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A Review: Modern Coral Characterization Studies in Malaysia

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Abstract

Coral reefs are highly diverse and productive ecosystem in the ocean that provides various goods services to human and environment. Located within the renowned 'Coral Triangle' region, Malaysia is one the thriving countries in Southeast Asia that possess rich marine resources and coral reefs. Like other coral reef around the world, coral reefs in Malaysia are exposed to multiple threat that jeopardize their well-being. Those relying on these ecosystems may face severe consequences if they are lost. In recent decades, research on characterizing modern coral reefs has increased in Malaysia, including identifying key species and their distribution, understanding the factors that control coral growth and assessing the impacts of environmental stressors on reef health. This study is aimed to provide an overview of the current state of knowledge of modern coral characterization studies conducted in Malaysia. It presents the distribution maps of these coral reef studies conducted throughout Malaysia and discusses the techniques employed to characterize them. Most of the studies was conducted in South China Sea, particularly in East Coast of Peninsular Malaysia with Tioman Island, Pahang being identified as having the greatest number of studies. And, visual assessment have the higher frequency of use in characterizing Malaysia coral reef. Going forward, future studies in Malaysia should continue to explore others Malaysia reef, and techniques for characterizing coral reefs, while also conduct more studies in locations with limited research. These studies could have served as foundation resource for future conservation efforts in the face of ongoing threat and challenges.

Keywords: *modern coral, characterization, Malaysia, visual assessment, remote sensing, geochemical analysis*

Introduction

Coral reef is the most diverse ecosystem in the ocean and are acknowledged for their remarkable biological diversity and productivity (Hoegh-Guldberg, 1999), providing various goods services. They have a higher structural complexity that provides variety niches and habitats for vast marine organisms to thrive in (Sale *et al*., 2014) including fish, crustaceans and other invertebrates making them biodiversity hotspot. In addition, coral reef also supports human well-being in the form of fisheries and tourism for important food sources and livelihood, coastline protection against coastal hazard by acting as natural breakwaters, and cultural service for local communities (Costanza *et al*., 2014; Harris *et al*., 2018; Spalding *et al*., 2017). A coral reef is a potential carbon storage for carbon sequestration. This carbon is locked up in the skeleton of corals that build the reef structure. Through the precipitation of calcium carbonate, they recycle CO_2, forming their framework and accompanying inter-reefal deposits (Heap *et al*., 2009). Due to this reason, coral reefs are thought to function as natural carbon sinks. Given all that, coral reefs are a key ecosystem in the marine environment.

Despite of their importance, coral reefs around the world are exposed to large numbers of local and global anthropogenic stressors over the last few decades (Bellwood *et al*., 2004; Eddy *et al*., 2021; Hughes *et al*., 2010), which has raised concern about their declination. The stressors that contribute to reef decline include coral bleaching, ocean acidification, coral diseases, overfishing, coastal development and nutrient enrichment (Eakin *et al*., 2010; O. Hoegh-Guldberg *et al*., 2007; Weil and Rogers, 2011; Zaneveld *et al*., 2016; Vega Thurber *et al*., 2014). The stressors are significant and multifaceted. According to the report by Global Coral Reef Monitoring Network, approximately 75% of the world's coral reefs are estimated to experience the threat level because of natural and anthropogenic disturbance by 2050 (Burke *et al*., 2011). If no action is taken, coral reefs are at risk of being lost. The loss of these ecosystems can have severe consequences for the communities that rely on them. Therefore, it is important to enhance the conservation efforts and effective

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management strategies for coral reefs, in order to ensure the continued provision of their ecosystem.

Malaysia, one of the prosperous countries in Southeast Asia, is a home to coral reefs and marine resources as it lies within the renowned 'Coral Triangle', where its coral reefs extend to Indonesia, Philippines, Papua New Guinea, Solomon Islands, and Timor-Leste (White *et al*., 2014). Advantages due to these facts are boosting Malaysia's tourism and economic growth, by promoting Malaysia as an outstanding tourism destination. Geography of Malaysia is unique with two distinct regions: West Malaysia (Peninsular Malaysia and East Malaysia (Sabah and Sarawak). Both regions are blessed with extensive coral reefs that cover vast area along the east coast in both regions has been documented and recorded in a wide range of coral species. Evident to that, 398 species were found in Peninsular Malaysia and 248 species were found on the west coast of Sabah (Huang *et al*., 2015). Importantly, coral reefs are widespread in Malaysia, with the most of the are being concentrated in the South China Sea, which is recognized as a significant hotspot of marine biodiversity.

Over the past few decades, research on characterizing modern coral reefs in Malaysia has seen to increase, including identifying key species and distribution patterns, underlying factors that control coral growth, and assessing the impacts of environmental stressors on reef health. This interest can be attributed primarily due to the growing concern for the conservation and preservation of coral reef ecosystem. In the quest to characterize the modern coral reefs in Malaysia, researcher have utilized advanced technologies and interdisciplinary approaches. These findings have helped to shed light on the resilience and vulnerability of coral reefs to environmental stressors. As such, the increased research efforts on modern coral reefs in Malaysia have not only helped in advancing our understanding of these ecosystems, but also in guiding conservation and management practices for their sustainability.

This research aims to provide an overview of the current state of knowledge of modern coral characterization studies conducted in Malaysia, highlighting the key findings, research gaps, and opportunities for future research. By doing so, this study will contribute as a foundation resource for future studies and enable the research to obtain a wealth of information on coral studies, facilitating their efforts to build upon previous research. Given the critical roles that coral reefs play in supporting marine biodiversity and human well-being, it is essential that we continue to build upon our knowledge of these complex ecosystem.

