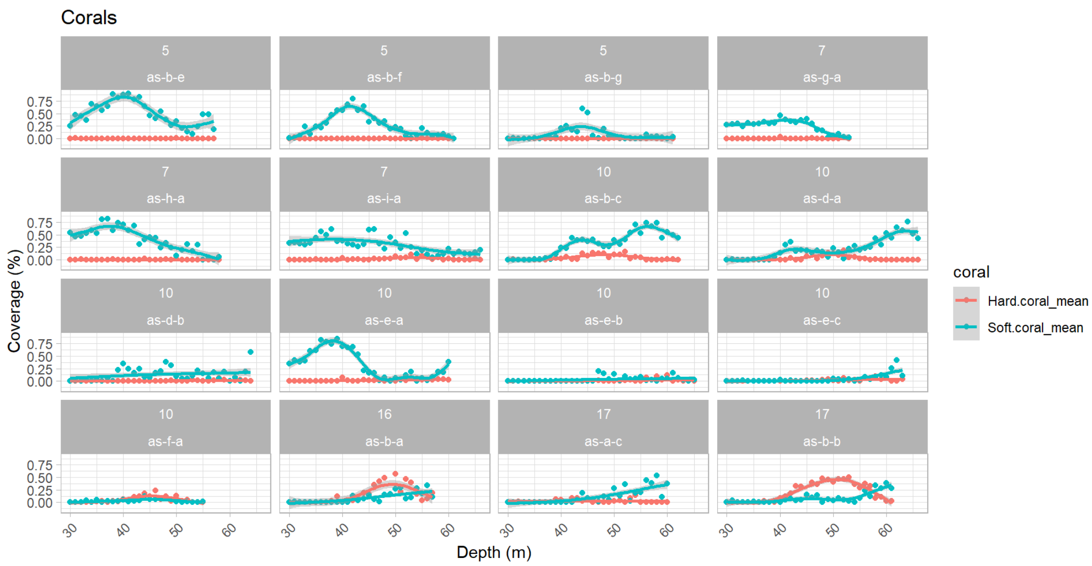

Figure 7. Relative coverage by platform and its respective age in 2014

In this study, five different platforms were investigated in different years to examine the soft and hard coral relative cover including platforms as-b-a, as-f-a, as-g-a, as-h-a and as-i-a. **Error! Reference source not found.** clearly shows that hard coral cover has a relatively slow occurrence rate at early years however the hard coral cover sharply increases as the age of platform increases above eight years. For example, as-h-a was surveyed in three different years (2009, 2011, 2014) at ages of two, four, and seven years old and the coral average cover was lower than 10%. While as-f-a was surveyed in five different years (2007, 2009, 2010, 2011, 2014) at ages of 9, 11, 12, 13 and 16 years old, the hard coral cover was sharply increased in 2014 to 15%. Another platform, that follow similar pattern is As-b-a. This platform was surveyed in 2007, 2009, 2010, 2011 and 2014, the age of the platform in 2011 and 2014 was 13 and 16 years old respectively and the hard coral cover jumped to around 15% as shown in **Error! Reference source not found.**.

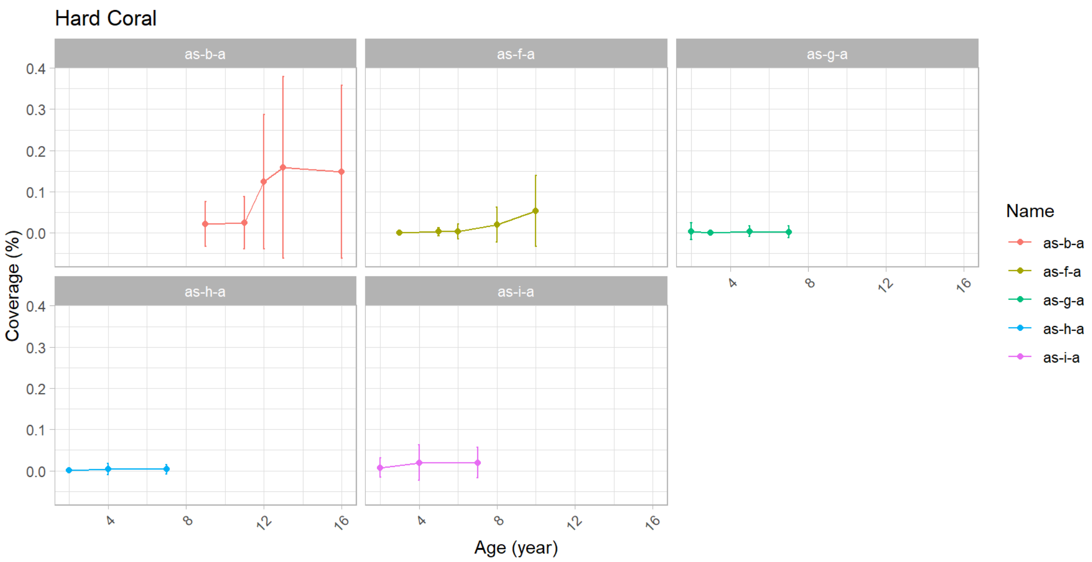

Figure 8. Average of hard coral relative coverage by platform age

While **Error! Reference source not found.** clearly prove that soft corals have faster rate of occurrence at early ages of different platforms such as as-g-a, as-h-a and as-i-a. In 2011 the. Age of as-h-a and as-i-a was 4 years old only and the average coral cover was around 10% in as-h-a and around 24% in as-i-a. In 2014 the age of those two platforms was 7 years and the coral cover was around 40% and 30% respectively.

