Development of Artificial Reefs in Southeast Asia: Malaysia in focus

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The development of artificial reefs (ARs) in Southeast Asia reflects a range of motivations and approaches, from fisheries management to coastal protection and coral reef restoration. Such development is in line with the Plan of Action on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030, specifically "*Plan of Action No. 35. Promote resource enhancement approaches with appropriate monitoring and evaluation programs, e.g. deployment of appropriate resource enhancement structures, restocking of commercially-important aquatic species, and restoration of degraded habitats, taking into consideration possible socio-ecological impacts.*"

While not without challenges, ARs have demonstrated their potential as a tool for marine conservation and sustainable development in the region. Since 2006, the Marine Fishery Resources Development and Management Department (MFRDMD) of SEAFDEC, in collaboration with the Department of Fisheries of Malaysia (DOFM), has been actively engaged in a research and development program on ARs. Over the years, the long-term research activities yielded valuable oceanographic information for the advancement of AR design and construction techniques, which have been effectively utilized in the Malaysia Artificial Reefs National Program since 2006. Besides, research findings were crucial for the DOFM to innovate and implement new technologies, leading to continuous improvements in the effectiveness of the ARs program. This has significantly enhanced marine habitats and fishery resources across Malaysia. Furthermore, the information obtained was also shared by MFRDMD during the conduct of several initiatives and activities in the region including the conduct of a series of regional workshops on ARs since 2004, publication of "A Guide to Make and Set Durable Artificial Reef Fish Aggregating Devices (ARFADs) for Coastal Waters" in 2004, and publication of research paper "Protecting Coastal Habitats and Enhancing Fisheries Resources Using Big Size Artificial Reefs in the East Coast of Peninsular Malaysia" in 2013.

Artificial reefs (ARs) are any human-made structures placed in water bodies, such as oceans or seas, that are designed to mimic natural reefs and provide a substrate, shelter, habitat, or breeding areas for aquatic organisms to settle and grow, which at the same time have an effect of hindering destructive fishing activities (SEAFDEC/TD, 2005; DoFM, 2008). They can also help to restore damaged or depleted natural reef systems by providing a place for new coral growth and other organisms to take root. Different forms of ARs have various purposes including habitats for marine life, structures for recreation for divers and anglers, and constructions to protect shorelines from erosion. They can be made of various materials, including concrete, steel, and even discarded materials such as sunken ships or tires.

The natural behavior of fish, known as thigmotropism, that is having the desire to be close to solid objects or naturally attracted to any sunken objects on the seabed, makes ARs one of the most effective fish assemblage devices to increase fish population in a certain area (Saharudin *et al*., 2012). The availability of food and shelter on these objects becomes an added attraction to the fish. The crevices of the reefs provide shelter against predators, thereby enhancing their chances of survival. Greater numbers and species of fish inhabit near the reef or sunken objects than on seabed areas with nothing but plain sandy or muddy strata. This idea was translated into the construction and deployment of ARs hundreds of years ago by the Japanese (Stone, 1972).

In the Southeast Asian region, the development of artificial reefs since the 1970s was driven by the need to enhance fish stocks, protect natural coral reefs, and promote sustainable fishing practices (**Box**). Today, artificial reefs are widely used in the region and are an important tool for coastal resource management. There has been a plethora of materials used for their development since their introduction to the region. The scientific understanding of their performance in the tropical marine ecosystem has resulted in material and design improvements over the year (Supongpan, 2006).

It is interesting to note that small-scale fishers in the region have been using their ingenuity and local ecological knowledge to innovate new AR devices to assist their fishing operations such as the tuna or deep sea payao in the Philippines, Thailand, and Indonesia. However, despite AR's potential as the key to community-based fishery management implementation in the region, it has only been realized in some parts of the Philippines and Timor Leste. Community-based fishery management is applied to manage the newly created deep sea payao-type ARs that have proven to assist local livelihoods (Beverly *et al*., 2012).

In contrast, the development of modern AR programs in the other countries in the region has been much less structured or even underexplored, with initiatives taken mainly by scientists and non-government organizations or bigger fishing operators. It is also noted that some of these unsupervised developments, particularly when carried out at an industrial scale, can cause concern among resource managers (Beverly *et al*., 2012).