Status of Coral Reef in Malaysia

For several years, coral reefs in Malaysia have been subjected to monitoring, with their health being evaluated based on coral health criteria (Chou *et al*., 1994), shown in Table 1. One of the earliest coral assessments which covered 193 reef sites in Malaysia reported that 52.8% of the reefs were rated as being in 'good' condition (Chou *et al*., 1995). As compared to the latest Annual Survey Report 2021 (Reef Check Malaysia, 2021), the average condition of Malaysian reefs is 'fair' with live coral is 40.13%. Importantly, this remark is the first occasion of the improvement since 2015, attributed to the reduction of tourist and tourism activity due to movement restriction during a COVID-19 pandemic. In the last two decades, data on coral conditions showed inconsistent patterns, with many reefs evaluated were in 'fair' than 'good' condition (Waheed *et al*., 2015; Safuan *et al*., 2016; Shahbudin *et al*., 2017; Safuan *et al*., 2018). However, despite the improvement in the overall condition of Malaysia reefs, there is still cause for concern as it is below the 'good' and 'excellent' rates and many reefs are still confronting different types of threats that put their well-being in jeopardy.

Multiple threats have been identified as having an impact on coral reefs in Malaysia (UNEP, 2011; Praveena *et al*., 2012), with the nature and severity of these threats vary depending on the location. Among these threats, sedimentation stand out as a significant factor in the deterioration of coral health in Peninsular Malaysia, particularly on the west coast Malaysia (Khodzori *et al*., 2019; Toda *et al*., 2007). The lasting effects of sedimentation on this region have caused the reef to have a less coral cover and diversity compared to the east coast of Peninsular Malaysia (Khodzori *et al*., 2019; Toda *et al*., 2007). Sedimentation occurs due to human activities such as land reclamation, degrading, and construction of coastal or coastal infrastructure. This can lead to increased turbidity, smothering of corals, and reduced light penetration, which can have a negative impact on their health.

Coral reefs in the east coast of Peninsular Malaysia face threat from both disease and predation (UNEP, 2011; Praveena *et al*., 2012). There have been records of more than 20 diseases affecting coral reefs around the world (Jaafar *et al*., 2023), with some of these diseases also recorded in Malaysia include black band disease (BBD), brown band disease, yellow band disease (YBD) and white syndrome (Miller *et al*., 2015; Akmal and Shahbudin, 2020). For example, the most prevalent disease observed in Tioman Island Marine Park, Malaysia was yellow band disease/YBD (Akmal and Shahbudin, 2020). These diseases are caused by various factors,

Table 1. Coral Reef Health Criteria (Chou *et al*., 1994)

Percentage of live coral cover	Rating
0-25	Poor
26-50	Fair
51-75	Good
76-100	Excellent

including bacterial infections, environmental stress, and water pollution. Meanwhile, predation by various organisms such as the Crown-of-thorns, snails, and some fish species also threatens Malaysian coral reefs. Crown-of-thorns, in particular, have been known to cause tissue loss and skeleton abrasion. Therefore, efforts have been taken to remove this eating predator (Chak *et al*., 2018). It is evident that coral reefs in Malaysia are susceptible to various diseases and predation.

In east Malaysia, coral reefs have been severely impacted by destructive fishing practices and overfishing, which are identified as the main reasons of reef degradation in the region. For example, coral reefs in Sabah have been ruined by destructive fishing practices, such as blasts and cyanide (UNEP, 2011; Praveena *et al*., 2012). These damages are attributed to inadequate enforcement and overreliance on coastal fisheries. As result, Sabah experienced a loss of more than 80% of its original coral cover (Yasin *et al*., 1998). Destructive fishing practices can cause physical damage to the reefs and result in coral mortality. Overfishing, on the other hand, can lead to the depletion of fish population and smothering coral reefs, which disrupt the ecological balance of the reef system.

Coral reefs in Malaysia are not excluded from experiencing coral bleaching. Severe and widespread coral bleaching on Malaysian reefs was not observed prior to 2010, including during the 1997/98 global event when coral bleaching was mild and localized (Wilkinson, 1998; Kushairi, 1998). Bleaching events are associated with high and fluctuating seawater temperatures, which have been linked to climate change. When coral is exposed to warmer water, causing them to expel their dinoflagellate endosymbionts, commonly known as zooxanthellae which essential for the growth of stony corals and coral reef ecosystems (LaJeunesse *et al*., 2018). As a result of this process, corals may take on a pale, white, or luminescent appearance, leading to the phenomenon known as coral bleaching. As consequence, coral bleaching results in coral mortality and a reduction in the overall health of the reefs. As these stressors become more severe, coral bleaching events are likely to become more frequent and intense, further straining the already fragile system.

Coral status provides information about the health and resilience of the coral reef ecosystems for understanding and addressing the threats facing them. Threats to coral reefs have been a topic of discussion among marine and coral biologist in Malaysia (Praveena *et al*., 2012), as these ecosystems face numerous challenges. However, despite ongoing research and monitoring efforts, the full extent of damage to Malaysia's coral reefs remains relatively unknown. Nevertheless, coral reefs in Malaysia, like those in many other parts of the world, are under significant stress and require urgent attention and action to ensure their survival.

Studies on coral reef characterization in Malaysia

Studies of modern coral reef characterization have been carried out in various locations across west and east Malaysia, with researchers exploring areas such as Strait of Malacca, South China Sea, Sulu Sea and Celeb Sea. Figure 1 present the distribution map of these studies conducted throughout Malaysia. It is evident from the map that a significant portion of these studies were conducted in South China Sea region. South China Sea is a significant location for coral reef studies as it has some of the most diverse and abundant coral reefs in the world. Thus, it is not surprising that this area is of particular interest in coral reef studies and most of the modern coral characterization studies have been conducted in this area. Some studies have been conducted in the Strait of Malacca, which is a narrow waterway that runs between the Malay Peninsular and the Indonesia island of Sumatra. The Strait of Malacca is an important shipping route and experience significant human activity, which can have negative impacts on the health of the coral reefs in the area.