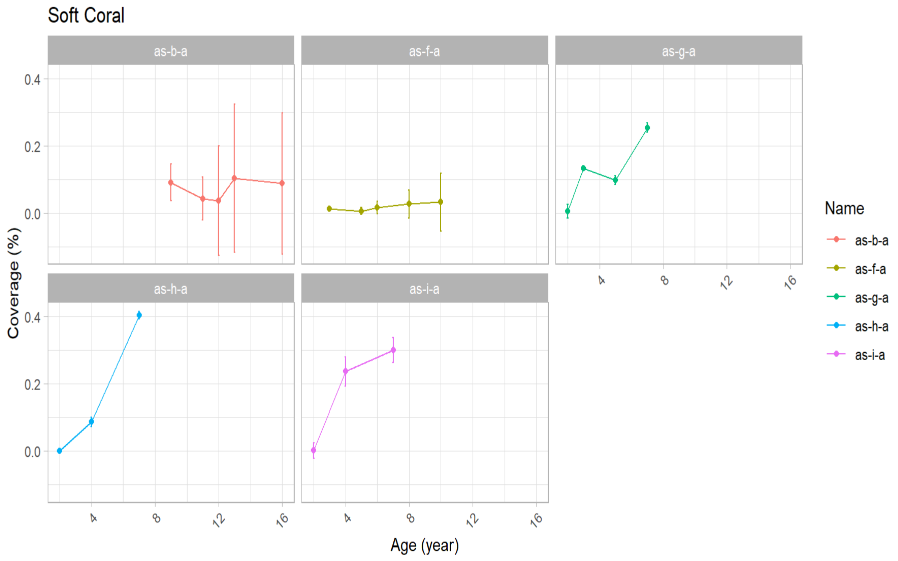

Figure 9. Average of soft coral relative coverage by platform age.

Vertical distribution

Based on the ROV survey, hard corals cover was significantly correlated with increasing depth. According to GLM analysis (**Error! Reference source not found.**) hard coral cover significantly increases with depth (GLM, ρ < 0.01). The highest coverage of hard corals was clearly observed in depths between 40 to 55 m, especially in platforms that are greater than 10 years old (**Error! Reference source not found.** and **Error! Reference source not found.**).

However, the soft coral average cover was not significantly affected with depth (GLM, ρ > 0.05). It was clear that soft corals were presented between 30m to 60m depth (**Error! Reference source not found.** 7 and **Error! Reference source not found.**) and the greatest occurrence was recorded between 40 to 50m. Based on the obtained data hard and soft coral cover decreases beyond 60 m depth.

Weight

The platform weight in AL-Shaheen oil field ranges from 671 ton to 8131 ton. Oil and gas platforms at AL-Shaheen oil field have various functions including flare platform, accommodation platform, wellhead platform, utility platform and process platform. The weight of utility platforms and process platforms are 7986 ton and 8131, respectively, which accounts for the greatest weight among other platforms. While flare platforms and accommodation platforms weights are 671 and 774 tons, respectively, and those two platforms have the lowest weight among other platforms in the field. Since the surveyed platforms in 2014 have different ages, which is an important variable, it was not possible to infer that the highest coral coverage was because the platform was heavy/light or because it is old/young (**Error! Reference source not found.**). Thus, the GLM incorporated the Age*Weight interaction and showed that hard coral cover was not significantly influenced by either the platform weight (GLM, ρ>0.05) or weight and age interaction, while the soft coral cover was positively correlated with platform weight (GLM, $p > 0.05$; **Error! Reference source not found.**).