Box. Development of artificial reefs in the Southeast Asian countries
Brunei Darussalam The Department of Fisheries Brunei Darussalam had been deploying the ARs since 1985 to provide protection to restricted/prohibited areas from encroachment by trawlers, enhance the productivity of coastal waters, and provide alternative sites for the rapidly expanding ecotourism industry. Various types have been deployed, including used tires, decommissioned offshore oil rigs, steel pipes, concrete piles, and prefabricated structures (Idris, 2005).
Cambodia The ARs program was initiated in Cambodia in 1991 using concrete modules and base/log of trees. These were deployed at depths less than 10 m into fish sanctuaries in the Great Lake Tonle Sap (inland water) and were aimed at providing habitats and improve fish stock (Sitha, 2005).
Indonesia Indonesia has been using ARs since the 1980s to enhance fish stocks and support the livelihoods of coastal communities. ARs were constructed using materials such as concrete, steel, and bamboo. These structures shown to improve fish biomass and biodiversity, and support the recovery of degraded coral reefs (Dahuri *et al*., 2006).
Malaysia ARs were established in Malaysian waters since 1975 using various materials such as discarded tires, derelict and confiscated fishing vessels, concrete, polyvinyl chloride (PVC), fiberglass reinforced concrete (FRC), steel reinforced concrete, fiberglass, ceramic, a combination of several materials (reef balls) as well as abandoned oil platforms (Ahmad *et al*., 2018).
Philippines Experimental artificial reefs were deployed by various organizations including Silliman University in Dumaguete in 1977 and 1978, University of the Philippines Marine Sciences Center (UPMSC) in Bolinao, Pangasinan in 1978, and Bureau of Fisheries and Aquatic Resources (BFAR) in Ilocos Sur, La Union, Pangasinan, Manila, Batangas, Albay, Masbate, Cebu, and Bohol between 1979 and 1984. These reefs were constructed using scrap tires and bamboo, and they had low profiles arranged in different configurations, sometimes combined with payao (Balgos, 1995. Currently, ARs are being used to enhance marine biodiversity and support sustainable fishing practices (Garcia & Aliño, 2012).
Singapore ARs projects were initiated in Singapore in 1989 using tire pyramids and hollow concrete modules. These were deployed at depths of 15 m and were aimed at improving fish stocks. Later, fiberglass modules referred to as "Reef Enhancement Units" were established in shallow reef areas to promote coastal tourism (Chou, 2005).
Thailand Thailand began developing ARs in the 1980s using materials such as concrete and discarded tires. The government initiated the program to support the local fishing industry and promote sustainable fishing practices (Chaiyawat *et al*., 2019).
Viet Nam ARs in Viet Nam were developed in early 2000 using concrete tanks with holes to play an important role in the conservation process, particularly in areas where reefs are unable to self-recover or suffering from mud siltation (Hung, 2005).

Evolution of artificial reefs in Malaysia

The coastal waters of Malaysia are among the region's richest ecosystems characterized by extensive coral reefs and dense mangrove forests. The high nutrient and food supplies from the mangroves and wetlands, accompanied by the fact that plankton growth is faster in the tropics, provide a high turnover rate of food for fish. Because economic benefits could be derived from them, these coastal areas teem with human settlements and become a very important fishing ground for thousands of fishers (Saharudin *et al*., 2012).

However, the coastal areas especially in Peninsular Malaysia have been intensively exploited by trawlers since the introduction of bottom trawls in the mid-1960s. Trawls are known to be highly efficient fishing gear but non-selective and destructive. This fishing gear sweeps along the seabed netting both juvenile and adult aquatic animals, destroying coral reef areas known to be natural habitats for many demersal fish species as well as traditional fishing gear such as traps and gillnets. Moreover, indiscriminate cutting of mangroves for aquaculture, urbanization, industrialization, fuel, timber, and the like have brought large economic benefits but destroyed the nursery area of commercially-important aquatic species. Large-scale destruction of the coastal areas caused serious degradation of the environment, thus, affecting the economic well-being of the coastal communities.

Since the early 1900s, local fishers on the east coast of Peninsular Malaysia constructed and deployed ARs to increase their catch by using derelict wooden boats and other plant-based materials (Wong, 1991). From then on, Malaysia developed different types of ARs using different materials for specific purposes.