From the graph in Figure 2, it is evident that the majority of the coral reef studies were conducted in the East Coast of Peninsular Malaysia, particularly around the South China Sea. 23 studies covered area of East Coast of Peninsular Malaysia, while 12 studies focused on the West Coast of Peninsular Malaysia. Additionally, 13 studies delved into the coral ecosystem of West Malaysia. This may indicate that east coast of Peninsular Malaysia is more accessible to conduct coral reef research. The presence of numerous study sites in this area may also indicate the availability of suitable coral reef habitats, research infrastructure, and logistical support for scientists and researchers. The accessibility of the east coast may be attributed to factors such as proximity to research institutions, established research stations, and favorable sea conditions for fieldwork. However, it is important to note that the concentration of studies in this region does not diminish the significance of other coastal areas in Malaysia, as they may hold valuable and understudied coral reef ecosystems.

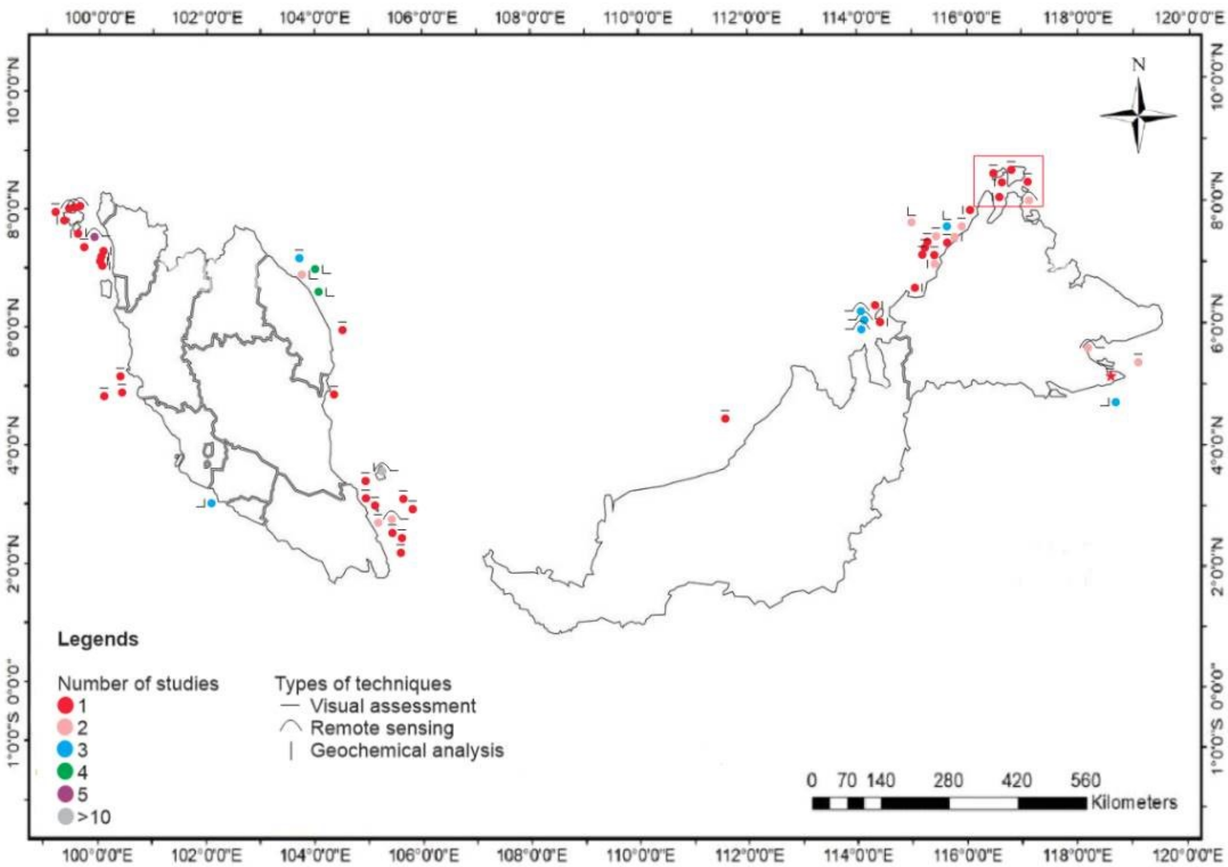

Figure 1. Geographical distribution of modern coral characterization studies across the state of Malaysia

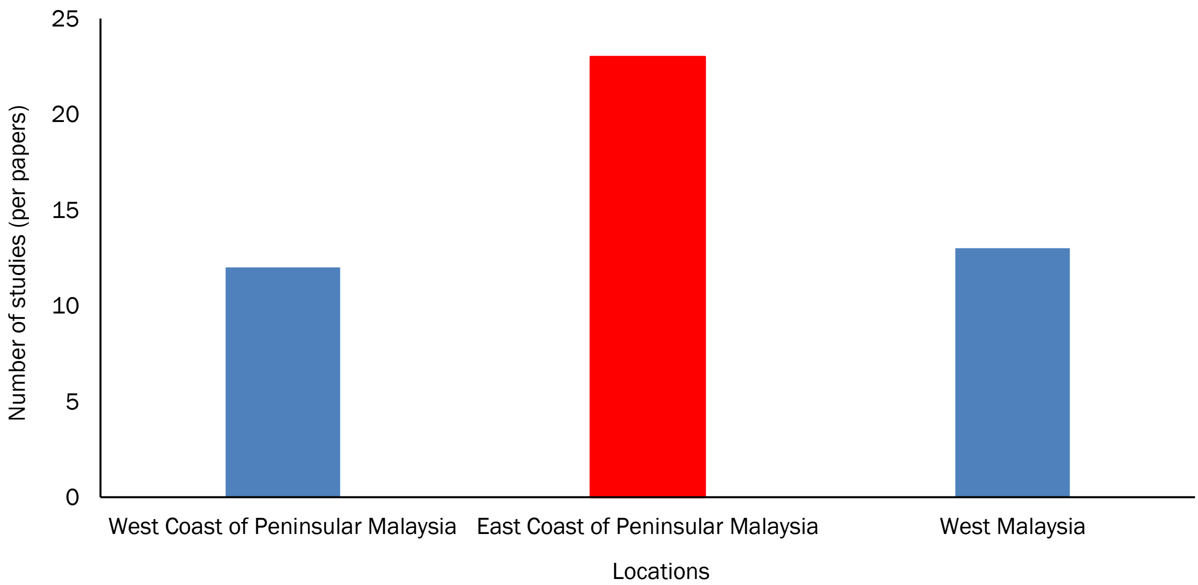

Figure 2. Graph of coral characterization studies based on the locations in Malaysia