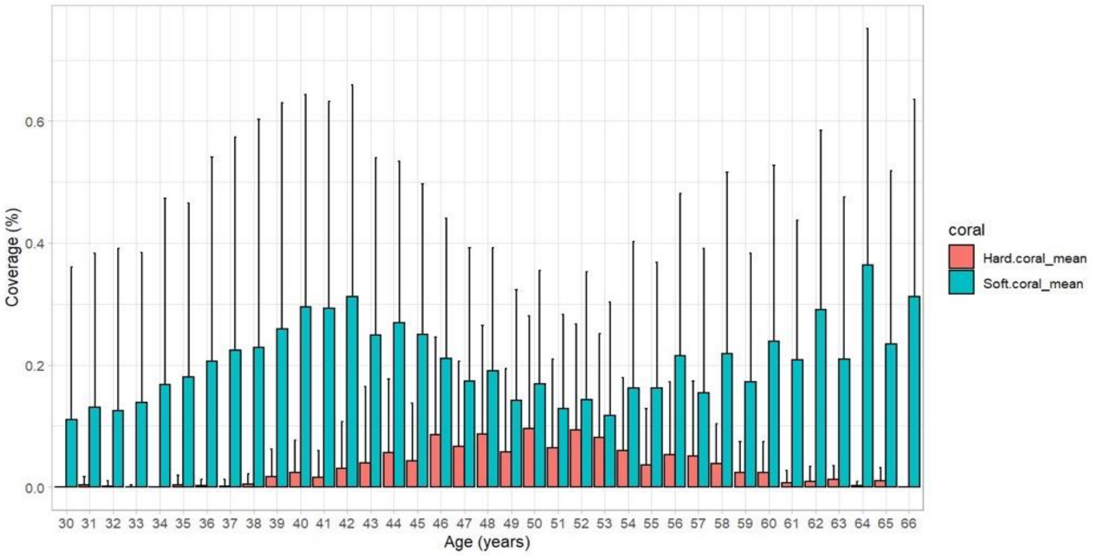

Figure 10. Average of soft and hard coral coverage by platform depth

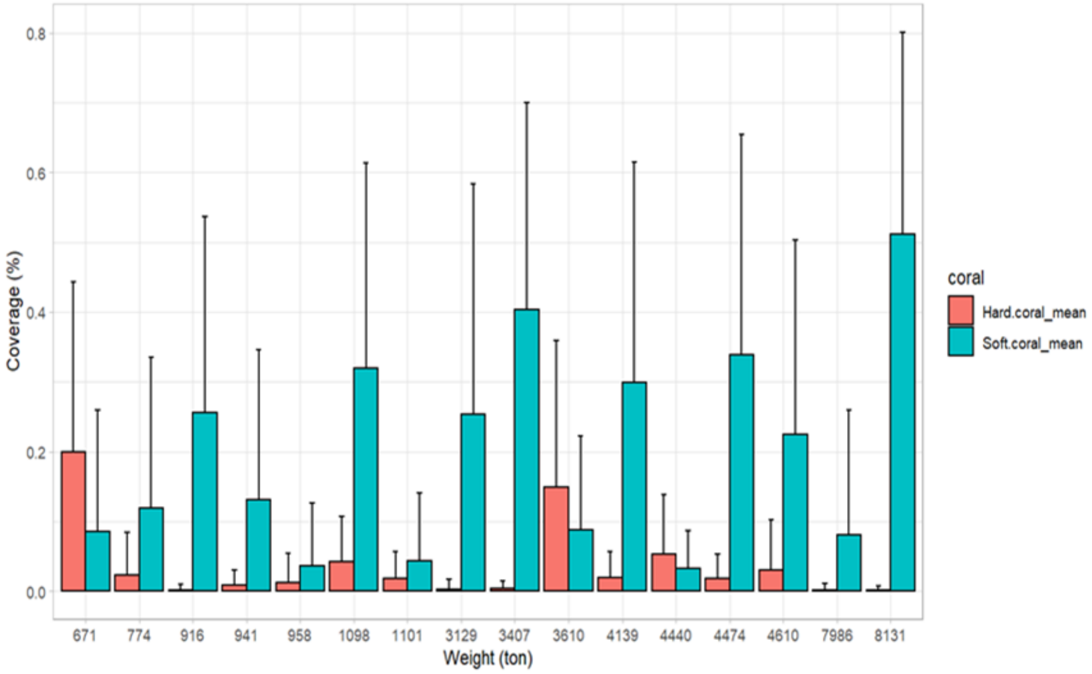

Figure 11. Average of soft and hard coral coverage according to platform weight.

Hard coral vs. soft coral

According to both GLM analyses there is no significant relationship between hard and soft corals cover (GLM, p > 0.05; **Error! Reference source not found.**). However, **Error! Reference source not found.** describes the hard and soft coral covers at different depths and could reflect a certain biological interaction among the two groups.

Table 1. Summary statistics of the tested beta regression models, where (*) highlights significant explanatory variables at a level of 5% of significance.

Hard Coral				
	Estimate	**Std. Error**	**t-value**	**p-value**
Intercept	-5.06E+00	5.58E-01	-9.075	< 2e-16 ***
Soft Coral	-5.94E-01	3.74E-01	-1.587	0.1131
Age	1.48E-01	1.96E-02	7.51	2.76e-13 ***

Depth	1.65E-02	7.83E-03	2.108	0.0355 *
Weight	1.85E-05	4.69E-05	0.394	0.6938
Weight*Age	7.47E-06	1.49E-05	0.501	0.6167
Soft Coral				
Intercept	-5.67E-01	3.57E-01	-1.589	0.11272
Hard Coral	-6.15E-02	6.43E-01	-0.096	0.92384
Age	-2.78E-03	5.43E-03	-0.512	0.60907
Depth	-6.21E-02	2.24E-02	-2.77	0.00582 **
Weight	1.14E-05	4.95E-05	0.231	0.81753
Weight*Age	3.21E-06	6.42E-06	0.5	0.61708

Chapter 5: DISCUSSION

The present study provides a new recording of one hard coral species that was not recorded in Qatari water before (*Cladopsammia ssp*). This can be due to lack of research in the region, or it can be justified by the lack of hard substrata prior to the installation of oil and gas platforms. The surficial geology of the Arabian Gulf comprises mud, sand, and gravel, therefore it lacks hard substrates needed for coral settlement. After the installation of oil and gas platforms the hard substrata became highly presented.