- **Discarded tires**

The first ARs in Malaysia were introduced in the 1970s by the Royal Australian Air Force Army based in Butterworth, Penang in joining efforts with the Kedah Fisheries Office using discarded tires. The early modules consisted of 3–4 tires or 4–5 tires (Sukarno *et al*., 1994) with design similar to the ones used in Virginia, USA (Meier *et al*., 1986). Two circular holes with 6–8 cm diameter or two rectangular holes of about 75 cm^2 were made at the periphery (tread wall) of the tires to release air during the sinking process. Tires were then tied up with polyethylene ropes to form small modules of tetrahedral shape (**Figure 1**). The modules were deployed near Pulau Songsong in Kedah, Malaysia for recreational activities such as diving and fishing (Ahmad *et al*., 2018). From 5,000 tires to 6,000 tires were deployed at each site and the deployment areas were expanded depending on the degree of success of the tire reefs.

Figure 1. Tetrahedral tire reefs developed in Malaysia in 1975

Figure 2. Tire reefs deployed near Pulau Ekor Tebu in 1979 overgrown with corals and other marine flora and fauna

The Department of Fisheries Malaysia (DoFM) conducted a series of monitoring programs using underwater video and photography during 1976–1996 to observe fish species and other marine organisms at all sites where tire reefs were deployed near Pulau Telur and Pulau Payar, Kedah. It was found that the surfaces of the tire reefs were covered and overgrown with various species of marine flora and fauna, indicating a high degree of success (**Figure 2**). This success prompted the DoFM to expand the construction of tire reefs to other states in Malaysia such as in Pulau Aman, Penang in 1976); Pulau Ekor Tebu, Terengganu in 1979); Sabah and Sarawak in 1982).

Nonetheless, the deployment of tire reefs started to decline significantly in 1996 and was ultimately banned by DoFM due to allegations that tire emissions were toxic and polluted the marine environment. In addition, a study conducted by DoFM in 2007 and 2008 using side scan sonar in Terengganu waters revealed that all tire reefs deployed in the open sea area were destroyed by strong water currents, particularly during the monsoon season (Muhammad Amirullah *et al*., 2022) (**Figure 3**).

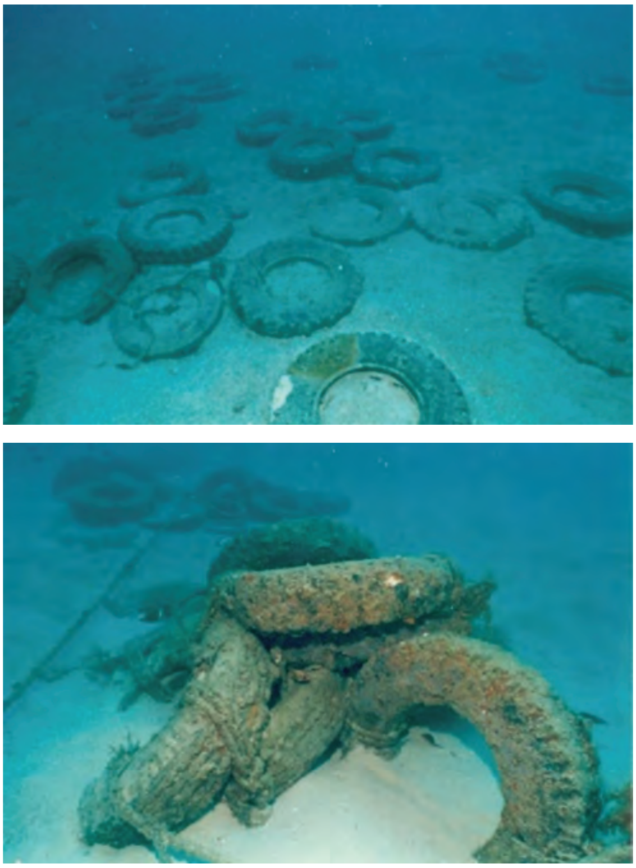


Figure 3. Tire reefs deployed in the open sea of Terengganu in 1990 destroyed by strong water currents (survey in 2007–2008)