An array of detailed, modern coral characterization studies has been conducted in Pahang, Terengganu, Johor, Kedah, Perak, Negeri Sembilan, Sabah, and Sarawak. Some of the notable locations include Tioman Island with thirteen studies (Figure 1), which makes Pahang state emerge as having the highest number of studies, Payar Island with five studies, and Redang Island and Bidong Island with both four studies. These islands are located on the East Cost of Peninsular Malaysia and are known for their high coral diversity and abundance. In West Malaysia, such studies have been conducted in the islands of Tunku Abdul Rahman Marine Park, Tun Mustapha Park, and Tun Sakaran Marine Park. However, it is worth noting that coral characterization studies have not been conducted in all areas of Malaysia, indicating still many islands yet to be explored. These islands may have important coral ecosystems that are currently under threat from anthropogenic activities. Ergo, it is essential to conduct further research, particularly in regions where studies have been limited, to better understand the coral conditions in that region.

Some studies have looked at the spatial distribution of different coral species and their associations with other organisms, which can provide important insight into the ecological functioning of coral reefs to better understand how they respond to changes in water quality and environment conditions. From these studies, a wide range of topics have been explored, including, not limited to, health evaluation, chemical composition, and mapping to better understand the current state of coral reefs in Malaysia. These studies demonstrate the importance of continued research into coral characterization in order to support effective conservation and management efforts.

Coral Characterizing Techniques

The coral characterization technique refers to a set of methods and technologies used to study and analyse the characteristic of coral reefs for understanding the structure, composition, health, and resilience of coral reef ecosystems. This paper will discuss these techniques, which include both qualitative and quantitative approaches ranging from visual assessment, remote sensing, and geochemical analysis. The advantages and limitations of these techniques will be highlighted, which can aid in selecting the most appropriate method respected to the research objective. Figure 3 provides a summary of techniques used in coral characterization study in Malaysia, showing their respective frequencies of use.

Within 45 published papers reviewed, it was found that visual assessment (underwater) has the higher frequency of use, accounting the most used technique in characterizing Malaysia coral reef with 27 studies employed this method (Figure 3). While 10 studies utilized remote sensing technique and 8 studies employed geochemical analysis. Graph in Figure 4 further support these findings, showing the prevalence of visual assessment as the most frequently employed technique in the three regions mentioned. This preference for visual assessment can be attributed to the aim of many coral studies in Malaysian is to aim to assess coral health and diversity, which is accomplished through visual assessment. However, the use of other two techniques is also important in understanding Malaysia coral reef.

Visual Assessment (Underwater)

One of the most common coral characterization techniques is visual assessment, which is a conventional technique. It involves direct

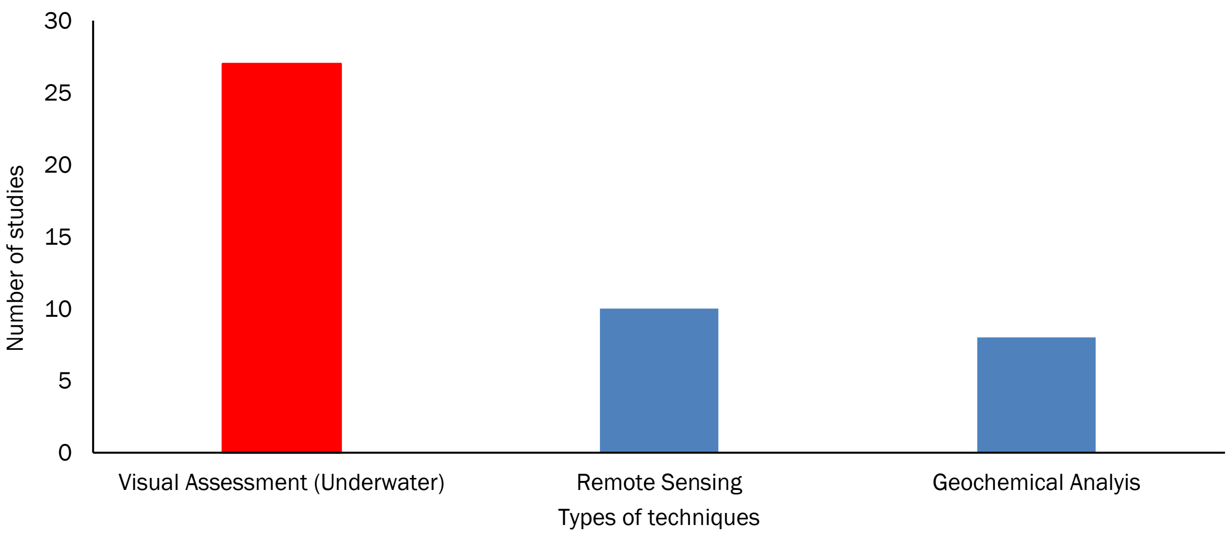

Figure 3. Frequency of use of coral characterization techniques

underwater observation of coral reefs' condition by snorkelling or diving using techniques such as in situ quadrats, line transect, and manta tows (Miller and Müller, 1999), as well as coral video transect (CVT). Add to these techniques is comprised with digital photography and computer image analysis. Visual assessment is often used for health status evaluation, which may include documenting parameters such as coral cover, growth forms, species diversity, and the occurrence of diseases and bleaching.