There are several environmental factors that contribute to control the assemblages of those hard substrata related organisms comprising the requirement for hard substrata that influence larval attachment (Freiwald, 2002), nutrient rich water since corals are filter feeders, temperature, salinity (Roberts et al., 2003), light, and currents. In this study the exitance of hard substrata offered by oil platforms rises the probability of soft and hard coral settlement. Thermocline location besides wave turbulence could be key parameters to clarify the vertical distribution of many marine species. The thermocline in our study region is located nearby 18 m (Reynolds, 1993). At AL-Shaheen oil field temperature fluctuates between 20℃ to 35℃ above the thermocline, while under the thermocline the temperature usually changes from 20℃ to 27℃ (Torquato et al.,2021). Furthermore, the greater splash wave close to the surface reduces species richness (van der Stap et al., 2016), and could reduce coral settlement (Gass and Roberts, 2006).

Effect of platform age

Among different locations, the platform age played a major role in structuring the soft and hard coral cover. The most observed soft coral species inhabiting AL-Shaheen oil field according to (Torquato et al.,2021) was Dendronephthya. This soft coral exhibits faster mode of occurrence on early ages platforms as shown in **Error! Reference source not found.**. And this is consistent with other studies that reveal the rapid reproduction rate of large colonies of this species on PVC plates where the recruitment of fragments was instantaneous and surprisingly high (Dahan & Benayahu, 1997). Moreover, this species retains specialized root-like processes that manage them to be promptly attached onto hard substrata (Dahan & Benayahu, 1997) such as oil platforms. Consequently, such an approach of clonal propagation offers a proficient mean for soft corals to utilize food resources and space efficiently.

Hard corals occurrence can be clearly noticed on platforms older than 7 years old and this reflects slower occurrence rate of hard corals as they require greater time to stabilize themselves and reproduce in the new habitat unlike the soft corals. Platforms that are 16 to 17 years old have greater hard coral cover than younger platforms and this suggests the transition of the hard coral communities from broadly composed into a more stable, as the age of the platform increases (**Error! Reference source not found.**).

Effect of platform depth

Increasing the depth significantly decreases the soft coral cover (**Error! Reference source not found.**) since the soft corals was presented among various depth ranges and their favorable growing depth was between 35 to 45 m. However, there was a significant positive correlation among platform weight and soft coral cover (**Error! Reference source not found.**), and this could be attributable to the increased complexity of the platform as weight increases which offer great portion of hard substrata for larval settlement.

Hard corals have very limited natural occurrence at depths ranges from 30 to 40m while increasing the depth significantly increases the hard coral cover. It was detected from 45 to 55 m which indicates that those hard corals indicated in this study are not truly light dependent organisms as their occurrence significantly increases with depth at older platforms. The deeper water had higher hard coral cover that could be associated to a certain dwelling creatures or grater habitat complexity (Hamel et al., 2020),

Hard corals and soft corals biological interactions

This work might reveal certain ecological interaction as our results could suggest various ecological facts. Analysis of soft and hard coral assemblages at distinct water depths resulted in an obvious pattern of natural occurrence of both groups. The soft coral cover at an intermediate depth could be attributable to the limited ecological completion with other organisms such as deep-sea corals. As noticed in **Error! Reference source not found.**, in platforms older than 10 years there was a sharp increase in hard coral cover followed by a decrease in soft coral cover which may indicate a exclusive ecological competition among the two groups over the space. This could describe a strong ecological succession (primary succession) of hard corals in changing the community structure of the existed ecological community over time. Moreover, our observed ecological scenario was consistent with the fact that specialist species (hard corals) have narrow niches while generalist species (soft corals) have wide niches.

Rig to reef approach

Natural habitat loss of coral reefs in the Arabian Gulf which is attributed to bleaching events and anthropogenic activities, derive an important debate on removing the platforms or converting them into artificial reefs to support marine life (RTR programs). Therefore, studying the communities inhabiting oil and gas platforms offer a baseline information of the status of these under water structures for future management and making right decisions. In addition, these kinds of studies are important in term of establishing studies that compare coral communities in oil and gas platforms and other natural habitats since there is a lack of research in the region.

In rig to reef programs, keeping the entire vertical relief of the platform is not always necessary (Ajemian et al., 2015). Therefore, studying the distribution of the inhabiting species along the platform depth is significantly important. Our data suggests that the distribution of corals is significantly influenced with increasing the platform depth and age. Therefore, removing the top structures of the platforms would not affect the hard coral cover (Torquato et al.,2021). Moreover, older platforms (8-17 years old) should be considered when implementing rig to reef approach since they support greater hard coral cover. Furthermore, heavier platforms are more valuable to be considered as an artificial reef since they support greater cover of soft corals.