- **Wooden vessels**

In addition to tires, derelict and confiscated wooden vessels were also used as AR material (**Figure 4**). The use of wooden vessels as ARs was an *ad-hoc* basis at selected locations using readily available vessels that would otherwise become marine debris on the shore or jetties. The first vessel reefs in Malaysia were established near Pulau Kapas in Terengganu in 1984. The project then expanded to Kuala Besar, Kelantan. Prior to sinking, the vessels were cleaned of all debris, hydrocarbons, and loose parts that could detach and float upon sinking. All water and fuel tanks of the vessels were opened or punctured to prevent trapped air from hindering the sinking of the vessel (Wong, 1991). Since 1984, DoFM has sunk more than 1,000 vessels in Terengganu waters (Ahmad *et al*. 2008).

Figure 4. Derelict and confiscated wooden vessels were cleaned, punctured, and burned during the sinking process

- **Concrete culverts**

Following the ban on discarded tire ARs, DoFM introduced ARs made from concrete and polyvinyl chloride (PVC) pipes. There were two basic designs for concrete ARs, one was a cylindrical concrete culvert (0.6 m length × 0.6 m diameter) and the other was a V-shaped concrete culvert (0.6 m length × 0.6 m height) (**Figure 5**). The concrete culverts were arranged in a pyramid shape on a hard wooden platform and secured together with a steel cable. In 1986, the initial concrete ARs in Malaysia were inaugurated near Pulau Payar in the state of

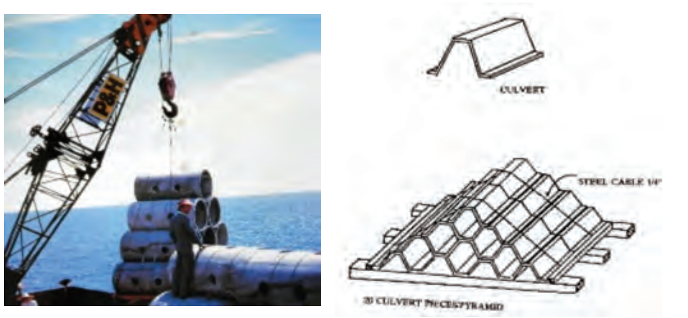


Figure 5. Concrete culvert ARs: cylinder *(left)* and V-shaped *(right)*

Kedah. Subsequently, 20 additional modules were deployed off Muka Head in Penang, followed by 144 modules off Kuala Ibai and Kuala Setiu in Terengganu in 1987. However, this type of ARs was later discontinued due to the high cost of logistics and construction in comparison to the immediate economic returns (Wong, 1991).

A new direction was taken in the advancement of concrete ARs, with a focus on luring specific commercial species, namely: lobsters and squids. The lobster concrete ARs were deployed near Pulau Redang in 1990 and squid concrete ARs near Jambu Bongkok, Terengganu in 1992 (Sukarno *et al*., 1994; Che Omar & Sukarno,1994). For lobster concrete ARs, the designs include 6-block and igloo-type structures (**Figure 6**). Meanwhile, the squid concrete ARs were designed to attract *Sepia pharaonis* to aggregate, mate, and lay their

Figure 6. Lobster concrete ARs: 6-block structure *(top)* and igloo-type *(bottom)*

eggs, but most of the structures were destroyed by illegal trawlers after the monsoon season.

- **PVC pipes**

In the 1990s, PVC pipes were used to construct ARs in Malaysia. A pilot project was introduced near Pulau Payar using 5 cm diameter PVC pipes (**Figure 7**). Later, a larger-scale project using 10 cm diameter PVC pipes was funded by the Asian Development Bank for deployment near Pulau Perhentian Marine Park. Each module had a special hole in the center at the bottom part for monsoon anchor attachment, and the structure covered an area of about 1,860 m^2. It was designed for the sea ranching project similar to one implemented in Japan. Hence, the pipes had holes measuring 5 cm in diameter and served as entrances into the pipes for juvenile fish to hide (Ahmad *et al*., 2018). However, the PVC material was not suitable for constructing ARs in the open sea exposed to various fishing activities, and most of the structures were destroyed within a year. As a result, the DOFM stopped using PVC pipes as a substrate for ARs but is still utilized for coral reef colonization, particularly in sheltered and tranquil zones such as marine parks.