Organization like Reef Check Malaysia have carried out previous assessment to determine the coral cover in Malaysia. The Line Intercept Transect (LIT) and Point Intercept Transect (PIT) have been the main methods used in these studies (Praveena *et al.*, 2012; Toda *et al.*, 2007). These methods start by laying a measuring tape along the reef, followed by the process of counting or identifying the coral species that intercept the tape. However, these methods have limitation and are prone to observer bias, which may affect the accuracy of the results. To address this limitation, a study conducted by Safuan *et al.* (2015) compared the efficiency of the CVT and LIT methods in assessing coral cover and species diversity. The CVT method allows for later analysis of the video footage, using Coral Point Count with Excel extension (CPCe), a tool proposed by Kohler and Gill (2006), which eliminates observer bias and provides more detailed information on the coral communities. Furthermore, this method consumes a short amount of time in the field, but it is time-consuming during the counting of coral reef components in the laboratory. 12 studies have employed the CVT method for visual assessment (Table 2). Many researchers employed CVT method to evaluate and determine reef condition, the generic diversity and abundance patterns, community structure, and disease prevalence (Safuan *et al.*, 2016; Khodzori *et al.*, 2019; Akmal and Shahbudin, 2020).

Remote sensing

With remarkable technological advancements in recent years, remote sensing has become increasingly prevalent in coral studies. Remote sensing is a technology, tool, or technique that allows the collecting of data and information about an object, area, or phenomenon from a distance (in this context coral reef), without having to make direct physical contact but through data analysis obtained with a tool (Lillesand *et al.*, 2015). This technique covers technologies from the hydroacoustic signal, satellite images, or drones for identifying, mapping, and assessing coral reef ecosystem health. Through remote sensing, high spatial resolution and frequency maps can be produced to depict the distribution and condition of coral reefs, allowing for a better estimation of the impact of climate change on reefs at regional scales (Foo and Asner, 2019). Therefore, the use of remote sensing in coral studies is expected to grow in the future as new and innovative technologies continue to emerge. In this review, the use of remote sensing includes six studies that use the hydroacoustic method, three studies that utilized satellite imagery, and one study that employed a drone (Table 2).

Initially introduced as an active sound (sonar) to evaluate fish biomass and spatial distribution, the hydroacoustic signal has now been expanded it's use in coral ecology and management (Abdullah *et al.*, 2016), providee a whole new dimension in obtaining crucial coral reef baseline information. RoxAnn, a product of the Acoustic Ground Discriminating

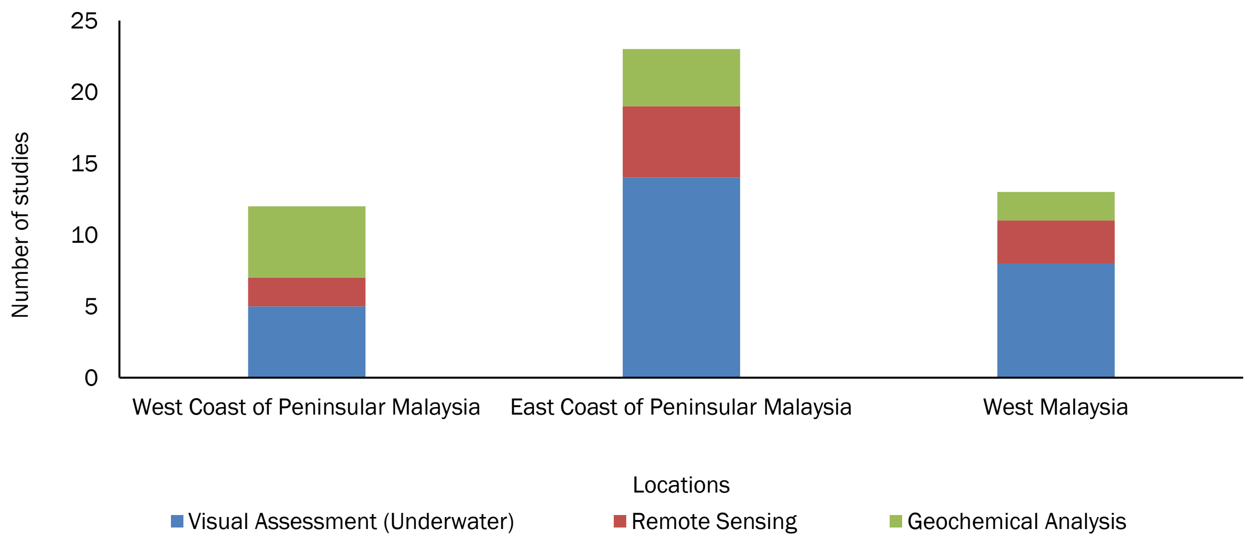

Figure 4 Frequency of use of coral characterization techniques based on the locations