In agreement with a previous study (Torquato et al.,2021) azooxanthellate scleractinian and Alcyonacea were frequently detected at depths deeper than 30m. These groups were more abundant in deeper layer as well as the older the platform the greater abundance of hard corals (Torquato et al.,2021) and this was consistent with our findings.

Our work follows worldwide literature studying the vertical patterns of coral distribution: Dutch and Danish offshore oil and gas platforms (Schutter et al., 2019), Gulf of Mexico (Lewbel et al., 1987), North Sea (Gass & Roberts, 2006).

A very important way toward enhancing the understanding of coral distribution at Alshaheen oil and gas platforms is to acknowledge the limitations. By investigating the previous studies, we deduced that there is a luch in research efforts particularly in the Arabian gulf. Very limited available studies worldwide concerning coral distribution at oil and gas platforms. In this study we couldn’t manage to compare coral cover and distribution at Alshaheen oil field with other oil and gas platforms in Qatar.

We would like to reveal if similar patterns of coral distribution according to platform age and depth could be revealed in in other oil and gas platforms in the gulf. Moreover, the ROV the was implemented to survey oil and gas platforms at Alshaheen oil field was not directed to our work. The actual aim of the footages was to survey the underwater structure of those platforms for maintenance purposes not to measure the oil and gas platforms associated marine biodiversity which limited our understanding of coral distribution and growth.

In addition, it was difficult to monitor the growth of certain coral colony to track the changes in its size overtime because there is a discontinuity of the obtained data since not all the platforms were surveyed at different years. Furthermore, the used ROV was in low quality which limited our ability to identify some species or to sample those species.

Chapter 6: CONCLUSION AND RECOMMENDATIONS

In this work we took advantage of opportunistic information to create this conclusion that otherwise would be unknown. The analysis of ROV survey at AL-Shaheen oil field proved to be an effective tool to examine the distribution of soft and hard corals among different platforms. This work reveals that oil and gas platforms at Al-Shaheen oil field are distinct habitats and offer hard substrata that support valuable distribution of soft and hard corals. Platform age was the strongest factor that controlled hard coral cover along different locations. In addition to the platform age, depth range was found to significantly influence the hard coral cover along the platform. While platform weight was the deriving factor that significantly increases the soft coral cover. In conclusion, platforms with older age, and greater weight should be considered as priority when implementing rig to reef approach.

To broaden our understanding of other possible factors that could affect coral distribution, further research is required concerning the impact of habitat complexity, and interspecific ecological interactions in addition to the measurement of environmental factors. Additionally, it would be interesting to reveal if similar patterns could be examined for hard and soft coral cover on other oil and gas platforms in Qatar or other underwater manmade structures. Moreover, our understanding toward the effect of oil and gas platforms on coral distribution and cover would be improved by studying coral coverage and distribution on areas surrounding of oil and gas platforms to reveal if coral recruitment influenced significantly by platforms. Additionally, studying the species richness of corals among oil and gas platforms will improve our understanding on the ways that coral recruits arrive at a platform and their reproduction and feeding mechanisms.

REFERENCES

Al-Shaheen - North Oil Company. (1994, January 1). North Oil Company. Retrieved October 22, 2022, from https://noc.qa/al-shaheen.html

Aldosari K. (2019). Marine safety and pollution prevention from oil spills in the Arabian Gulf: a comparative study of applicable international and regional conventions. *World Maritime University Dissertations*, 1164.

Azman N.U., Abu Husain M.K., Mohd Zaki N.I., Mat Soom E., Mukhlas N.A., Syed Ahmad S.Z.A. (2021). Structural Integrity of Fixed Offshore Platforms by Incorporating Wave-in Deck. Journal of Marine Science Engineering, 9.

Baine, M. (2001). Artificial reefs: a review of their design, application, management and performance. Ocean & Coastal Management, 44(3-4), 241-259.

Bauman, A. G., Baird, A. H., Burt, J. A., Pratchett, M. S., & Feary, D. A. (2014). Patterns of coral settlement in an extreme environment: the southern Persian Gulf (Dubai, United Arab Emirates). *Marine Ecology Progress Series*, *499*, 115-126.

Beadnall, S. & Moore, S. (2021). Offshore construction : law and practice. Abingdon, Oxon UK New York, NY: Routledge.

Bishop, M. J., Mayer-Pinto, M., Airoldi, L., Firth, L. B., Morris, R. L., Loke, L. H., ... & Dafforn, K. A. (2017). Effects of ocean sprawl on ecological connectivity: impacts and solutions. Journal of Experimental Marine Biology and Ecology, 492, 7-30.

Bohnsack, J. A., & Sutherland, D. L. (1985). Artificial reef research: a review with recommendations for future priorities. Bulletin of marine science, 37(1), 11-39.

Bouwmeester, J., Ben-Hamadou, R., Range, P., Al Jamali, F., & Burt, J. A. (2022). Spatial patterns of reef fishes and corals in the thermally extreme waters of Qatar. *Frontiers in Marine Science*, 1900.