Figure 7. X-shaped PVC ARs

- **Ceramic sewerage pipes**

Ceramic ARs were first introduced at Pulau Redang in 1992. These three-layer ARs were designed for lobsters using two sizes of domestic ceramic cylindrical sewerage pipes (**Figure 8**). The structure comprised flat concrete slabs on top of two large-sized (0.4 m diameter) ceramic pipes, with the middle and top layers using smaller-sized (0.25 m diameter) cylinder pipes. Unfortunately, the ceramic ARs failed to attract lobsters as intended, and monitoring showed that about 40 % of the modules were buried in the seafloor. As a result, the DoFM discontinued the use of ceramic material for constructing ARs after 1993.

Figure 8. Three-layer ARs using ceramic cylindrical sewerage pipes

- **Reinforced concrete**

In 1993, ARs made of reinforced concrete grade-30 (**Figure 9**) were installed near Pulau Tioman, Pahang with funding from the Asian Development Bank for enhancing fishery resources and making the reef site available for recreational activities such as angling and scuba diving. The initial module was made of a three-layer module consisting of 9 units with 6 units at the bottom, 2 units in the middle, and 1 on the top. Later on, a greater number of cube concrete units were used to build a larger and more complex module. The AR modules had an estimated weight of 500 kg each and were deployed at depths

Figure 9. Reinforced concrete ARs installed near Pulau Tioman, Pahang for recreational activities

of 24–27 m. Unfortunately, the project did not achieve its desired outcome because the site was unsuitable and there was insufficient sunlight for the growth of marine fouling, sessile, and encrusting organisms (Mohamed Pauzi *et al*., 1995).

- **Reef balls**

The patented ARs known as reef balls (**Figure 10**) were deployed in Sarawak waters for coral reef enhancement since 1998 by the DOFM and the Department of Forestry, Sarawak has extensively used these ARs, while it is only used in Marine Park areas in Kedah and Terengganu in Peninsular Malaysia. The reef balls weigh 2,000 kg and are made of reinforced concrete. With a height of 1.37 m and width of 1.83 m, reef balls provide a sturdy and expansive structure for underwater habitats. The surface area of the reef balls is 13.9 m^2 offering ample space for marine organisms to thrive and seek shelter. With 22–24 holes strategically placed throughout its surface, the reef balls allow water circulation and create additional niches for marine life to inhabit, enhancing biodiversity within the ecosystem. The reef balls were suitable only on a hard bottom seabed and not suitable to prevent illegal trawlers or to be placed on a soft bottom sea bed. Over 5,000 reef balls were deployed around the turtle nesting islands in Sarawak to deter fish netting and have successfully increased turtle nesting numbers (Daud and Mohd Zakaria, 2007).

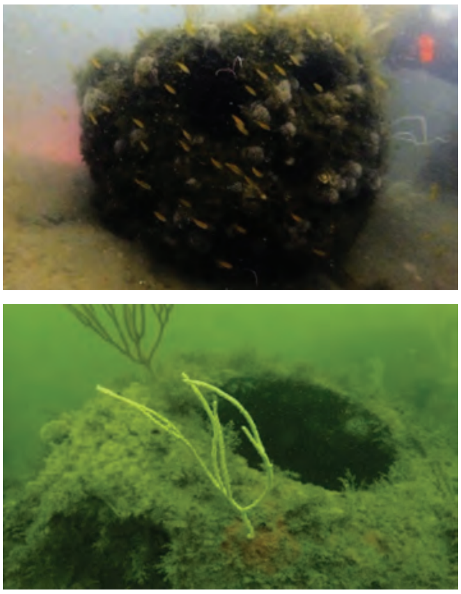


Figure 10. Reef balls deployed in Sarawak waters in 1998 for coral reef enhancement monitored in April 2021

- **Artificial reefs and fish aggregating devices (ARFADs)**

In 2000–2001, SEAFDEC funded a short-term R&D project to develop the design and construction of artificial reefs and fish aggregating devices (ARFADs) (**Figure 11**) to enhance recreational fishing activities. The ARs were made of plastic crates to attract pelagic fish and a concrete anchor weighing between 0.3 t and 3.2 t to attract demersal fish. Three large plastic buoys with a diameter of 30.5 cm were placed between