Table 2. Summary of coral characterization studies in Malaysia

No	Location	Method	Objective	Result	Source
Visual assessment					
1	Patricia shoal	LIT	To assess coral reef health status	**Development Index (DI):** Four areas had good development and two areas had fair development. **Conditions Index (CI):** Five areas had good conditions and one area had fair conditions. **Succession Index (SI):** One area had poor succession, three areas had very poor succession and two areas could not be determined	Idris *et al*., 2006
2	Pangkor Island Perhentian Island Sibu Island Payar Island Tioman Island	Line Transect	To assess coral reef health status and determine the dominant coral community and to describe the coral community structure biogeographically	Overall reef condition: Fair Porites massive is dominant in west coast, while Montipora and Acropora are dominant in the east coast	Toda *et al*., 2007
3	Gaya Island Sepanggar Island UMS jetty	LIT, Fish Visual Census and Belt transect.	To assess coral reef health status	Overall reef condition: Fair to good The low levels or absence of species indicator species suggest that invertebrate and fish on reef is being overexploited	Waheed *et al*., 2007
4	Tioman Island	Random swim SCUBA	To document the coral diversity	221 hard coral species from 14 families were identified.	Amri *et al*., 2008
5	Tioman Island	Line Transect	To test the hypothesis that coral growth is affected by sedimentation	The coral species diversity is high. Blast fishing has caused damage at some reefs.	Nakajima *et al*., 2013
6	Semporna Island	Roving diver	To determine coral species diversity pattern	The coral species diversity is high and remarkable. Blast fishing has caused damage at some reefs.	Waheed and Hoeksema, 2013
7	Tun Abdul Rahman Park Mengalum Island Sepanggar Island Udar Besar Island	Roving diver, PIT	To determine the species richness patterns of coral	Overall reef condition: Fair and good. Low coral cover and high rubble fragments at sites are evidence of blast fishing.	Waheed and Hoeksema, 2014
8	Tun Mustapha Park	Roving diver, PIT	To determine the species richness patterns of coral	Overall reef condition: Fair and good Low coral cover and high rubble fragments at sites are evidence of blast fishing.	Waheed *et al*., 2015
9	Tunku Abdul Rahman Park Tun Sakaran Park Sipadan Park	Underwater photography	To provide baseline for coral disease dataset	High mean coral cover and variable disease were found across the three sites with the site closest to the coastal exhibiting the highest disease frequency.	Miller *et al*., 2015
10	Sembilan Island	CVT		Overall reef condition: Poor	

No	Location	Method	Objective	Result	Source
	Jarak Island		To assess coral reef health status and determine the coral community structure	22 genera from 11 families were identified.	Safuan *et al*., 2016
11	Tioman Island	CVT	To assess coral reef health along the Malacca Strait	Overall reef condition: fair 25 genera from 12 families of coral were identified	Shahbudin *et al*., 2017
12	Cape Rachado	CVT	To assess coral reef health along the Malacca Strait	Overall reef condition: fair 25 genera from 12 families of coral were identified	Safuan *et al*., 2018
13	Labuan Marine Park	CVT	To assess coral reef health status and determine coral community pattern	Overall reef condition: poor 38 genera from 13 families of corals were identified.	Safuan *et al*., 2018
14	Payar Island Segantang Island	CVT	To assess coral reef health status and determine generic diversity and abundance patterns	Overall reef condition: poor to fair 38 genera from 14 families of corals were identified.	Khodzori *et al*., 2019
15	Redang Island Tioman Island	CVT	To determine the coral diversity and abundance patterns	Overall reef condition: good 128 species from 47 genera in Redang and 239 species from 55 genera in Tioman were identified.	Akmal *et al*., 2019
16	Balok reef	CVT	To determine benthic community composition	Overall coral cover is 39% 28 genera from 12 families were identified, dominated by Porites	Hanapiah *et al*., 2019
17	Bidong Island Redang Island Cape Rachado	CVT	To compare the spatial distribution of coral genera among study area	Bidong Island (least anthropogenic impacts) has the highest coral cover, Redang Island (tourist destination) has greatest algal cover and Cape Rachado (affected by sediment) has the lowest coral cover	Crehan *et al*., 2019
18	Mertang Island	PIT	To examine coral community structure	Overall reef condition: good 25 genera of scleractinian corals from 12 family were identified, dominated by Acropora and Montipora.	Ismail and Khoo, 2019
19	Bidong Island	CVT	To examine the physical changes to the coral reefs	Reduction in live coral cover. The shallow reef area (3 m) exhibited the majority of damage, whereas only minor breakages were noticed in the deeper reef area (8 m).	Safuan *et al*., 2020
20	Tioman Island	CVT	To assess coral reef health status and disease prevalence	Coral diseases and indications of compromised health were found to be prevalent in reef sites that had a higher frequency of tourism	Akmal and Shahbudin, 2020
21	Labuan Marine Park Tioman Island Kapas Island Bidong Island Perhentian Island	CVT	To assess coral reef health status in the southern part of the South China Sea (SCS)	Overall reef condition: fair 52 genera from 15 families were identified, dominated by Acropora and Porites	Safuan *et al*., 2021

No	Location	Method	Objective	Result	Source
22	Udar Besar Island	Photogrammetry	To map a section of the coral reef and identify coral species and growth forms	Mapping was achieved using Photogrammetry. The most coral growth form observe is free living coral	Waheed *et al*., 2021
23	Seri Buat Island	PIT	To examine coral community structure	Overall reef condition: good 30 genera of scleractinian corals from 11 family were identified, dominated by Acropora and Porites	Ismail, 2021
24	Mersing Islands	Line Transect	To update species checklist	261 species from 16 families were identified	Lee *et al*., 2022
25	Anak Datai Island	Line Transect	To assess coral reef health status	Overall coral cover <40% 25 genera from 11 families were identified, dominated by Porites, Favites, and Diploastrea	Ismail *et al*., 2022
26	Perhentian Island	CVT	To assess coral reef status health using 2D-CHI (Coral Health Index)	Overall reef condition: fair to every degraded The findings suggest coral reef is threatened by sedimentation, nutrient enrichment and tourism	Safuan *et al*., 2022
27	Lang Tengah Island	LIT and belt transect	To analyze the demographic structure and size frequency distribution (SFD) of coral	There are significant differences in SFD across gradients of reef health	Bernard *et al*., 2022
Remote sensing					
28	Payar Island	Hydroacoustic	To map the reef substrate	The live hard coral covered 19.3% with four main growth forms identified	Lee, 2000
29	Lang Tengah Island	Satellite imagery: Quickbird combined with in situ data	To generate coral habitat map	The accuracy produced was higher than conventional supervised techniques.	Muslim *et al*., 2012
30	Tioman Island	Satellite imagery: Landsat ETM, SPOT and IKONOS	To assess the use of multi sensor satellite images in coral reef mapping	The final classification results high overall accuracy	Pradhan and Kabiri, 2012
31	Gasing Island Pasir Island Dangli Island	Hydroacoustic	To analyse acoustic signal from two systems that potentially to produce spatially explicit map of coral reef	RoxAnn and side scan sonar described different acoustic information on seabed types	Che Hasan, 2014
32	Tinggi Island	Satellite imagery: ALOS	To determine the coral characteristics and to map its spatial distribution	The spectral characteristics of corals and habitats vary, but they exhibit similar spectral curves. Seagrass was the most prevalent, followed by coral reefs, sandy shores, intertidal zones, and rocky areas.	Mustapha *et al*., 2014
33	Labuan Marine Park	hydroacoustic	To classify the marine substrates and habitat	Coral exhibits the second dominant seabed structure	Mustajap *et al*., 2015