Brandl, S. J., Rasher, D. B., Côté, I. M., Casey, J. M., Darling, E. S., Lefcheck, J. S., &

Duffy, J. E. (2019). Coral reef ecosystem functioning: eight core processes and the role of biodiversity. *Frontiers in Ecology and the Environment, 17*(8), 445-454.

Brki, D. (2021). *Safe, Secure, and Sustainable Oil and Gas Drilling, Exploitation and Pipeline Transport Offshore*. S.l: MDPI AG.

Buhl-Mortensen, L., Vanreusel, A., Gooday, A.J., Levin, L.A., Priede, I.G., Buhl- Mortensen, P., Gheerardyn, H., King, N.J., Raes, M., 2010. Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Mar. Ecol. 31 (1), 21–50.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). Reefs at risk revisited. World Resources Institute.

Burt, J. A., Bartholomew, A., & Feary, D. A. (2012). Man-made structures as artificial reefs in the Gulf. In *Coral Reefs of the Gulf* (pp. 171-186). Springer, Dordrecht.

Burt, J. A., Paparella, F., Al-Mansoori, N., Al-Mansoori, A., & Al-Jailani, H. (2019). Causes and consequences of the 2017 coral bleaching event in the southern Persian/Arabian Gulf. Coral Reefs, 38(4), 567-589.

Burt, J., Al-Harthi, S., & Al-Cibahy, A. (2011). Long-term impacts of coral bleaching events on the world's warmest reefs. Marine environmental research, 72(4), 225-229.

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.

Chapman, D., & Khanna, N. (2000). World oil: The growing case for international policy. Contemporary economic policy, 18(1), 1-13.

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, 111(43), 15462-15467.

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... & Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global environmental change*, *26*, 152-158.

Dahan, M., & Benayahu, Y. (1997). Clonal propagation by the azooxanthellate octocoral Dendronephthya hemprichi. *Coral Reefs*, *16*(1), 5-12.

Difiglio C. (2014). Oil, economic growth and strategic petroleum stocks. *Energy Strategy Reviews*, 5.

Downing, N., & Roberts, C. (1993). Has the Gulf War affected coral reefs of the northwestern Gulf?. Marine Pollution Bulletin, 27, 149-156.

Driessen, P. (1986, September). Offshore oil platforms: An invaluable ecological resource. In OCEANS'86 (pp. 516-521). IEEE.

Elsayed T., El-Shaib M., and Gbr K. (2016). Reliability of fixed offshore jacket platform against earthquake collapse. *Ships Offshore Struct*ure, 11.

Fabricius, K.E., 2011. Octocorallia. In: Hopley, D. (Ed.), Encyclopedia of Modern Coral Reefs: Structure, Form and Process Encyclopedia of Earth Sciences. Springer, Dordrecht, The Netherlands, pp. pp740–745.

Fazeres-Ferradosa T., Chambel J., Taveira-Pinto F., Rosa-Santos P., Taveira-Pinto F., Giannini G., and Haerens P. (2021). Scour Protections for Offshore Foundations of Marine Energy Harvesting Technologies: A Review. *Journal of Marine Science Engineering*, 9, 297.

Felipe Torquato, Mustafa H. Omerspahic, Pedro Range, Steffen S. Bach, Rodrigo Riera, Radhouan Ben-Hamadou. 2021. Epibenthic communities from offshore platforms in the Arabian Gulf are structured by platform age and depth. Marine Pollution Bulletin, In press, MPB-D-21-01149

Fisher, R., O'Leary, R. A., Low-Choy, S., Mengersen, K., Knowlton, N., Brainard, R. E., & Caley, M. J. (2015). Species richness on coral reefs and the pursuit of convergent global estimates. *Current Biology*, *25*(4), 500-505.

Fowler, A. M., Jørgensen, A. M., Svendsen, J. C., Macreadie, P. I., Jones, D. O., Boon, A. R., ... & Coolen, J. W. (2018). Environmental benefits of leaving offshore infrastructure in the ocean. *Frontiers in Ecology and the Environment*, *16*(10), 571-578.

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.

Gass, S. E., & Roberts, J. M. (2006). The occurrence of the cold-water coral Lophelia pertusa (Scleractinia) on oil and gas platforms in the North Sea: colony growth, recruitment and environmental controls on distribution. *Marine Pollution Bulletin, 52*(5), 549-559.

Grossowicz, M., Benayahu, Y., 2015. Occurrence and survivorship of azooxanthellate octocorals reflect recruitment preferences and depth distribution. Hydrobiologia 759, 85–93. https://doi.org/10.1007/s10750-015-2270-9.

Hamel, J. F., Wareham-Hayes, V. E., & Mercier, A. (2020). Reproduction of a bathyal pennatulacean coral in the Canadian Arctic. *Deep Sea Research Part I: Oceanographic Research Papers*, *162*, 103321.