Figure 11. Plastic straps of ARFADs colonized by biofouling and marine organisms

the anchor and water surface and two Styrofoam buoys with a 30 cm diameter were placed on the water surface to ensure the plastic crates remain afloat. The ARFADs were initially deployed at three sites near Pulau Kapas which became popular fishing and scuba diving spots due to the abundance of pelagic and demersal fish. Moreover, various marine flora and fauna similar to those found in natural coral reefs grew on the concrete anchors attracting the attention of scuba divers (Ahmad *et al*., 2004). Subsequently, more ARFADs were deployed in other areas to promote the recreational fishing industry. However, over time, the ARFADs became less effective in attracting pelagic fish since the plastic crates became heavy after being colonized by marine organisms such as barnacles and mollusks. This caused the plastic crates and buoys to sink to the seafloor and entangled with the concrete anchors (Ahmad *et al*., 2008). Despite this, the concrete anchors remained functional and served as a habitat for demersal fish such as grouper (Ahmad *et al*., 2004).

- **Oil platforms**

The first oil platform to be converted into ARs in Malaysia was Baram 8, now known as BA 8. The oil platform was built in 1968 and is located about 8 nm from the coast of Kuala Baram, Sarawak at a depth of 60 m. After being decommissioned by PETRONAS when the structure became unstable in 1975, it was cut into two parts (30 m and 35 m), and transported and sunk 6.21 nm off Miri coast in Sarawak at a depth of 21 m. In 2005, ARs were officially handed over to the DOFM and the site was named Miri-Sibuti Coral Reefs National Park and became a popular scuba diving spot.

In 2017, another two oil platforms (43 t and 18 t) of the PETRONAS named KAPAL were deployed in Pulau Kapas, Terengganu (**Figure 12**). PETRONAS bore all the expenses in cutting, transporting, cleaning at the original site, and deploying at the designated location by the DoFM. Furthermore, the Sarawak Fisheries Department (JPLS) and PETRONAS continued the collaboration for the" Rig to Reef" program by deploying two more decommissioned oil