No	Location	Method	Objective	Result	Source
34	Tioman Island	hydroacoustic	To map the reef substrates	Detailed maps of coral reefs with information on reef substrate type and coral growth forms were produced, with a high degree of accuracy	Yap, 2017
35	Darval Bay	hydroacoustic	To map the benthic habitat	Overall reef condition: good The maps with decent accuracy and were obtained	Lee and Lin, 2018
36	Tioman Island	UAV-Drone	To monitor coral bleaching in using aerial drone photography	The bleaching point was successfully identified by drone	Zuhairi *et al*., 2018
37	Mandi Darah Island	hydroacoustic	To examine the distribution of seabed substrate	Low coral density has been observed, which is mainly scattered towards the south and east. The distribution is possibly influenced by boat traffic passing through this area which could have affected coral growth	Yusop *et al*., 2021
Geochemical analysis					
38	Payar Island	AAS and XRF	To determine selected heavy metal content	The levels detected were low and reflected the clean environment	Mokhtar *et al*., 2001
39	Bunting Island Telur Island Songsong Island Bidan Island Burung Island Lima Island	NAA	To determine chromium (Cr), manganese (Mn) and zink (Zn) concentration	Zn levels is higher than Cr and Mn Coral can serve as a historical recorder for heavy metal pollution in the environment	Mazlin *et al*., 2001
40	Tioman Island Labuan Island Sepanggar Bay Tanjung Aru	NAA	To determine mercury, manganese, zinc and chromium content	The results show that the trace metals content vary between species, with some species having higher levels than others.	Mokhtar *et al*., 2002
41	Tuba Island	Alpha-Spectrometry	To determine ^{210}Po and ^{210}Pb content in coral bands	The levels of 210Po were greater than 210Pb.	Lee *et al*., 2007
42	Langkawi Island Redang Island Tioman Island	ASS	To determine Ca, Mg, Sr and Zn concentration	Coral collected from Pulau Langkawi possessed high concentration of Zn indicates the water surrounding the island was highly polluted	Lee and Mohamed, 2009
43	Sabah Islands	FAAS	To determine trace metal level and determine the abilities as a bioindicator	Fe, Mn and Ni levels is higher than Cd and Zn Highest bioaccumulation is present in Zn followed by Mn, Ni, Fe, Cd and Cu	Mokhtar *et al*., 2012
44	Bidong Island	XRD and SEM-EDX	To determine coral physical and chemical properties, and evaluate its potential for bone graft development	All corals have calcium carbonate content All corals from this study were suitable for bone graft application	Ahmad Zubir *et al*., 2015
45	Redang Island Tioman Island Payar Island Cape Rachado	ICP-OES	To examine the relationships of Sr/Ca and sea surface temperature (SST)	Coral core showed a significant negative correlation between Sr/Ca ratios and SST.	Amir and Mohamed, 2018

*The abbreviation in the table is explain in the text

System (AGDS) is a type of hydroacoustic sensing system that is used for seabed classification and mapping reef substrate (Lee, 2000; Mustajap *et al*., 2015; Lee and Lin, 2018; Yusop *et al*., 2021). Unlike traditional SCUBA diving, which can be time-consuming and labor-intensive, the hydroacoustic sensing technique can cover larger areas in a shorter amount of time, making it a faster means of ground truthing (Bour, 1988). Moreover, it reduces the potential for human error that may result from subjective personal interpretation and observation during the survey (Yap, 2017). Even so, the technology may be affected by several environmental factors, such as water turbidity or seafloor topography, which can reduce the accuracy of the results. Importantly, hydroacoustics sensing can be used to study coral reef and their environment as it has the ability to map reef substrate type and coral growth forms (Lee, 2000).

The availability of satellite instruments for coral reef applications has grown over the last four decades. This growth began with the early Landsat and SPOT sensors (Smith *et al*., 1975; Bour, 1988) and has rapidly expanded in recent years with the introduction of high-resolution commercial satellites such as Ikonos, and Quickbird. For example, changes in coral reef communities have been detected using Ikonos satellite sensor imagery has been utilized for detecting changes in coral reef communities (Palandro *et al*., 2003), and tropical-marine benthic habitats have been identified and classified using QuickBird multispectral data (Mishra *et al*., 2006). Similarly, one of the studies in Malaysia has used ALOS satellite imagery to classify the coral reef and surrounding habitats based on their spectral characteristics thus capable of mapping the spatial distribution of this ecosystem (Mustapha *et al*., 2014). Satellites provide large-scale reconnaissance of coral reef health, yet, the spatial resolution may be relatively poor, especially when there is limited cloud cover (Teague *et al*., 2020). This limitation highlights the importance of using a variety of tools and techniques, including in situ observations, to complement satellite imagery in coral studies (Muslim *et al*., 2012).