Hughes, T. P., Kerry, J. T., Álvarez-Noriega, M., Álvarez-Romero, J. G., Anderson, K. D., Baird, A. H., ... & Wilson, S. K. (2017). Global warming and recurrent mass bleaching of corals. *Nature*, *543*(7645), 373-377.

Hvidt M. (2011). Economic and Institutional Reforms in the Arab Gulf Countries. *Middle East Journal*, 65, 1.

Islam, M. (2018). *Shipboard power systems design and verification fundamentals*. Piscataway, NJ: IEEE Press.

Issa N. & Vempatti S. (2018). Oil spills in the Arabian Gulf: A case study and environmental review. *Environment and Natural Resources Research*, 8, 1.

Jagerroos, S., & Krause, P. R. (2016). Rigs-To-Reef; impact or enhancement on marine biodiversity. Journal of Ecosystem & Ecography, 6(2), 1000187.

Johnson, K., Dalton, G. & Masters, I. (2018). *Building industries at sea : 'blue growth' and the new maritime economy*. Gistrup, Denmark: River Publishers.

Kashubsky, M., & Morrison, A. (2013). Security of offshore oil and gas facilities: exclusion zones and ships' routeing. Australian Journal of Maritime & Ocean Affairs, 5(1), 1-10.

Khalique, A. (2016). *Basic offshore safety: safety induction and emergency training for new entrants to the offshore oil and gas industry*. Abingdon, Oxon New York, NY: Routledge, is an imprint of the Taylor & Francis Group, an Informa business.

Kharade A.S. & Kapadiya S.V. (2014). Offshore Engineering: An Overview of Types and Loadings on Structures, *International Journal of Structural and Civil Engineering*, 3, 2.

Krishnakumar, P.K., Lindo, R., 2019. Chapter 3.10: coral reef ecosystem -the Hermatypic Scleractinian (hard) corals. In: Al-Abdulkader, K., Loughland, R.A., Qurban, M.A.(Eds.), Ecosystems and Biodiversity of the Arabian Gulf - Saudi Arabian Waters: 50 Years of Marine Research. Saudi Aramco and King Fahd University of Petroleum and Minerals, pp. 278–308.

Larkin, M. F., Davis, T. R., Harasti, D., Cadiou, G., Poulos, D. E., & Smith, S. D. (2021). The rapid decline of an Endangered temperate soft coral species. *Estuarine, Coastal and Shelf Science, 255*, 107364.

Legrenzi M. & Lawson F. (2017). The changing role of the Gulf in the international political economy, *Global Change, Peace & Security*, 29, 2.

Lin, Y. J., Rabaoui, L., Basali, A. U., Lopez, M., Lindo, R., Krishnakumar, P. K., ... & Roa-Ureta, R. H. (2021). Long-term ecological changes in fishes and macro-invertebrates in the world's warmest coral reefs. Science of The Total Environment, 750, 142254.

Neves, B.M., Edinger, E., Layne, G., Wareham, V., 2015. Decadal longevity and slow growth rates in the deep-water sea pen *Halipteris finmarchica* (Sars, 1851) (Octocorallia: Pennatulacea): implications for vulnerability and recovery from anthropogenic disturbance. Hydrobiologia 759 (1), 147–170.

Nugraha B. & Basuki R. (2019). Rigs-To-Reef (R2R): A new initiative on re-utilization of abandoned offshore oil and gas platforms in Indonesia for marine and fisheries sectors. *IOP Conference Series Earth and Environmental Science*, 241, 1.

Pajuelo, J. G., González, J. A., Triay-Portella, R., Martín, J. A., Ruiz-Díaz, R., Lorenzo, J. M., & Luque, Á. (2016). Introduction of non-native marine fish species to the Canary Islands waters through oil platforms as vectors. Journal of Marine Systems, 163, 23-30.

Patterson III, W. F., Dance, M. A., & Addis, D. T. (2009). Development of a remotely operated vehicle based methodology to estimate fish community structure at artificial reef sites in the northern Gulf of Mexico.

Ponti, M., Abbiati, M., & Ceccherelli, V. U. (2002). Drilling platforms as artificial reefs: distribution of macrobenthic assemblages of the "Paguro" wreck (northern Adriatic Sea). ICES Journal of Marine Science, 59(suppl), S316-S323.

Prasad G. & Anuprakash M. (2016). Pollution due to oil spills in marine environment and control measures. *Journal of Environmental Science, Toxicology and Food Technology*, 10, 9.

Range, P., Riera, R., Omerspahic, M., Bouwmeester, J., Bach, S. S., Møller, P. R., & Ben-Hamadou, R. (2018, March). Fouling assemblages on offshore oil platforms: diverse vertical reefs in the Arabian Gulf. In Qatar Foundation Annual Research Conference Proceedings Volume 2018 Issue 1 (Vol. 2018, No. 1, p. EEPP894). Hamad bin Khalifa University Press (HBKU Press).

Roberts, C.M., 2002. Deep impact: the rising toll of fishing in the deep sea. Trends Ecol. Evol. 17 (5), 242–245.