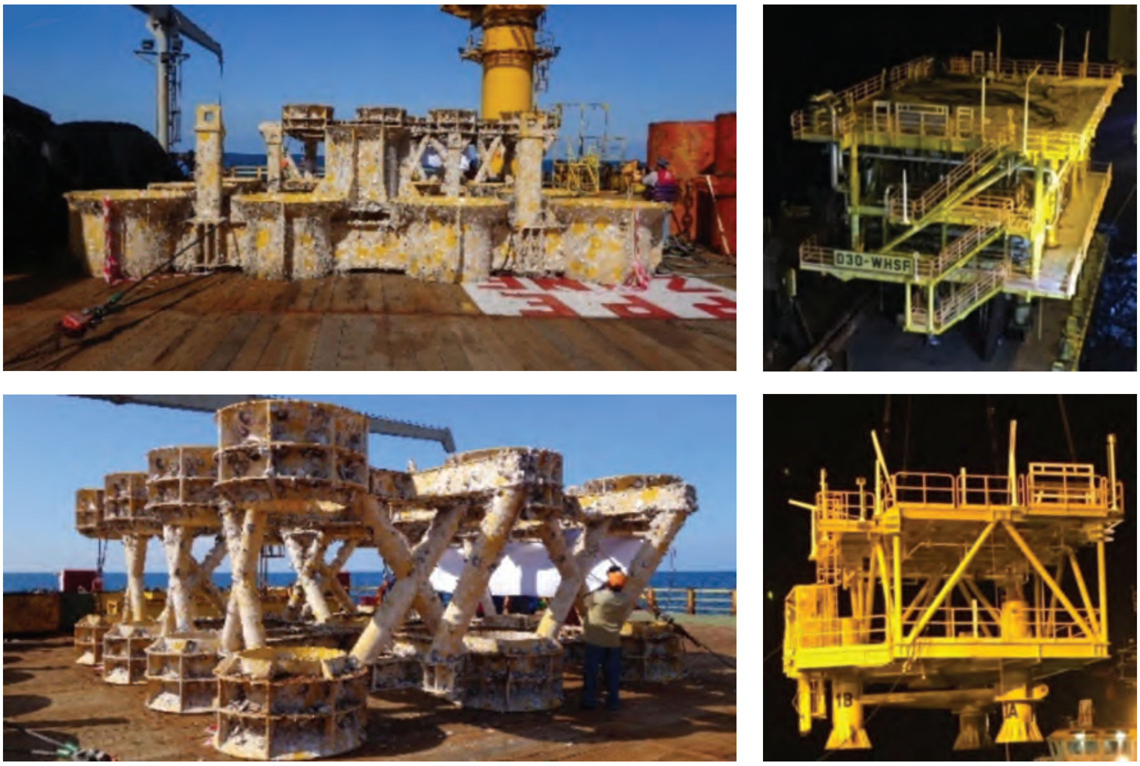


Figure 12. Oil platforms converted to ARs (*top and bottom left*: KAPAL oil rigs deployed in Pulau Kapas, Terengganu; *top right*: DANA platform; and *bottom right:* D30 platform deployed in Miri, Sarawak)

platforms, the DANA Platform (685 t) and the D30 Platform (1,070 t) also in 2017 in Miri waters.

- **Big-sized ARs**

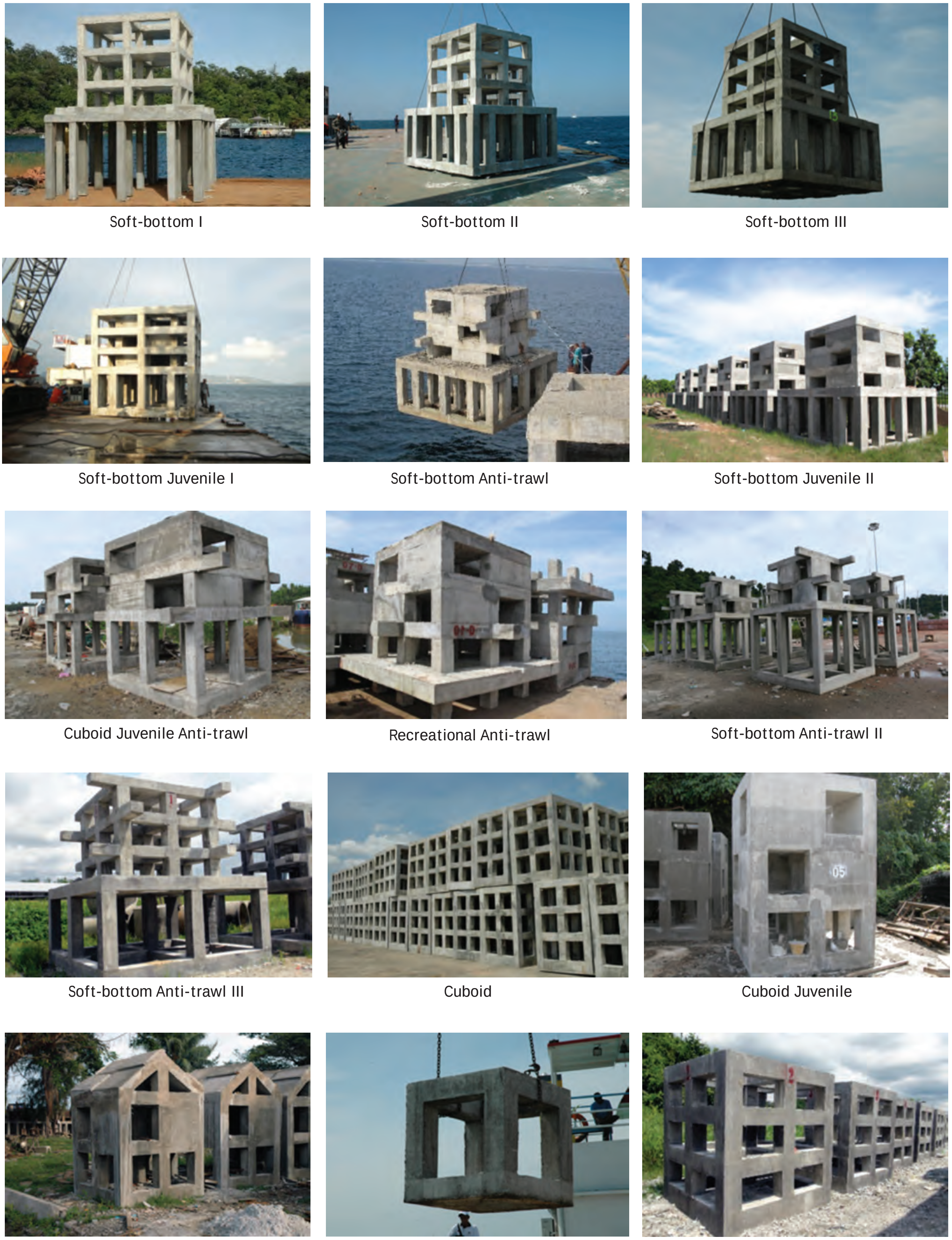
Certain types of ARs materials used in the past were found to be insufficient due to their inability to withstand strong water currents and ravages of natural degradation. Consequently, these materials suffered a premature demise a few years after their deployment. As a result, the DoFM devised a cutting-edge and durable ARs structure in 2006 using robust materials such as reinforced concrete and steel that would be impervious to the harsh marine environment and ensure long-lasting efficacy.