The use of airborne technology such as drones has emerged as a viable option for obtaining detailed and rapid spatial data and information. A drone is categorized as UAV-based remote sensing. The use of UAV-based remote sensing has been found to be more effective in classifying coral habitat types over a finer spatial resolution compared to other high-resolution commercial satellite image acquisitions such as WorldView-2, Ikonos, and Quickbird (Zaki *et al*., 2022). Furthermore, it has been proven the potential of drones as a low-cost and rapid survey tool on shallow-water coral reefs, producing multispectral and bathymetric data, provided that the environmental conditions are favorable, such as calm waters, low winds, and minimal sun glint (Casella *et al*., 2017). In this review, at least one study has used a drone in their coral study (Table 2). The study demonstrated the utilization of drone-based aerial photography is feasible for monitoring coral bleaching in Malaysia (Zuhairi *et al*., 2018), which is becoming increasingly common due to environmental stressors such as rising sea temperatures. This technology successfully identified bleaching point and provides results comparable to traditional in-water monitoring methods. Drones have proven to be advantageous in facilitating coral studies; however, they are limited by factors such as flight time, weather dependency, and workflow of data processing. Thus, nnumerous studies have been carried out to enhance the utilization of drones, aiming to maximize their potential for future application (Muslim *et al*., 2012; Muslim *et al*., 2019; Mohamad *et al*., 2022; Chong *et al*., 2022).

Geochemical analysis

Coral skeletons can provide a wealth of information about the environment in which they grew. By employing geochemical techniques, researchers can measure the concentration of trace elements in coral skeletons to obtain information about water quality, pollution levels, and other environmental stressors. An overview of some of the widely used analytical techniques, their advantages, and limitations for the estimation of trace element content has been provided (Hossain *et al*., 2021). The authors also have provided guidance on the selection of equipment and technique, including the preparation of various sample arrays. Some of these have been mentioned in this review such as Atomic Absorption Spectrometry (AAS), X-ray Fluorescence (XRF), Neuron Activation Analysis (NAA), Flame Atomic Absorption Spectrophotometry (FAAS), X-ray Diffraction (XRD), Scanning Electron Microscope with Energy Dispersive X-ray (SEM-EDX) and Inductively Couple Plasma Optical Emission Spectroscopy (ICP-OES).

The study carried out by (Mokhtar *et al*., 2001) can be considered one of the earliest studies in Malaysia to evaluate the concentration of trace elements in the coral. Using AAS and XRF, this study measured the level of Cd, Cr, Mn, Ni, Pb, and Zn in coral band. The levels detected were low, evident that the environment was clean. In another example, Lee *et al*. (2007) performed one of the early evaluations of trace metals in coral collected from Sabah. In this study, the concentration of Hg, Mg, Zn, and Cr in coral skeletons was measured through the use of FAAS. The results indicate that corals in Sabah, Borneo have accumulated high levels of some trace metals, possibly due to anthropogenic activities. Both studies shed light on the extent of trace metal contamination in coral reefs and the potential impact on the marine ecosystem.

The analysis of coral skeleton through geochemical methods presents several advantages such as help to reconstructing past environmental condition, identifying source of pollution and monitoring current environmental condition by tracking the trace element, for instance (Mazlin *et al*., 2001; Mokhtar *et al*., 2012; Amir and Mohamed, 2018). Even so, this analysis is a laborious process which time-consuming and required specialized equipment (Hossain *et al*., 2021). This makes it difficult to conduct large-scale studies and may limit the number of samples that can be analyzed. The collection of coral samples can also be challenging, especially in remote or protected areas. In addition, sampling can damage coral, so researchers must carefully balance the need for data with the need to protect coral reefs. Overall, geochemical analysis of coral skeletons is still considered an important approach for understanding the past, present, and future of coral reef ecosystems.

Table 3. Comparison of the techniques

Visual Assessment (Underwater)	Remote Sensing	Geochemical Analysis
Involves direct observation	Involves no direct observation	Involves chemical analysis
Provides qualitative information on coral health and morphology	Provides objective data that can be analysed quantitatively	Provides quantitative data on coral health and environmental conditions
Detect changes in coral cover and health over time	Detect changes in coral cover and health over time	Detect changes in coral physiology and response to stressors over time
Can cover large areas quickly when performed by multiple observers	Can cover large areas in a shorter amount of time	May not be feasible for large-scale assessments
Can be completed in relatively in relatively short amount of time	Data collection and processing can be time-consuming	Sample collection, preparation, and analysis can be time-consuming
Not requires specialized equipment	Requires specialized equipment	Requires specialized equipment

Comparison between visual assessment, remote sensing and geochemical analysis

The summary provided in Table 3 presents a comparison between the techniques of visual assessment, remote sensing, and geochemical analysis in characterizing coral reef. Each technique has its advantages and limitation in terms of their applicability, data quality, capability-time-effective and specialization requirements. By comparing and contrasting these techniques, researchers can better understand their respective strengths and weaknesses and make informed decisions about which method is most appropriate for their study objectives.

Overall, each of these modern techniques has its own strengths and limitations, and the choice of technique will depend on the research question being addressed, budget and the specific conditions of the study site. Combining multiple techniques may provide a more comprehensive understanding of coral health and condition.

Conclusion

In conclusion, this study has provided an overview of modern coral characterization studies in Malaysia, shed light on the numerous studies conducted in various locations across the country. Most of the studies was conducted in South China Sea, particularly in East Coast of Peninsular Malaysia with 23 studies, which Tioman Island, Pahang being identified as having the greatest number of studies. The techniques used in these studies have also been discussed, with the visual assessment have the higher frequency of used in characterizing Malaysia coral reef, being the most used method with 27 studies employed this method. While 10 studies utilized remote sensing technique and 8 studies employed geochemical analysis. Going forward, future studies in Malaysia should continue to explore others Malaysia reef, and techniques for characterizing coral reefs, while also conduct more studies in locations with limited research. This will help to provide a more complete picture of coral reef ecosystems in Malaysia, which is critical for effective management and conservation efforts.

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