Sadeghi K. (2007). An Overview of Design, Analysis, Construction and Installation of Offshore Petroleum Platforms. *GAU Journal of Sociology and Applied Sciences*, 2, 4.

Sammarco, P. W. (2013). Corals on oil and gas platforms near the Flower Garden Banks: population characteristics, recruitment, and genetic affinity. US Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM, 216, 106.

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.

Schutter, M., Dorenbosch, M., Driessen, F. M., Lengkeek, W., Bos, O. G., & Coolen, J. W. (2019). Oil and gas platforms as artificial substrates for epibenthic North Sea fauna: Effects of location and depth. *Journal of Sea Research*, *153*, 101782.

Seaman, W. (2007). Artificial habitats and the restoration of degraded marine ecosystems and fisheries. In Biodiversity in Enclosed Seas and Artificial Marine Habitats (pp. 143-155). Springer, Dordrecht.

Seznec J. F. & Kirk M. (2010). *Industrialization in the Gulf: A Socioeconomic Revolution*

(1 ed., pp. 97-185). New York: Routledge.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., ... & Zainal, K. (2010). The Gulf: a young sea in decline. *Marine Pollution Bulletin*, *60*(1), 13-38.

Sheppard, C., Al-Husiani, M., Al-Jamali, F., Al-Yamani, F., Baldwin, R., Bishop, J., ... & Zainal, K. (2010). The Gulf: a young sea in decline. Marine Pollution Bulletin, 60(1), 13-38.

Singh N. (1983). International Maritime Law Conventions. *British Shipping Laws*, 8, 4.

Society for Underwater Technology. (1987). *Economics of floating production systems : proceedings of an international conference (Cost effectiveness of floating production systems*. London, UK Norwell, MA, USA: Graham & Trotman.

Society for Underwater Technology. (1994). *Subsea control and data acquisition for oil and gas production systems : papers presented at a conference organized by the Society for Underwater Technology and held in London, UK, April 20-21, 1994*. Dordrecht Boston: Kluwer Academic Publishers.

Sparks, C. (2007). *Fundamentals of marine riser mechanics : basic principles and simplified analyses*. Tulsa, Okla: Penn Well.

Speight, J. (2015). *Handbook of offshore oil and gas operations*. Waltham, MA: Gulf Professional Pub.

Stone, R. B., Sprague, L. M., McGurrin, J. M., & Seaman Jr, W. (1991). Artificial habitats of the world: synopsis and major trends. Artificial habitats for marine and freshwater fisheries, 31-60.

Teixidó, N., Garrabou, J., & Harmelin, J. G. (2011). Low dynamics, high longevity and persistence of sessile structural species dwelling on Mediterranean coralligenous outcrops. PloS one, 6(8), e23744.

Thomasen, J. B., Al-Emadi, I. A., Noman, R., Ogelund, N. P., & Damgaard, A. P. (2005, November). Realizing the potential of marginal reservoirs: The Al Shaheen field offshore Qatar. In International Petroleum Technology Conference. OnePetro.

Thomasen, J., Al-Emadi, A., & Noman, N. (2005). *Realizing the Potential of Marginal reservoirs: The Al shaheen Field Offshore Qatar*. International Petroleum Technology Conference.

Thomson, P. G., Fowler, A. M., Davis, A. R., Pattiaratchi, C. B., & Booth, D. J. (2018). Some old movies become classics–a case study determining the scientific value of ROV inspection footage on a platform on Australia's North West Shelf. *Frontiers in Marine Science*, *5*, 471.

Titlyanov, A. E., Titlyanova, V. T., Li, X., & Huang, H. (2016). *Coral reef marine plants of Hainan island*.

Todd, V. L. G., Warley, J. C., & Todd, I. B. (2016). Meals on wheels? A decade of megafaunal visual and real-time Passive Acoustic Monitoring detections from on-tow and stationary offshore oil and gas rigs and platforms in the North and Irish Seas. PLoS One, 11(4), 25.

Torquato, F., Jensen, H. M., Range, P., Bach, S. S., Ben-Hamadou, R., Sigsgaard, E. E., ... & Riera, R. (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.

Torquato, F., Omerspahic, M. H., Range, P., Bach, S. S., Riera, R., & Ben-Hamadou, R. (2021). Epibenthic communities from offshore platforms in the Arabian Gulf are structured by platform age and depth. *Marine Pollution Bulletin*, *173*, 112935.

Vaughan G.O. & Burt J.A. (2016). The changing dynamics of coral reef science in Arabia. *Marine Pollution Bulletin*, 105.

Verbeek, S. (2013). Worldwide rigs-to-reefs experiences: considerations and motivation for a Living North Sea. *Would the North Sea Benefit from Reusing Offshore Materials for Artificial Reefs*.

Vikas M. & Dwarakish G.S. (2015). Coastal pollution: a review. *Aquatic Procedia*, 4.

Wei., Ge, S., How, B. & Choo, Y. (2013). *Dynamics and Control of Mechanical Systems in Offshore Engineering*. Dordrecht: Springer.

World Ocean Review (2014). Marine Resources, Opportunities and Risks. Hamburg: Maribus.