By the end of 2017, the DoFM developed several new types of big-sized ARs (2.5–3.8 m height, 2.0–3.8 m length and width, and 10–30 t weight) (**Figure 13**). The construction process followed the British Standard 8110 with a concrete cover of at least 50 mm and reinforcement using Y12 rods, R8 links, and BRC A10 slabs. Ecological surveys were conducted before deployment to assess biological productivity, sediment, depth, current, and other physical factors that could affect the success of the project. Planning was done in collaboration with fishers, administrators, and researchers. Other agencies such as the Marine Department, district office, and port authority were involved in site selection to ensure long-term success.

Way Forward

ARs are frequently proposed as a potential solution to overfishing and are seen as a widely accessible technology to restore aquatic ecosystems. However, it should be noted that ARs are not a panacea for traditional fishers, managers, and policymakers. When managed effectively, ARs can be useful to enhance the coastal marine environment and increase fish biomass. Proper management entails planning for materials, site selection, construction, deployment, and monitoring and evaluation before and after deployment. On the other hand, mismanagement can contribute to the aggregation of juvenile fish, making them vulnerable to capture, and may result in overfishing.

MFRDMD will continue to implement comprehensive research and monitoring programs to evaluate the ecological impacts of artificial reefs to ensure their effectiveness as habitat restoration tools. This includes assessing the success of deployments, monitoring species colonization as well as studying the long-term ecological dynamics. The acquired information and knowledge will be utilized by MFRDMD in conducting capacity-building activities in the Southeast Asian region to train local stakeholders, including fishers, divers, and marine resource managers, in artificial reef construction, monitoring techniques, and maintenance protocols to empower the communities to actively contribute to the development and management of artificial reefs.



Soft-bottom I | Soft-bottom II | Soft-bottom III

Soft-bottom Juvenile I | Soft-bottom Anti-trawl | Soft-bottom Juvenile II

Cuboid Juvenile Anti-trawl | Recreational Anti-trawl | Soft-bottom Anti-trawl II

Soft-bottom Anti-trawl III | Cuboid | Cuboid Juvenile

Cuboid Bioactive | Recreational I | Recreational II

Figure 13. Different models of big-sized ARs developed by the Department of Fisheries Malaysia in 2006–2017

Recreational Juvenile

Cube Reefs

Cube Juvenile

Cube Juvenile Anti-trawl

Lobster Reefs

Lobster Reefs II

Tetrapod Reefs

Tetrapod Reefs II

Steel Reefs

Steel reefs II

Concrete pipe reefs

Juvenile Anti-trawl reefs

Figure 13. Different models of big-sized ARs developed by the Department of Fisheries Malaysia in 2006–2017 *(Cont'd)*

Lastly, it is important to establish clear policies and regulations that govern artificial reef deployments, including guidelines for site selection, materials, and maintenance. Regular assessments and adaptive management strategies should be implemented to address any emerging challenges or unforeseen impacts. By adopting a collaborative and science-based approach, focusing on community engagement, and implementing sound governance practices, Southeast Asian countries can harness the potential of artificial reefs as a valuable tool for marine conservation, sustainable fisheries management, and coastal development.

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